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Household Energy, Indoor Air Pollution and Health: A Multisectoral Intervention Program in Rural China

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Enis Barış and Majid Ezzati (Eds.)

Energy Sector Management Assistance Program (ESMAP)

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Preface

Decades of research have shown that Indoor Air Pollution (IAP), resulting from household cooking and heating, using low quality fuels and poorly ventilated stoves, is responsible for an array of respiratory-related and other diseases. In 2002, the World Health Organization (WHO) reported that, in developing countries, IAP is the fourth leading cause of death and burden of disease, surpassed only by malnutrition, unsafe sex and lack of safe water and appropriate sanitation. Families in poor rural areas are disproportionately affected as they typically lack the resources and opportunity to access cleaner, more efficient fuels and appliances.

While household energy use behavior varies around the world, one common feature remains: In most societies, women are responsible for cooking. Because they usually have primary responsibility for child care as well, children and infants also may spend several hours a day inhaling harmful pollutants and are at risk of burns from hot stoves. In colder climates, such as northern China – where heