Chapter **42**

Indoor Air Pollution

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Access to modern energy sources has been described as a "necessary, although not sufficient, requirement for economic and social development" (IEA 2002). It is, therefore, of great concern that almost half the world's population still relies for its everyday household energy needs on inefficient and highly polluting solid fuels, mostly biomass (wood, animal dung, and crop wastes) and coal.

The majority of households using solid fuels burn them in open fires or simple stoves that release most of the smoke into the home. The resulting indoor air pollution (IAP) is a major threat to health, particularly for women and young children, who may spend many hours close to the fire. Furthermore, the reliance on solid fuels and inefficient stoves has other, far-reaching consequences for health, the environment, and economic development.

NATURE, CAUSES, AND BURDEN OF CONDITION

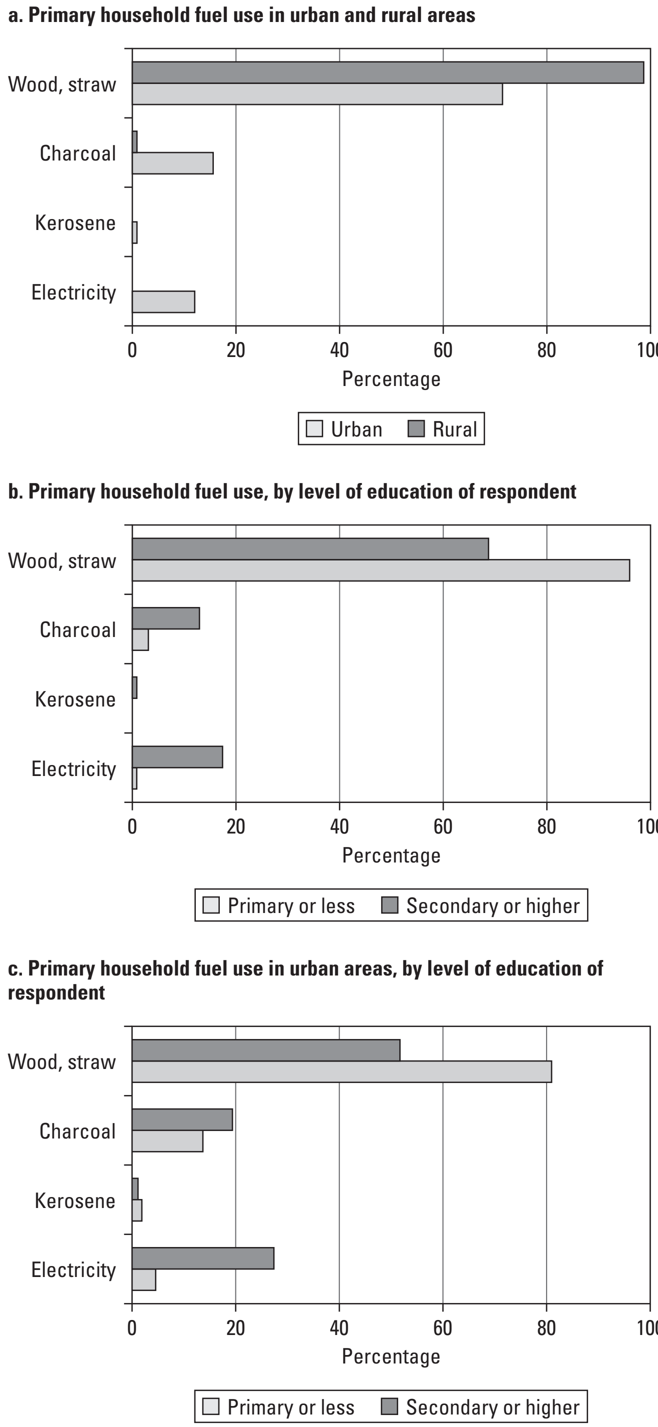
About 3 billion people still rely on solid fuels, 2.4 billion on biomass, and the rest on coal, mostly in China (IEA 2002; Smith, Mehta, and Feuz 2004). There is marked regional variation in solid fuel use, from less than 20 percent in Europe and Central Asia to 80 percent and more in Sub-Saharan Africa and South Asia.

This issue is inextricably linked to poverty. It is the poor who have to make do with solid fuels and inefficient stoves, and many are trapped in this situation: the health and economic consequences contribute to keeping them in poverty, and their poverty stands as a barrier to change. Where socioeconomic circumstances improve, households generally move up the energy ladder, carrying out more activities with fuels and appliances that are increasingly efficient, clean, convenient, and more expensive. The pace of progress, however, is extremely slow, and for the poorest people in Sub-Saharan Africa and South Asia, there is little prospect of change.

Illustrated in figures 42.1 and 42.2 are findings for Malawi and Peru, respectively, from Demographic and Health Surveys (ORC Macro 2004). The examples are selected from available national studies with data on main cooking fuel use to represent the situation in poor African and South American countries. The main rural and urban cooking fuels are illustrated in figures 42.1a and 42.2a; the findings are then broken down nationally by level of education of the principal respondent (woman of childbearing age) in figures 42.1b and 42.2b, and in urban areas by her level of education in figures 42.1c and 42.2c.

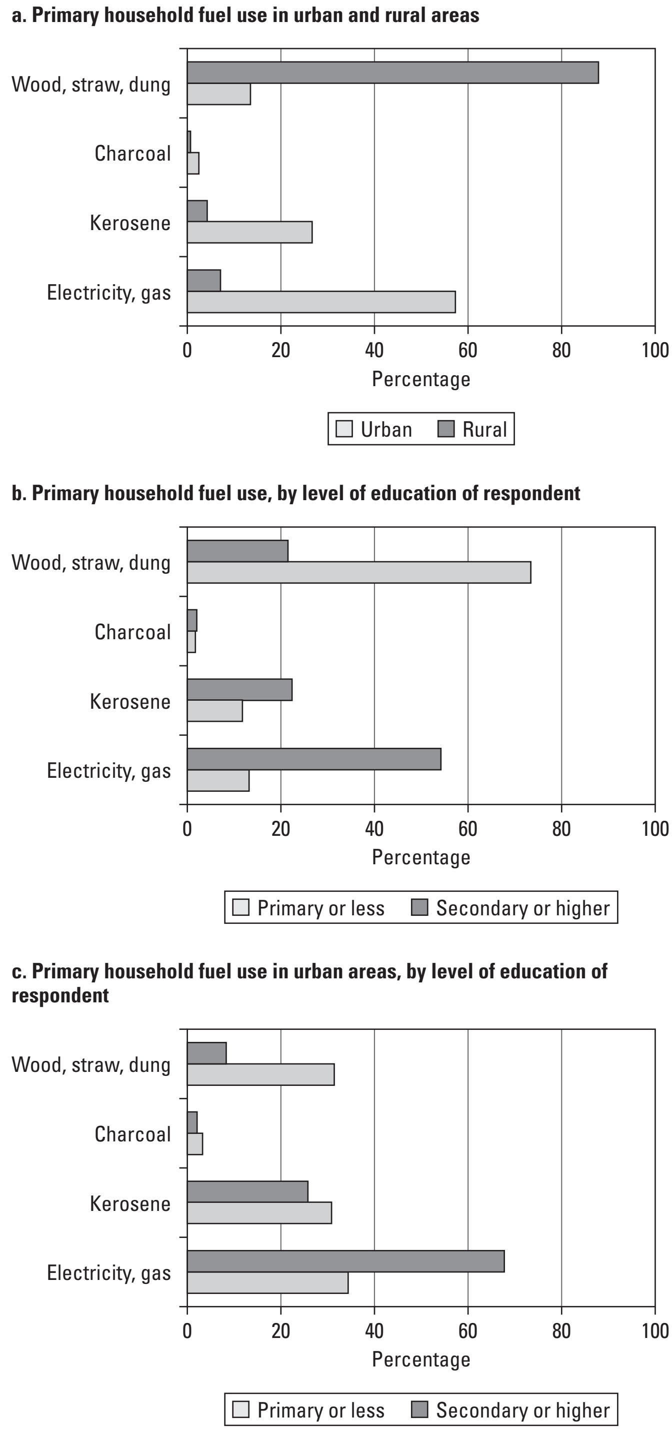
Biomass is predominantly, though not exclusively, a rural fuel: indeed, in many poor African countries, biomass is the main fuel for close to 100 percent of rural homes. Marked socioeconomic differences (indicated by women's education) exist in both urban and rural areas. During the 1990s, use of traditional fuels (biomass) in Sub-Saharan Africa increased as a percentage of total energy use, although in most other parts of the world the trend has generally been the reverse (World Bank 2002).

In many poorer countries, the increase in total energy use accompanying economic development has occurred mainly through increased consumption of modern fuels by better-off minorities. In Sub-Saharan Africa, however, the relative increase in biomass use probably reflects population growth in rural and poor urban areas against a background of weak (or negative) national economic growth. Reliable data on trends in



Source: Unpublished data derived from Demographic and Health Survey.

Figure 42.1 Patterns of Household Fuel Use in Malawi, 2000



Source: Unpublished data derived from Demographic and Health Survey.

Figure 42.2 Patterns of Household Fuel Use in Peru, 2000

household energy use are not available for most countries. Information is available from India, where the percentage of rural homes using firewood fell from 80 percent in 1993–94 to 75 percent in 1999–2000 (D'Sa and Narasimha Murthy 2004). Nationally, liquid petroleum gas (LPG) use increased from 9 to 16 percent over the same period, with a change from 2 percent to 5 percent in rural areas, and it is expected to reach 36 percent nationally and 12 percent for rural homes by 2016. International Energy Agency projections to 2030 show that, although a reduction in residential biomass use is expected in most developing countries, in Africa and South Asia the decline will be small, and the population relying on biomass will increase from 2.4 billion to 2.6 billion, with more than 50 percent of residential energy consumption still derived from this source(OECD and IEA 2004). The number of people without access to electricity is expected to fall from 1.6 billion to 1.4 billion. Because electricity is used by poor households for lighting and not as a cleaner substitute for cooking, electrification will not, at least in the short to medium term, bring about substantial reductions in IAP.

Levels of Pollution and Exposure

Biomass and coal smoke emit many health-damaging pollutants, including particulate matter (PM),[1] carbon monoxide (CO), sulfur oxides, nitrogen oxides, aldehydes, benzene, and polyaromatic compounds (Smith 1987). These pollutants mainly affect the lungs by causing inflammation, reduced ciliary clearance, and impaired immune response (Bruce, Perez-Padilla, and Albalak 2000). Systemic effects also result, for example, in reduced oxygen-carrying capacity of the blood because of carbon monoxide, which may be a cause of intrauterine growth retardation (Boy, Bruce, and Delgado 2002). Evidence is emerging, thus far only from developed countries, of the effects of particulates on cardiovascular disease (Pope and others 2002, 2004).

Saksena, Thompson, and Smith (2004) have recently compiled data on several of the main pollutants associated with various household fuels from studies of homes in a wide range of developing countries. Concentrations of PM_{10}, averaged over 24-hour periods, were in the range 300 to 3,000 (or more) micrograms per cubic meter ($\mu g/m^3$). Annual averages have not been measured, but because these levels are experienced almost every day of the year, the 24-hour concentrations can be taken as a reasonable estimate. By comparison, the U.S. Environmental Protection Agency's annual air pollution standard for PM_{10} is 50 $\mu g/m^3$, one to two orders of magnitude lower than levels seen in many homes in developing countries. During cooking, when women and very young children spend most time in the kitchen and near the fire, much higher levels of PM_{10} have been recorded—up to 30,000 $\mu g/m^3$ or more. With use of biomass, CO levels are generally not as high in comparison, typically with 24-hour averages of up to 10 parts per million (ppm), somewhat below the World Health Organization (WHO) guideline level of 10 ppm for an eight-hour period of exposure. Much higher levels of CO have been recorded, however. For example, a 24-hour average of around 50 ppm was found in Kenyan Masai homes (Bruce and others 2002), and one Indian study reported carboxyhemoglobin levels similar to those for active cigarette smokers (Behera, Dash, and Malik 1988). The health effects of chronic exposure of young children and pregnant women to levels of CO just below current WHO guidelines have yet to be studied. For additional information on levels of other pollutants in biomass and coal smoke, see Saksena, Thompson, and Smith (2004).

Fewer studies of personal exposure have been done than of area pollution, mainly because measurement of personal PM typically requires wearing a pump, a cumbersome procedure. CO can be measured more easily and has been used as a proxy: time-weighted (for example, 24-hour average) CO correlates well with PM if a single main biomass stove is used (Naeher and others 2001). Time-activity and area pollution information can also be combined to estimate personal exposure (Ezzati and Kammen 2001). These various methods indicate that personal 24-hour PM_{10} exposures for cooks range from several hundred $\mu g/m^3$ to more than 1,000 $\mu g/m^3$ (Ezzati and Kammen 2001), with even higher exposures during cooking (Smith 1989). Few studies have measured personal PM exposures of very young children: one study in Guatemala found levels a little lower than those of their mothers (Naeher, Leaderer, and Smith 2000).

Health Impacts of IAP

A systematic review of the evidence for the impact of IAP on a wide range of health outcomes has recently been carried out (Smith, Mehta, and Feuz 2004; see table 42.1). This review identified three main outcomes with sufficient evidence to include in the burden-of-disease calculations and a range of other outcomes with as yet insufficient evidence.

Studies for the key outcomes used in the burden-of-disease calculations—acute lower respiratory infection (ALRI), chronic obstructive pulmonary disease (COPD), and lung cancer—had to be primary studies (not reviews or reanalyses), written or abstracted in English (and for lung cancer, Chinese), that reported an odds ratio and variance (or sufficient data to estimate them) and provided some proxy for exposure to indoor smoke from the use of solid fuels for cooking and heating purposes.

A limitation of almost all studies has been the lack of measurement of pollution or exposure: instead, proxy measures have been used, including the type of fuel or stove used, time spent near the fire, and whether the child is carried on the mother's back during cooking. The studies do not, therefore, provide data on the exposure-response relationship, although a recent study from Kenya has gone some way to addressing this omission (Ezzati and Kammen 2001).

In some countries, household fuels carry locally specific risks. It has been estimated that more than 2 million people in China suffer from skeletal fluorosis, in part resulting from use of fluoride-rich coal (Ando and others 1998). Arsenic, another contaminant of coal, is associated with an increased risk of lung cancer in China (Finkelman, Belkin, and Zheng 1999). There has been concern, however, that reducing smoke could increase risk of vectorborne disease, including malaria. Some

Table 42.1 Status of Evidence Linking Biomass Fuels and Coal with Child and Adult Health Outcomes

Health outcome	Age	Status of evidence
Sufficient evidence for burden-of-disease calculation		
Acute lower respiratory infections	Children < 5 years	*Strong.* Some 15–20 observational studies for each condition, from developing countries. Evidence is consistent (significantly elevated risk in most though not all studies); the effects are sizable, plausible, and supported by evidence from outdoor air pollution and smoking.
Chronic obstructive pulmonary disease	Adult women	
Lung cancer (coal exposure)	Adult women	
Chronic obstructive pulmonary disease	Adult men	*Moderate-I.* Smaller number of studies, but consistent and plausible.
Lung cancer (coal exposure)	Adult men	
Not yet sufficient evidence for burden-of-disease calculation		
Lung cancer (biomass exposure)	Adult women	*Moderate-II.* Small number of studies, not all consistent (especially for asthma, which may reflect variations in definitions and condition by age), but supported by studies of outdoor air pollution, smoking, and laboratory animals.
Tuberculosis	Adult	
Asthma	Child and adult	
Cataracts	Adult	
Adverse pregnancy outcomes	Perinatal	*Tentative.* Adverse pregnancy outcomes include low birthweight and increased perinatal mortality. One or a few studies at most for each of these conditions, not all consistent, but some support from outdoor air pollution and passive-smoking studies.
Cancer of upper aerodigestive tract	Adult	
Interstitial lung disease	Adult	
Ischemic heart disease	Adult	Several studies from developed countries have shown increased risk for exposure to outdoor air pollution at much lower levels than IAP levels seen in developing countries. As yet, no studies from developing countries.

Source: Smith, Mehta, and Feuz 2004.

studies have shown that biomass smoke can repel mosquitoes and reduce biting rates (Palsson and Jaenson 1999; Paru and others 1995; Vernede, van Meer, and Alpers 1994). Few studies have examined the impact of smoke on malaria transmission: one from southern Mexico found no protective effect of smoke (adjusted odds ratio 1.06 [0.72–1.58]; Danis-Lozano and others 1999), and another from The Gambia found that wood smoke did not protect children in areas of moderate transmission (Snow and others 1987).

Method Used for Determining Attributable Disease Burden

Smith, Mehta, and Feuz (2004) have provided a full explanation of the calculation of the disease burden associated with IAP. Summarized here are the methods they used to estimate the two most critical components of these calculations: the number of people exposed and the relative risks.

Exposure. The absence of pollution or exposure measurement in health studies required use of a binary classification: the use or nonuse of solid fuels. The authors obtained estimates of solid fuel use for 52 countries from a range of sources, mostly household surveys, and statistical modeling was used for countries with no data (the majority) (Smith, Mehta, and Feuz 2004). They assumed, conservatively, that all countries with a 1999 per capita gross national product (GNP) greater than US$5,000 had made a complete transition either to electricity or cleaner liquid and gaseous fuels or to fully ventilated solid fuel devices. To account for differences in exposure caused by variation in the quality of stoves, they applied a *ventilation factor* (VF), set from 1 for no ventilation to 0 for complete ventilation. In China, a VF of 0.25 was used for child health outcomes and 0.5 for adult outcomes, reflecting a period of higher exposure (to open fires) before the widespread introduction of chimney stoves. Countries with a 1999 GNP per capita greater than US$5,000 were assigned a VF of 0, and all other countries a value of 1, reflecting the very low rates of use of clean fuels or effective ventilation technologies. The authors obtained the final point estimate for exposure by multiplying the percentage of solid fuel use by the VF. They arbitrarily assigned an uncertainty range of ±5 percent to the estimates.

Risk. Smith, Mehta, and Feuz (2004) carried out meta-analyses for the three health outcomes with sufficient evidence (table 42.2). They used fixed-effects models and sensitivity analysis that took account of potential sources of heterogeneity, including the way in which exposure was defined and whether adjustment had been made for confounders (Smith, Mehta, and Feuz 2004).

Table 42.2 Summary of Relative Risk Estimates for Health Outcomes Used in Burden-of-Disease Estimates

Health outcome	Age and sex group	Number of studies	Relative risk	95 percent confidence interval
ALRI	Children < 5 years	8	2.3	1.9–2.7
COPD	Women > 30 years	8	3.2	2.3–4.8
	Men > 30 years[a]	2	1.8	1.0–3.2
Lung cancer (coal)	Women > 30 years	9	1.9	1.1–3.5
	Men > 30 years	3	1.5	1.0–2.5

Sources: Smith, Mehta, and Feuz 2004.

a. Because of the limited quantity and quality of available evidence, the male COPD relative risk and range have been fixed to include 1.0 (no effect) as the lower estimate.

The Burden of Disease from Solid Fuel Use

Information on the proportions exposed and risk of key disease outcomes was combined with total burden-of-disease data to obtain the population attributable fractions associated with IAP (WHO 2002b). Globally, solid fuels were estimated to account for 1.6 million excess deaths annually and 2.7 percent of disability-adjusted life years (DALYs) lost, making them the second most important environmental cause of disease, after contaminated water, lack of sanitation, and poor hygiene (table 42.3). Approximately 32 percent of this burden (DALYs) occurs in Sub-Saharan Africa, 37 percent in South Asia, and 18 percent in East Asia and the Pacific. In developing countries with high child and adult mortality, solid fuel use is the fourth most important risk factor behind malnutrition, unsafe sex, and lack of water and sanitation, and it is estimated to account for 3.7 percent of DALYs lost (WHO 2002b).

Overall, there are more female deaths but similar numbers of male and female DALYs (table 42.3b). The reason can be found by looking further at the health outcomes. Deaths and DALYs from ALRI in children under five years of age are slightly greater for males (table 42.3c). Women experience twice the DALYs and three times the deaths from COPD (male smoking-attributable COPD deaths excluded). Far fewer cases of lung cancer are attributable to IAP, but women experience about three times the burden of men.

Table 42.3 also shows how the poorest regions of the world carry by far the greatest burden, particularly for ALRI. More than half of all the deaths and 83 percent of DALYs lost attributable to solid fuel use occur as a result of ALRI in children under five years of age. In high-mortality areas, such as Sub-Saharan Africa, these estimates indicate that approximately 30 percent of mortality and 40 percent of morbidity caused by ALRI can be attributed to solid fuel use, as can well over half of the deaths from COPD among women. Because they derive from WHO risk assessments, these estimates include age weights, such that years of life lost at very young or advanced ages count less than years lost in the prime of adult life. Age weighting makes little difference to the DALYs lost per death up to age five; how much it affects the DALY cost of adult deaths depends on the age distribution of deaths from COPD. Because these are likely to occur at age 45 or beyond, the DALY losses are underestimated compared with estimates without age weighting that follow the usual practice in this volume.

Other Effects of Household Energy Use in Developing Countries

A number of other health impacts—for example, burns from open fires—were not assessed because the burden-of-disease assessment process allowed inclusion of only those health effects resulting directly from pollution. Children are at risk of burns and scalds, resulting from falling into open fires and knocking over pots of hot liquid (Courtright, Haile, and Kohls 1993; Onuba and Udoidiok 1987). Modern fuels are not always safe either, because children are also at risk of drinking kerosene, which is often stored in soft drink bottles (Gupta and others 1998; Reed and Conradie 1997; Yach 1994).

Families—mainly the women and children—can spend many hours each week collecting biomass fuels, particularly where environmental damage and overpopulation have made them scarce. This time could be spent more productively on child care and household or income-generating tasks. There are also risks to health from carrying heavy loads and dangers from mines, snake bites, and violence (Wickramasinghe 2001). Inefficient stoves waste fuel, draining disposable income if fuel is bought. Although women carry out most of the household activities requiring fuels, they often have limited control over how resources can be spent to change the situation (Clancy, Skutsch, and Batchelor 2003). These conditions can combine to restrict income generation from home-based activities that require fuel energy (for example, processing and preparing food for sale).

Homes that are heavily polluted and dark can hinder productivity of householders, including children doing homework and others engaged in home-based income-generating activities such as handicrafts. In many poor homes, lighting is obtained from the open fire and simple kerosene wick lamps, which provide poor light and add to pollution.

Solid fuel use has important environmental consequences. Domestic use of solid fuels in high-density rural and urban environments contributes to outdoor air pollution. Many low-income urban populations rely on charcoal, the production of which can place severe stress on forests. The use of wood as fuel can contribute to deforestation, particularly where it is combined with population pressure, poor forest management, and clearance of land for agriculture and building timber. Damage to forest cover can increase the distance traveled to obtain wood and can result in the use of freshly cut (green) wood, dung, and

Table 42.3 Deaths and DALYs Lost Because of Solid Fuel Use
a. Overall

World Bank region	Deaths (thousands)	DALYs (thousands)	Total burden (percent)
East Asia and the Pacific	540	7,087	18.4
Europe and Central Asia	21	544	1.4
Latin America and the Caribbean	26	774	2.0
Middle East and North Africa	118	3,572	9.3
South Asia	522	14,237	36.9
Sub-Saharan Africa	392	12,318	32.0
World	1,619	38,532	100.0

b. All causes, by sex

	Deaths (thousands)			DALYs (thousands)		
World Bank region	Male	Female	All	Male	Female	All
East Asia and the Pacific	152	388	540	3,028	4,060	7,087
Europe and Central Asia	9	13	21	251	293	544
Latin America and the Caribbean	12	14	26	368	405	774
Middle East and North Africa	57	61	118	1,849	1,724	3,572
South Asia	218	304	522	6,641	7,596	14,237
Sub-Saharan Africa	211	181	392	6,901	5,417	12,318
World	658	961	1,619	19,037	19,495	38,532

c. From ALRI (children under age five)

	Deaths (thousands)			DALYs (thousands)		
World Bank region	Male	Female	All	Male	Female	All
East Asia and the Pacific	40	41	81	1,502	1,535	3,036
Europe and Central Asia	7	6	13	235	204	439
Latin America and the Caribbean	8	7	15	324	281	605
Middle East and North Africa	51	44	95	1,794	1,571	3,365
South Asia	177	178	355	6,228	6,278	12,506
Sub-Saharan Africa	198	153	351	6,777	5,191	11,967
World	481	429	910	16,860	15,058	31,918

d. From COPD (men and women 30 years and over)

	Deaths (thousands)			DALYs (thousands)		
World Bank region	Male	Female	All	Male	Female	All
East Asia and the Pacific	105	338	443	1,461	2,430	3,891
Europe and Central Asia	2	7	9	16	89	104
Latin America and the Caribbean	4	7	11	44	125	168
Middle East and North Africa	6	17	23	55	153	208
South Asia	41	126	167	410	1,314	1,724
Sub-Saharan Africa	13	28	41	124	227	351
World	171	522	693	2,110	4,336	6,446

Source: Modified by authors to World Bank regions, from Smith, Mehta, and Feuz 2004.

twigs, which are more polluting and less efficient. In some urban communities, poverty and supply problems are resulting in the use of plastic and other wastes for household fuel (IEA 2002).

Stoves with inefficient combustion produce relatively more products of incomplete combustion, such as methane, which have a markedly higher global-warming potential than carbon dioxide (Smith, Uma, and others 2000). It has, therefore, been argued that, although the energy use and greenhouse gas emissions from homes in developing countries are small relative to the emissions generated in industrial countries, cleaner and more efficient energy systems could provide the double benefit of reduced greenhouse gas emissions (with opportunities for carbon trading) and improved health through reduced IAP (Wang and Smith 1999).

The evidence available for assessing these effects, which together could have a substantial influence on health and economic development, is patchy at best. This area is important for research (Larson and Rosen 2002).

INTERVENTIONS AND POLICY

The uses of energy in the home—for example, for cooking and keeping warm and as a focus of social activities—have important attributes that are specific to the locality, culture, and individual households and are often associated with established traditions and deeply held beliefs. Encouraging the use of cleaner and more efficient energy technologies by populations that are among the poorest in the world has not been easy, but recent years have seen progress being made with respect to suitable technology that meets the needs of households and with respect to the development of supportive policy.

Poverty Reduction and the Millennium Development Goals

Given the close relationship between socioeconomic conditions and solid fuel use, poverty reduction must be a key element of policy to alleviate IAP. The United Nations Millennium Development Goals set targets for poverty eradication, improvements in health and education, and environmental protection; they represent the accepted framework for the world community to achieve measurable progress (United Nations Statistics Division 2003). Although reducing IAP can contribute to achieving a number of these goals, it is particularly relevant to reducing child mortality (Goal 4) from ALRI.

Goal 7, Target 9, aims at integrating sustainable development into country policies and programs. The proportion of population using solid fuels has been adopted as an indicator for Target 9. Alleviating drudgery resulting from collecting fuel and using inefficient stoves, together with the involvement of women in implementing changes, can promote gender equality and empower women (Goal 3). Household energy interventions can also contribute to eradicating extreme poverty (Goal 1) through health improvements, time saving, and better environments for education and facilitating income generation (WHO 2004a).

Interventions

Although the main focus of this chapter is IAP, the many other ways in which household energy can affect health and development emphasize why interventions should aim to achieve a range of benefits, including the following:

- reduced levels of IAP and human exposure
- increased fuel efficiency
- reduced time spent collecting fuel and using inefficient stoves
- reduced stress on the local environment
- 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.

Interventions for reducing IAP can be grouped under three headings: those acting on the *source of pollution*, those improving the *living environment* (aspects of the home), and changes to *user behaviors* (table 42.4).

It should not be assumed that an intervention that reduces IAP will necessarily achieve other aims listed previously. For example, in colder areas, an enclosed stove with a flue that reduces IAP may reduce radiant heat and light, forcing households to use other fuels for those purposes. If not addressed with households, such problems may well result in disappointing reductions in IAP exposure, poor acceptance of interventions, and lack of motivation to maintain them.

Policy Instruments

Although a range of interventions is available, poor households face many barriers to their adoption, and enabling policy is needed (table 42.5). This area of practice is complex and evolving, often requiring solutions that are highly setting specific.

INTERVENTION COSTS AND EFFECTIVENESS

The cost-effectiveness analysis discussed in this chapter is based on recent work by Mehta and Shahpar (2004). The key components of this analysis are described here, with particular emphasis on the underlying assumptions.

Table 42.4 Interventions for Reducing Exposure to IAP

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

Source: Modified from Ballard-Tremeer and Mathee 2000.

Table 42.5 Policy Instruments for Promoting Implementation of Effective Household Energy Interventions

Policy instruments	Examples	Applications
Information, education, and communication	Schools	Learning about household energy, health, and development should be integrated in school curricula, particularly in countries where these topics are a priority for health and economic development. This goal can be achieved through programs such as the WHO Global School Health Initiative, which promotes environmental health education, including education about IAP.
	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 can be used (for example theater).
Taxes and subsidies	Tax on fuels and appliances	Reduced tax on fuels and appliances may promote development of distribution networks and uptake, and it may be seen as efficient if there is evidence of health, education, and economic benefits.
	Subsidy on fuels and appliances	General (for example, national) subsidies on fuels such as kerosene have been applied 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 (for example, clean fuel appliances, 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.
Regulation and legislation	Air quality standards	Although some developing countries have air quality standards for urban air, none have them for indoor air in settings where solid fuels are widely used. Routine monitoring and enforcement is not practical, but it may be useful to set standards and targets linked to specific assessments. For more routine use, information from censuses and surveys, such as fuel type, stove type, and venting for smoke, offers a practical alternative for setting air quality standards for IAP in developing countries.
	Design standards for appliances	Design standards can be applied to safety (prevention of burns, gas leaks, and explosions); venting of emissions; and efficiency. Although such standards may be difficult to enforce in an informal economy, they could become valuable with wider-scale production.
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 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.

Table 42.5 Continued

Policy instruments	Examples	Applications
	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.
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 the like are important for planning interventions.
	Development and evaluation of interventions	Evaluation of interventions should be conducted in a range of settings, using harmonized methods, if possible, that allow local flexibility but permit comparison with other types of interventions and other locations.
	Studies of health effects	Stronger and better-quantified evidence of the effects on health of reducing IAP, which includes exposure measurement, is required not only 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, to monitoring and evaluation of interventions, to more complex health studies—requires strengthening in those countries where the problems associated with household energy and IAP are most pressing.

Source: Authors.

Costs

Intervention costs have a number of components, the relative importance of which will vary with the type of fuel and device (box 42.1).

The level of costs incurred by consumers and others, including government, depends not only on the type of intervention but also on how it is delivered, supplied, and adopted. Experience indicates that successful interventions are sustainable in local markets, implying that the consumer pays the majority of initial and recurrent costs. The contributions of the government, utilities, nongovernmental organizations (NGOs), and the commercial sector will depend on many factors, including the type of intervention and fuel, location (urban or rural), existing level of supply and distribution

Box 42.1

Cost Components for Household Energy Interventions

- *Fuels,* which vary from zero (in direct cash terms, though not in opportunity cost) for collected biomass to a U.S. dollar or so per week for kerosene and several U.S. dollars per week for electricity (where used for cooking).
- *Stove appliances*, which vary from zero for a simple three-stone fire (stones arranged on the floor to support cooking pots, with the fire lit between the stones), to US$50 (and in some cases more than US$100) for a good-quality woodstove with a chimney and up to several hundred U.S. dollars for a biogas installation.
- *Additional appliances*—for example, an LPG storage bottle has a moderately high initial cost but should last for many years.
- *Maintenance costs*, which vary from zero for a three-stone fire up to modest, but not negligible, costs of repairing (and periodically replacing) woodstoves and chimneys. Appliances for using kerosene, LPG, and electricity also require maintenance and periodic replacement.
- *Program costs*, which apply to various aspects of provision of energy services, particularly LPG and electricity, but may also include costs of, for example, establishing more sustainable biomass reserves and administrative costs.

Source: Authors.

Box 42.2

Cost Issues in Switching to Cleaner Fuels for a "Typical" Poor Kenyan Family

Ruth[1] and her family live 3 kilometers from a small town on the main road about one hour by bus from Kisumu. They are subsistence farmers, with a small income from selling vegetables, from irregular laboring work obtained by her husband, and from making and selling handicrafts. Ruth, a mother of five, cooks over a three-stone fire using mostly wood, which she collects every other day from plots up to two hours walking distance from home. She spends 8 to 12 hours each week collecting wood. Ruth and her family use about 2 liters of kerosene each week for wick lamps and for cooking. They use dry cell batteries for the radio; grid electricity runs nearby, but connection is far too expensive. In all, the family spends an equivalent of US$1 to US$2 per week on fuel and batteries.

Through her women's group, Ruth hears that a few families are using LPG, now available at a nearby petrol station. The women say it is very quick and easy to use, and it keeps pots, clothes, and walls clean. The women and children seem to feel better, with less cough, runny eyes, and headaches. But those families run small shops and have been able to find the money to buy the gas bottle and cooker.

She talks with her husband about LPG, and although quite supportive, her husband thinks they cannot afford it. They could spend a little more on fuel, but income is irregular. Why abandon free fuel when they are so poor? Ruth thinks she could earn more money from her handicrafts in the time she saves collecting wood. On balance, they reckon they could probably afford the cost of the gas if they could be sure of more regular income, but they do not know where they could find the money to pay for the cooker and bottle.

Ruth then learns about a revolving fund set up by her women's group with the help of an NGO. If she can make small regular payments, she and her husband could get a loan to buy the stove and gas bottle next year. But they have never saved before, and what if they need money for medicines or for the children at school? Will they be able to keep saving each week to make sure they have enough to refill the gas bottle when needed?

1. Not her real name.
Source: Authors.

networks, and support for credit (for example, seed funds and fund capital) and targeted subsidies.

Some degree of market support may be required to stimulate demand and to encourage adoption by poor households, particularly those using three-stone fires (and other simple stoves) and collected biomass, because those methods do not incur direct monetary costs. Some countries have applied subsidies on fuels such as kerosene to assist poor families, but general subsidies are now considered to be an inefficient instrument for this purpose (von Schirnding and others 2002). Targeted subsidy and small-scale credit may be more appropriate ways of helping poor families acquire new household energy technologies and can have low default rates. Experience shows, however, that households are more likely to access credit for directly productive (with regard to income) uses of energy, rather than for everyday cooking and space-heating needs. Because the latter are the most important sources of IAP, more promotion of other benefits is needed, such as improved family health; fuel cost savings; time saved by faster cooking and reduced need for biomass; greater prestige; and cleaner homes, clothes, and utensils. A number of these benefits may result in reduced expenditure or increased income generation. Box 42.2 illustrates how these various issues can influence the decisions of a "typical" poor rural African household considering transition from gathered biomass to predominant use of a commercial fuel (LPG).

Effectiveness

Most evidence available for assessing intervention effectiveness deals with the effect on IAP levels and in some cases personal exposure. No experimentally derived evidence is available, however, on the effect of reducing IAP exposure on incidence of ALRI or the course of COPD in adults. A randomized trial of an improved chimney stove is currently under way in Guatemala, focusing on ALRI in children up to 18 months of age (Dooley 2003). A cohort study in Kenya by Ezzati and Kammen (2001) describes significant exposure-response relationships for all acute respiratory infections—and for ALRI specifically—associated with the use of traditional and improved woodstoves and charcoal. However, those effect estimates require confirmation because the study has small numbers of children (93 children under age five, living in 55 homes). For the other major health outcome, lung cancer, Lan and others (2002) reported adjusted hazard ratios of 0.59 (95 percent confidence interval: 0.49 to 0.71) for men and 0.54 (0.44 to 0.65) for women using improved coal stoves compared with traditional open coal fires in a 16-year retrospective cohort study in rural China.

Measuring evidence on reductions in pollution and exposure is nonetheless an important step in assessing effectiveness. Summarized here are the main findings of studies that have measured pollution levels in homes using traditional open fires, various improved stoves, kerosene, and LPG (see also Saksena, Thompson, and Smith 2004) and one that examined the effect of rural electrification in South Africa (Rollin and others 2004).

Effect of Improved Stoves. In East Africa, cheap improved stoves without flues, burning either wood or charcoal, are popular. These wood-burning stoves can reduce kitchen pollution by up to 50 percent, but levels still remain high (Ezzati, Mbinda, and Kammen 2000). Charcoal emits much less PM (but with a higher CO-to-PM ratio than wood), and stoves such as the Kenyan *jiko* yield particulate levels in the region of 10 percent of those from wood fires.

In a number of Asian and Latin American countries, improved stoves with flues have been promoted quite extensively, although many such stoves are found to be in poor condition after a few years. Some studies from India have shown minimal or small reductions in PM (Ramakrishna 1988; Smith, Aggarwal, and Dave 1983). Other studies, from Nepal, have shown reductions of about two-thirds, although the very high baseline levels mean that homes with stoves still recorded total suspended particulate values of 1,000 to 3,000 $\mu g/m^3$ during cooking (Pandey and others 1990; Reid, Smith, and Sherchand 1986). Results from Latin American countries are similar, although the IAP levels are generally lower. Studies have shown that *plancha*-type stoves (made of cement blocks, with a metal plate and flue) reduce PM by 60 to 70 percent and by as much as 90 percent when they are in good condition. Typical 24-hour PM levels (PM_{10}, $PM_{3.5}$ [respirable], and $PM_{2.5}$ have variously been reported) with open fires of 1,000 to 2,000 $\mu g/m^3$ have been reduced to 300 to 500 $\mu g/m^3$, and in some cases to less than 100 $\mu g/m^3$ (Albalak and others 2001; Brauer and others 1996; Naeher, Leaderer, and Smith 2000). One study from Mexico found little difference between homes with open fires and with improved stoves (Riojas-Rodriguez and others 2001), but the 16-hour levels of PM_{10} at about 300 $\mu g/m^3$ with open fires were relatively low.

Improved stoves with flues have so far had little success in Sub-Saharan Africa, although recent work developing hoods with flues for highly polluted Kenyan Masai homes reported reductions in 24-hour mean respirable PM of 75 percent from more than 4,300 $\mu g/m^3$ to about 1,000 $\mu g/m^3$ (Bruce and others 2002).

Personal exposures were usually found to have been reduced proportionately less than area pollution levels. For example, in Kenya, where hoods with flues achieved a 75 percent reduction in 24-hour mean kitchen $PM_{3.5}$ and CO, the woman's mean 24-hour CO exposure was reduced by only 35 percent (Bruce and others 2002). Similar results were found for child exposures in a study of improved wood stoves in Guatemala (Bruce and others 2004). We are aware of only one study that has used direct measurement of personal particulate exposure in very young children (Naeher, Leaderer, and Smith 2000). This study, also in Guatemala, reported mean 10- to 12-hour (daytime) $PM_{2.5}$ levels for children under 15 months of age of 279 $\mu g/m^3$ (+SD of 19.5) for the open fire and 170 $\mu g/m^3$ (+154) for the *plancha* stoves, a 40 percent reduction.

Impact of Cleaner Fuels. Good evidence shows that kerosene and LPG can deliver much lower levels of pollution, although it is important to determine the extent to which the cleaner fuel is substituting for biomass. 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. As a result, the *plancha* stoves achieved the lowest pollution levels in that setting (Albalak and others 2001). Still, a number of studies, mainly from India, show that introducing kerosene and LPG dramatically reduces kitchen pollution, which perhaps reflects different cooking requirements and less need for space heating. In rural Tamil Nadu, two-hour (mealtime) kitchen respirable PM levels of 76 $\mu g/m^3$ using kerosene and of 101 $\mu g/m^3$ using gas contrasted with levels of 1,500 to 2,000 $\mu g/m^3$ using wood and animal dung (Parikh and others 2001). Personal (cook) 24-hour exposure to respirable PM was 132 $\mu g/m^3$ with the use of kerosene as opposed to 1,300 and 1,500 $\mu g/m^3$, respectively, with the use of wood and dung (Balakrishnan and others 2002). Other studies confirm those findings, for example, with the use of gas in Mexico (Saatkamp, Masera, and Kammen 2000).

Delivering electricity to rural homes requires extensive infrastructure, and most poor people with access to electricity can afford to use it only for lighting and running low-demand electrical appliances. Without marked improvements in socioeconomic conditions, electrification has little potential to bring about substantial reductions in IAP. South Africa is one of the few countries with a large rural population traditionally dependent on biomass that has the resources for rural electrification. An investigation of three rural villages with similar socioeconomic characteristics, two not electrified and one electrified, in the North West province found that 3.6 years (average) after connection to the grid, 44 percent of the electrified homes had never used an electric cooker (Rollin and others 2004). Only 27 percent of electrified homes cooked primarily with electricity; the remainder used a mix of electricity, kerosene, and solid fuels. Despite the mixed fuel use, households cooking with electricity had the lowest pollution levels. Overall, homes in the electrified village had significantly lower 24-hour mean respirable PM and CO levels and significantly lower mean 24-hour CO exposure for children under 18 months of age than homes in the nonelectrified villages.

Effect of Other Interventions. Little systematic evaluation has been made of other interventions listed in table 42.4. Investigation of the potential of improving ventilation has, overall, shown that although enlarging eaves can be quite effective (Bruce and others 2002), removing smoke generally requires a well-functioning flue or chimney. Behavioral changes are currently the subject of an intervention study in South Africa (Barnes and others 2004a, 2004b).

Cost-Effectiveness Analysis

Although clean fuels can be expected to have a greater health effect than improved stoves (even those with flues), clean fuels may be too expensive and inaccessible for many poor communities over the short to medium term. Furthermore, even though clean fuels may be the best longer-term goal, an intermediate stage of improved biomass stoves may promote change by raising awareness of benefits and thus creating demand by improving health, saving time, and mitigating poverty. For those reasons, this cost-effectiveness analysis (CEA) examines both improved biomass stove and clean fuel options in the following scenarios:

- access to improved stoves (stoves with flues that vent smoke to the exterior), with coverage of 95 percent
- access to cleaner fuels (LPG or kerosene), with coverage of 95 percent
- part of the population with access to cleaner fuels (50 percent) and part with improved stoves (45 percent).

In each case, the intervention is compared with the current level of coverage of the respective technology or fuel.

Cost Assumptions. The assumptions for costs include program costs, fixed costs (including stoves), and recurrent fuel costs. Household costs for each region were drawn from the most comprehensive estimates available in the literature (von Schirnding and others 2002; Westoff and Germann 1995). For LPG, costs include the initial price of a cooker and cylinder and the recurrent refill costs. Assumed household annual costs, discounted at 3 percent, range from US$1 to US$10 for improved stoves and from US$3 to US$4 for kerosene or up to US$30 for LPG. Recurrent costs of fuel were found to be the most significant cost for the cleaner fuel interventions. Wood fuel costs are estimated at US$0.25 per week and assumed to be the same for traditional and improved stoves.

Costs were estimated separately for cleaner fuel and improved stove programs, using an "ingredients" approach (Johns, Baltussen, and Hutubessy 2003) and a costing template developed by WHO (2003). In summary, all the ingredients—including administrative, training, and operational costs—necessary to set up and maintain a given program must be added up. For regional estimates, costs of all traded goods were in U.S. dollars, whereas nontraded (local) costs were estimated in local currency and converted to U.S. dollars using relevant exchange rates. All costs were annualized using a 3 percent discount rate. Costs for tradable goods are scaled, using region-specific standardized price multipliers to reflect the increasing costs of expanding coverage caused by higher transportation costs to more remote areas (Johns, Baltussen, and Hutubessy 2003). Price multipliers were not applied to improved stoves because they tend to be manufactured locally with mainly local materials. Program costs were found to make up a small proportion of the overall intervention costs. Savings from averted health care costs are not included; because many of these cases currently go untreated, it can be argued that including treatment costs could result in inflated cost-effectiveness ratios (CERs).

Effectiveness and Health Outcome Assumptions. For this analysis, cleaner fuels are assumed to remove exposure completely, whereas improved stoves are assumed to reduce exposure by 75 percent (ventilation factor of 0.25). The effect on health of the exposure reduction will vary from region to region, because it depends on current levels of exposure as well as region-specific rates of morbidity and mortality. A number of assumptions have been made about households in carrying out analyses at the regional level. First, regional estimates of household composition (numbers of people, by age group and sex) and, hence, the effect of interventions on exposure and health apply at the level of individual households. Second, the age distribution of household members is similar in exposed and nonexposed groups; for example, the number of children per household is the same irrespective of household fuel use and ventilation characteristics. That assumption is likely to be conservative, since poorer, more polluted homes will typically have higher fertility and more children under five; all other factors being equal, such households would therefore experience a higher burden of disease from IAP exposure.

The health outcomes included are ALRI and COPD, because they were responsible for nearly all of the 1.6 million deaths attributable to IAP. The risk estimates used are those derived from the meta-analyses, as summarized in table 42.2. Smoking is an important confounding variable for COPD, particularly with men, because they generally smoke more than women do in developing countries. At present, information is sparse on the independent effect of solid fuel use on COPD in the presence of smoking. To avoid possible overestimation of the impact of IAP on COPD, attributable fractions for COPD from solid fuel use were applied to disease burdens remaining after removal of smoking-attributable burdens (Ezzati and Lopez 2004). Current estimates of exposure are used in combination with estimates of disease burden to obtain region-specific disease burdens for exposed and unexposed populations. Regional patterns of disease for 2000 have been used, including incidence, mortality, remission, duration, and case-fatality rate, obtained from WHO (2004b). In contrast to the estimates of burden in table 42.3, no age weighting has been used in the cost-effectiveness analysis. Health impacts are discounted at 3 percent.

Implementation Period. The implementation period is 10 years, although effects have been evaluated over 100 years in order to approximate the benefits for an entire population cohort. Thus, health effects are calculated for a cohort with a typical age structure for the population concerned that experiences the intervention for 10 years. It is assumed that after 100 years, all of the cohort (including children born during the 10-year implementation period) will have died.

The implementation period has critical implications, particularly in situations in which it takes several years to establish an intervention (for example, developing local markets for cleaner fuel), in which there are high start-up costs, and in which disease prevention is experienced in the distant future. This is especially true for chronic health effects (for example, COPD) that result from exposure over many years. If the intervention is implemented and exposure reduced for only 10 years, the disease burden is effectively deferred by 10 years, whereas longer-term implementation would result in many more cases being averted. For this analysis, using the 10-year intervention scenario specified for the Disease Control Priorities Project-2, incident cases are deferred by 10 years. For COPD, it is assumed that reduced exposure results in a milder form of COPD, accounted for by using a lower severity weighting.

Findings for Cost-Effectiveness Analysis. Findings from the CEA are expressed, for the four intervention scenarios with differing coverage (50 percent, 80 percent, 95 percent), by region, as (a) total healthy years gained in each region, (b) CERs in U.S. dollars per healthy year gained, and (c) healthy years gained per US$1 million (table 42.6). For all regions, the cleaner fuels yield the greatest gain in healthy years, but improved stoves also have a significant effect. The largest total population gains in healthy years are in Sub-Saharan Africa and South Asia for all types of interventions and in East Asia and the Pacific (mainly China) for cleaner fuels.

In the two regions with the largest burden of disease attributable to solid fuel use (Sub-Saharan Africa and South Asia), CERs are lowest (most favorable) for improved stoves, although in both regions kerosene has CERs just over twice those of improved stoves. In East Asia and the Pacific, kerosene is most cost-effective, followed by improved stove and clean fuel combinations and then by LPG (for coverage over 50 percent). In Latin America and the Caribbean, kerosene has the most favorable CER, followed by kerosene in combination with improved stoves. When the 50 percent and 80 percent coverage scenarios are compared, large differences in the ratio are seen in regions where coverage for that intervention is already substantial, and there is much less health gain at lower levels of coverage. Where no result is given, the specified coverage of the intervention has already been reached.

Multivariate sensitivity analysis was conducted to assess the effect of uncertainty in cost and effectiveness estimates. Costs were assumed to vary with a standard deviation of 5 percent, and effectiveness by the range of the confidence interval around the relative risk for each health endpoint. Results for Southeast Asia are shown in figure 42.3: the "clouds," or uncertainty regions, illustrate the range of possible point estimates emerging from the sensitivity analysis. This example is representative because other regions show essentially similar results. Despite the uncertainty, the ranking of the interventions remains the same (Mehta and Shahpar 2004).

Discussion. Results of this cost-effectiveness analysis indicate that an improved biomass stove is the most cost-effective intervention for South Asia and Sub-Saharan Africa, the two regions with the highest solid fuel–related disease burden. This finding is important given International Energy Agency 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 over that period (IEA 2002). Cleaner fuels (particularly kerosene) are the most cost-effective options for East Asia and the Pacific, the other region with a high burden of solid fuel–related disease. Cleaner fuels, in particular LPG, appear relatively costly for South Asia and Sub-Saharan Africa, but circumstances in individual countries may vary considerably and in ways that make this fuel much more cost-effective. Sudan, for example, has abundant cheap supplies of LPG and favorable excise arrangements for imported appliances, which would result in a lower CER for LPG than in other countries in the region. Furthermore, as will be discussed later, costs and benefits from the user's perspective will differ markedly, depending on whether the starting point is free fuel collection or purchased biomass fuel.

In interpreting the results, one should bear in mind the assumptions underlying the CEA. Much of the evidence indicates that, although improved biomass stoves may reduce kitchen pollution by up to 75 percent, the reduction in exposure of women and children is typically no more than 30 to 40 percent (equivalent to VF of 0.6 to 0.7). Achievement of the 75 percent reduction in exposure (VF = 0.25) assumed for this analysis is consistent only with well-designed and -maintained chimney stoves that meet most of the cooking and heating energy needs of the household and high population coverage (to avoid exposure from neighbors and others). Those conditions may be

Table 42.6 Intervention Scenarios for World Bank Regions
a. Healthy years gained

Intervention	Coverage (percent)	Sub-Saharan Africa	Latin America and the Caribbean	Middle East and North Africa	Europe and Central Asia	South Asia	East Asia and the Pacific
LPG	50	22,160,000	160,000	n.a.	n.a.	44,810,000	2,560,000
	80	60,370,000	4,670,000	15,570,000	1,330,000	149,300,000	228,710,000
	95	75,630,000	11,260,000	22,510,000	4,810,000	184,940,000	568,640,000
Kerosene	50	22,160,000	160,000	n.a.	n.a.	44,810,000	2,560,000
	80	60,370,000	4,670,000	15,570,000	1,330,000	149,300,000	228,710,000
	95	75,630,000	11,260,000	22,520,000	4,810,000	184,940,000	568,640,000
Improved stove	50	18,010,000	n.a.	n.a.	n.a.	48,880,000	1,120,000
	80	40,270,000	1,380,000	6,630,000	n.a.	101,670,000	6,980,000
	95	51,540,000	2,600,000	11,640,000	n.a.	128,380,000	32,760,000
Combined (with stove)	LPG	69,250,000	8,650,000	19,540,000	3,230,000	170,340,000	427,350,000
	Kerosene	69,250,000	8,650,000	19,540,000	3,230,000	170,340,000	427,350,000

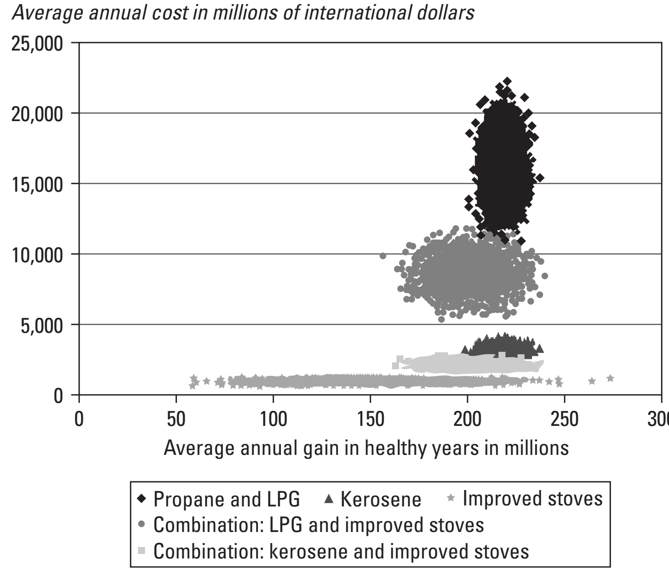
b. Cost-effectiveness ratios (US$ per healthy year gained)

Intervention	Coverage (percent)	Sub-Saharan Africa	Latin America and the Caribbean	Middle East and North Africa	Europe and Central Asia	South Asia	East Asia and the Pacific
LPG	50	715	1,405	n.a.	n.a.	542	1,695
	80	518	783	756	1,221	312	115
	95	518	814	762	1,321	314	100
Kerosene	50	84	631	n.a.	n.a.	63	225
	80	60	115	95	183	36	14
	95	60	106	95	167	36	12
Improved stove	50	25	n.a.	n.a.	n.a.	15	297
	80	21	947	457	n.a.	13	587
	95	20	1,101	368	n.a.	13	327
Combined (with stove)	LPG	295	761	606	1,375	177	83
	Kerosene	45	296	220	507	26	25

c. Healthy years gained per US$1 million

Intervention	Coverage (percent)	Sub-Saharan Africa	Latin America and the Caribbean	Middle East and North Africa	Europe and Central Asia	South Asia	East Asia and the Pacific
LPG	50	1,400	710	n.a.	n.a.	1,840	590
	80	1,930	1,280	1,320	820	3,210	8,680
	95	1,930	1,230	1,310	760	3,190	10,040
Kerosene	50	11,970	1,580	n.a.	n.a.	16,000	4,440
	80	16,600	8,690	10,500	5,470	27,850	72,840
	95	16,620	9,470	10,560	6,000	27,680	85,840
Improved stove	50	39,640	n.a.	n.a.	n.a.	67,330	3,360
	80	47,940	1,060	2,190	n.a.	74,750	1,700
	95	49,510	910	2,720	n.a.	76,300	3,060
Combined (with stove)	LPG	3,390	1,310	1,650	5,660	5,660	12,020
	Kerosene	22,250	3,380	4,550	38,590	35,590	40,730

Source: Authors.
n.a. = not applicable because the specified coverage of the intervention has already been reached.



Source: Mehta and Shahpar 2004.

Figure 42.3 Multivariate Sensitivity Analysis for Three Types of Interventions and Combined Intervention Scenarios, Southeast Asia Region

achievable and should be the goal, but they are not currently widespread. The relative cost-effectiveness advantage for improved stoves over cleaner fuel reported here should therefore be viewed as relating more to what might be achievable with good biomass stoves rather than to what is currently being achieved. The assumption that kerosene and LPG are equally clean and achieve zero exposure (VF = 0) presumes, at the very least, the use of high-quality kerosene fuel and pressurized burners. In many places, kerosene is of low quality, and the types of kerosene stoves and lamps used result in poor combustion.

Cost comparisons for the various fuels also need careful consideration. For example, the cost of solid fuel has been assumed to be constant for traditional open fires and improved stoves. As a general assumption this is reasonable, because the efficiency of "improved" stoves varies, and some may even be less fuel efficient than are open fires. However, new stove technology is markedly improving efficiency, and some designs reduce daily fuel consumption by 40 percent or more, resulting in savings of time (where fuel is collected) and money (where fuel is bought) (Boy and others 2000).

Transition from biomass (collected free) or charcoal (typically paid for daily in small amounts) to LPG would almost certainly require changes in saving and budgeting habits for a poor household (see also box 42.2). Those changes may entail arranging a loan to purchase the gas bottle and stove and saving money for the relatively large, periodic outlay to refill the cylinder. Such changes are very likely to have other consequences for the family that should not be overlooked. However, those consequences are complex and difficult to allow for within the current CEA framework. Empirical data are required on how household budgets change with various interventions and approaches to implementation.

The calculations have been undertaken for whole regions and provide no indication of how CERs differ among countries and specific communities. As local data on exposure, risk factors, health outcomes, and intervention effectiveness become available, similar analyses should be conducted at national and subnational levels.

Averted treatment costs have not been included on the grounds that most users of solid fuel are poor and have limited access to health services; many do not seek medical care for ALRI and even fewer do so for COPD. Inclusion of averted costs would increase cost-effectiveness. However, efforts to raise awareness about health risks and the importance of seeking care for ALRI (and COPD), which should accompany an intervention program, may increase care seeking and costs to the consumer. As more complete information becomes available, future CEAs should include treatment costs, with the option of allowing for an increase in care seeking associated with the intervention.

Interpretation of the results of this CEA, particularly with respect to comparisons with other types of intervention, needs to acknowledge that, although public organizations and other agencies will (or may) have some involvement in funding intervention programs, most of the cost of market-based interventions will be borne by households and those involved in production and marketing. Furthermore, it is hoped that, in addition to reducing IAP, interventions (and the means of accessing them) will have other positive effects, including on household budgets, in creating opportunities for income generation and empowering women in decisions about how energy is used. The promotion of market-based solutions implies new opportunities for artisans and entrepreneurs, but also the loss of traditional employment. The balance sheet for interventions is therefore complex, is specific to the setting, and will evolve as markets and enterprise develop.

Cost-Benefit Analysis

The CER gives cost per unit of health gained (healthy year) based on reduced risk of specified disease outcomes (ALRI, COPD). As discussed earlier, however, household energy interventions can affect a wide range of social, economic, and environmental issues, with important implications for health and development. In an economic analysis of water and sanitation interventions, Hutton and Haller (2004) found that time saved was the most important benefit. Those other effects cannot easily be expressed in units of health gain. Cost-benefit analysis (CBA) offers an alternative approach that may be better suited to environmental health interventions, given that health arguments alone will not motivate the multiple sectors involved in financing and implementing household energy interventions.

All main benefits in CBA are expressed in a common unit of monetary value and compared with costs in the cost-benefit ratio (CBR). The assessment of costs in CBA would have many assumptions and methods in common with CEA. The key differences lie in the selection of effects for inclusion as benefits and the methods for valuing them. In principle, there is no reason all the full range of effects discussed earlier could not be included (table 42.7), although in practice some, such as global climate effects, may be too uncertain. Where disadvantages of interventions are identified, they should also be included.

Benefit valuation presents particular challenges: effects are highly setting specific; evidence for some is limited, and their effects poorly quantified; and valuation in monetary units of benefits, such as lost working time averted for women, is difficult because women frequently are unpaid or work in informal markets. As a result, methods of valuation based on human capital may not be suitable, and alternative approaches such as contingent valuation, in which communities are involved in agreeing on market values for nontradable commodities, may be preferable. A related issue is valuing benefits that relate to sustainability and health, which would be experienced after many years and by subsequent generations. Larson and Rosen (2002) used a mix of valuation of statistical life and contingent valuation methods to examine the CBRs for improved stoves with respect to mortality (Guatemala, East Africa) and morbidity (Pakistan), concluding that ratios appeared favorable. Although they discuss other benefits, those benefits were not included in their valuations. Their observation that the favorable CBRs are not reflected in the generally low adoption of improved stoves led them to conclude that the information required for assessing household demand correctly is not currently available.

IMPLEMENTATION OF CONTROL STRATEGIES: LESSONS FROM EXPERIENCE

The past 30 to 40 years have seen many diverse programs on household energy, from small-scale NGO- and community-led

Table 42.7 Possible Data Requirements for Quantifying Benefits

Impact category	Variables or elements to identify
Direct benefits related to specific health outcomes	
Expenditure and time for health care–seeking	Health service use of those with diseases caused by IAP (number of cases, visits or days per case)
	Health service use of those having accidents or injuries due to reasons related to fuel use:
	Direct: burns, poisoning
	Indirect: injuries in collecting fuel
	Access features to get to health services (distance, mode of transport, time; average visits per case)
	Other consumption related to health care–seeking
	Time loss of seeking health care, both of the patient and of those accompanying patient
Other direct benefits in and around the home	
Time gained owing to less illness and death	Activities of those with diseases caused by IAP
	Impact of disease on activities (time input, productivity)
	Value of time of various occupations
Time saving of changed technology	Reduced time spent collecting fuel
	Reduced time spent cooking and on other tasks requiring fire or stove
	Value of time of various occupations
	Income-generating activities achieved through increased time
	Impact on household cleanliness and hygiene and need for cleaning
Change in household environment and production	Effect of improved lighting on evening activities (education, production)
	Effect of availability of electricity and other fuels on household production activities
	Impact on ergonomics related to cooking
Consequences of process of acquiring new technology and related changes	Increased confidence in capacity of the household to save for immediate or future needs
	More involvement of women in decision making with respect to changes in household energy use and related issues
Indirect benefits related to the environment	
Local environment	Impact of fuel scarcity on local environment, average fuel collection time
	Increased risk of environmental effects (such as soil fertility) or disasters (such as flooding, landslides)
Global environment	Contribution of local area to greenhouse gases

Source: Authors.

initiatives to ambitious national programs, the largest of which has been the installation of some 200 million improved stoves in rural China. Although few have been subjected to rigorous evaluation, an assessment has been made of the Indian national stove program (box 42.3; ESMAP and World Bank 2001); the Chinese national stove program (box 42.4; Sinton and others 2004; Smith and others 1993); and LPG promotion (box 42.5; UNDP and ESMAP 2002). Experience with a number of smaller initiatives has also been reported—for example, the ceramic and metal stoves in East Africa, which have proved popular and provided local employment (Njenga 2001), and improved stove interventions in Guatemala (UNDP and ESMAP 2003).

Implementation of the Chinese national program differed substantially from that in India. Although the Chinese rural populations concerned are poor, they do have greater effective purchasing power than the poor in many developing countries, allowing development of a program with the majority of consumers purchasing stoves at close to full cost (Smith and others 1993). 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 parts of the combustion chamber; and engagement of local technical institutions in modifying national stove designs to local needs. National-level stove competitions were held among counties for contracts, ensuring local interest and 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 central government (in contrast, for example, to India); local governments provided the major financial contributions. As a result, delays and other problems associated with transferring large amounts of money have been

Box 42.3

Key Features and Lessons from India's National Stove Program

The Indian National Programme of Improved Cookstoves was established in 1983 with goals common to many such initiatives:

- conserving fuel
- reducing smoke emissions in the cooking area and improving health conditions
- reducing deforestation
- limiting the drudgery of women and children and reducing cooking time
- 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 in each state trained rural women or unemployed youths to become self-employed workers to construct and install the stoves.

Between 1983 and 2000, the program distributed more than 33 million improved stoves. Despite extensive government promotion efforts, improved stoves now account for less than 7 percent of all stoves. Among those that have been adopted, poor quality and lack of maintenance have resulted in a life span of two years at most and typically much less. Evaluation of the program identified four main problems:

- Most states placed inadequate emphasis on commercialization, now seen as crucial for effective and sustainable uptake.
- Overall, there was insufficient interaction with users, self-employed workers, and NGOs, so the designs did not meet needs of households, and there was very poor acceptance of user training.
- Quality control for installation and maintenance of the stove and its appropriate use was lacking.
- High levels of subsidy (about 50 percent of the stove cost) were found to reduce household motivation to use and maintain the stove.

Some more successfully managed areas of the program focused resources 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 program promotes only durable cement stoves with chimneys that have a minimum life span of five years. The introduction of these stoves will make adhesion to technical specifications and quality control much easier.

Source: Authors, based on ESMAP and World Bank 2001.

Box 42.4

Household Effects of China's National Improved Stove Program

In 2002, an independent multidisciplinary evaluation was undertaken by a team of U.S. and Chinese researchers to evaluate (a) implementation methods used to promote improved stoves; (b) commercial stove production and marketing organizations that were created; and (c) effects 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 4,000 households in three provinces: Zheijang, Hubei, and Shaanxi. Key findings were as follows:

- The household survey revealed highly diverse fuel usage patterns: 28 and 34 different fuel combinations were used in kitchens in winter and summer, respectively. Most households owned at least one or more coal and one or more biomass stoves. Of the biomass stoves 77 percent, but only 38 percent of the coal stoves, were classified as improved. On average, improved stoves had a mean efficiency of 14 percent, which is well below the program target of between 20 and 30 percent, but above the mean efficiency of 9 percent for traditional stoves.
- With respect to air quality (measured with PM_4, the "thoracic fraction" of particulate matter, and CO), coal stoves showed significantly higher concentrations than biomass stoves during the summer, but not during the winter. Among households using biomass fuels (but not among households using combinations of fuels that included coal or LPG), improved stoves showed significantly lower PM_4 and CO concentrations than traditional stoves.
- In both children and adults, coal use was associated with higher levels of exposure (as measured by CO in exhaled breath) and improved biomass stoves with lower levels. Reported childhood asthma and adult respiratory disease were negatively associated with use of improved stoves and good stove maintenance. These results should, however, be treated as indicative because of limited sample size.

Overall, several important conclusions emerge with relevance to future improved stove programs:

- A wide range of combinations of different fuel and stove types may limit the effect of an improved stove program.
- Given the importance of space heating, making available an improved biomass stove for cooking may not be a sufficient strategy to reduce IAP. Improved coal stoves need to be promoted among rural Chinese households.
- Even among households using improved stoves, PM_4 and CO levels were higher than Chinese national indoor air standards, implying that a large fraction of China's rural population is still chronically exposed to pollution levels substantially above those determined by the Chinese government to harm human health.

Source: Authors, based on Sinton and others 2004.

avoided. The Chinese program succeeded in shifting norms: most biomass stoves now available on the market have flues and other technical features that classify them as improved.

Experience in the promotion of LPG has also been reported, for example, from the Indian Deepam Scheme (ESMAP and World Bank 2004; UNDP and ESMAP 2002) and from the LPG Rural Energy Challenge (UNDP 2005). The 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 developing partnerships in countries; enabling regulatory environments that facilitate LPG business development and product delivery; reducing barriers, for example, by introducing smaller (more affordable) gas bottles; and raising government and consumer awareness of costs and benefits. McDade (2004) has recently identified a number of key lessons emerging from experience with the promotion of LPG markets (box 42.5).

Electrification has an important role in development (IEA 2002). Evidence from South Africa suggests that communities with grid access experience lower IAP exposure (Rollin and others 2004). Electricity is not expected to bring about large reductions in IAP exposure in most low-income countries, however, because most poor households can afford it only for uses such as lighting and running entertainment appliances and not for cooking and space heating. The International Energy Agency has recently carried out a detailed review of electrification, including the issues involved in supply and cost recovery among poor (and especially rural) communities (IEA 2002).

Box 42.5

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

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

Source: Authors, based on McDade 2004.

The key lessons from experience with interventions to date may be summarized as follows:

- Too often, intervention technologies have been developed without adequate reference to users' needs and, as a result, have been poorly used and maintained or abandoned. Consequently, it is important to involve users—particularly women—in assessing needs and developing suitable interventions.
- Sustainable adoption should also be promoted through greater availability of a choice of appropriately priced interventions through local commercial outlets (artisans, shops, markets). This situation will come about only if demand is sufficient and if producers and distributors recognize this demand.
- All too commonly, communities most at risk exhibit low awareness, low demand, and poverty (often extreme poverty). A combination of user involvement and market approaches is needed, supported by the promotion and availability of targeted subsidies or microcredit facilities or both. The nature and extent of such financial support should depend on the purchasing power of the community.
- Local initiatives such as those outlined above must be led by national (and subnational) policy that acknowledges the contributions of a range of actors (government, business, NGOs, and so on) and sectors (energy, health, environment, finance, and so on) and that results in coordinated action. The instruments listed in table 42.5 should be considered when developing national policy.

In a recent review of the situation in Guatemala, the United Nations Development Programme and Energy Sector Management Assistance Programme (UNDP and ESMAP 2003) found that, despite the almost total reliance of the rural population on biomass, a marked lack of national policy, leadership, and coordinated action existed in relation to household energy. Countries need to develop mechanisms for action and coordination in light of local needs, available institutional capacity, and leadership potential.

THE RESEARCH AND DEVELOPMENT AGENDA

WHO has, through a process involving multistakeholder meetings and reviews, developed some consensus on research and development priorities for household energy, IAP, and health (see for example WHO 2002a). Effective coordination is a prerequisite because of the need for input from, and collaboration between, many different organizations and "actors" that have generally not previously worked in partnership on this issue. One recent response to this need has been the establishment of the Partnership for Clean Indoor Air, following the Johannesburg World Summit on Sustainable Development in 2002 (EPA 2004; http://www.pciaonline.org/).

The evidence base on health effects requires further strengthening, particularly to quantify the effect of a measured reduction in IAP exposure on the risk of key outcomes (for example, ALRI). A randomized controlled trial is currently under way in Guatemala, focusing primarily on ALRI in children up to 18 months of age (Dooley 2003); however, at least one other such trial on another continent would be desirable. Also required are observational studies for outcomes for which few studies currently exist, including tuberculosis, low birthweight and perinatal mortality, cataracts, asthma, and cardiovascular disease. A small number of such studies are in progress, but further effort is required, with perinatal outcomes being a particular priority.

Despite limitations in the evidence on health effects, what is known about the health, social, and economic consequences of current patterns of household energy use in poor countries is of sufficient concern to press ahead with an active program of research and development regarding interventions. This activity should address both the technology (and associated knowledge and behavior) and the approaches taken for implementation. Although some development and innovation in technology and fuels (for example, clean fuels derived from biomass) are likely to be valuable, the single greatest challenge is to promote wider access to—and adoption of—existing knowledge and interventions. Projects and programs currently in progress or being developed should be carefully evaluated using quantitative and qualitative methods to assess a range of effects. Work is currently under way to develop suitable methods and tools for this purpose (WHO 2005). Experience and lessons learned need to be disseminated widely to ensure that they reach governments, donors, researchers, NGOs, and communities. As part of this effort, WHO is developing a resource for countries that offers information on the effectiveness of interventions as well as the enabling factors that facilitate long-term, sustained adoption and use of suitable improved technologies in different settings (WHO 2004c).

Economic assessment, including cost-effectiveness analysis, has a valuable part to play. Critical issues resulting from limited evidence have been identified about estimations and assumptions for costs, exposure reductions, health effects, and averted treatment costs, as well as the current inability to assess national and subnational cost-effectiveness. CBA may be more suitable for interventions in this and similar areas but will require better description of environmental, social, and economic effects and further development of valuation methods. New health studies and broadly based evaluations of interventions should help fill some of these gaps.

Determination of the macroeconomic costs to countries of current household energy use and the potential gains resulting from change to more efficient and cleaner options could substantially add to the case for action.

Monitoring progress requires the development and testing of standard indicators for use in such policy documents as the *World Development Report* and for routine application at national and subnational levels. The Millennium Development Goal Indicator on the proportion of the population using solid fuels is a key starting point, and WHO, the reporting agency, is working to broaden the monitoring of this indicator through international surveys, such as demographic and health surveys (ORC Macro 2004), the Multiple Indicator Cluster Survey (UNICEF 2004), and the World Health Survey (WHO 2004d), as well as through work on regional and national indicators conducted under the Global Initiative on Children's Environmental Health Indicators (WHO 2004e). Future reporting will need to be further refined by taking into account differences in cooking practices (for example, type of stove and cooking location), as well as in fuel use for lighting and heating.

Advocacy for stronger action, internationally and in countries, is required. Products and guidance for a range of audiences should be prepared, with clear messages on the extent of the problem, the population groups most affected, what works, and what should be avoided. Tools such as the recently published guidelines on estimating the national burden of disease from solid fuels will help provide local evidence to argue for greater attention and action (Desai, Mehta, and Smith 2004).

CONCLUSIONS

IAP from solid fuel use is responsible for a large burden of disease among the world's poorest and most vulnerable populations. Inefficient and polluting household energy systems hold back development through resulting ill health, constraints on women's time and income generation, environmental impacts, and other factors. Although there is a trend toward cleaner and more efficient energy with increasing prosperity, little improvement is in prospect for more than 2 billion of the world's poorest people, particularly in South Asia and Sub-Saharan Africa. The number of people relying on traditional biomass is actually expected to increase until 2030.

Although the development of new energy technologies has a part to play in addressing this problem, many effective interventions are already available. The single greatest challenge is to dramatically increase the access of poor households to cleaner and more efficient household energy systems. Much valuable experience has been gained from successful—and unsuccessful—programs in household energy over the past three to four decades. Despite this experience, coherent, evidence-based policy is lacking in most of the countries concerned, where the lessons from experience now need to be implemented. Implementation will require greater awareness of the problem at international and national levels, provision of support for national collaborative action, and a focus on supporting appropriate, mainly market-based interventions.

Better information is crucial to this effort, including stronger evidence of the health effects of IAP exposure; assessment of the social, economic, and environmental benefits of interventions; and indicators to monitor progress. Economic analysis can help bring the case for action into policy, but it needs to be applied at country level and to include a wider range of benefits. Results from analysis at the regional level show that interventions can be cost-effective, particularly improved stoves, as long as these interventions can deliver substantial exposure reductions in practice. This conclusion, as well as its qualification, is important given the expectation that biomass will remain the principal household fuel in many developing countries for more than 20 years. The balance of effort and resources put into promoting cleaner biomass interventions rather than cleaner fuels, or vice-versa, will be an important policy issue for many countries and for the international community (Smith 2002).

With a range of innovative projects and programs under way in a number of countries and regions of the world, now is an important time to focus attention and effort on achieving the health, social, and economic gains that should result from improvements in household energy systems in developing countries.

NOTE

1. Particles are typically described according to the aerodynamic diameter, and although the devices used to separate particles of a given size do not yield a very sharp cutoff, this classification is functionally useful because smaller particles are able to penetrate farther into the lungs. Total suspended particles (TSP) include suspended particles of all sizes. Commonly defined smaller particles include PM_{10} (up to 10 microns diameter); respirable PM (includes all very small particles, about 50 percent of those 4 microns in diameter, and none above 10 microns in diameter); and $PM_{2.5}$ (up to 2.5 microns in diameter).

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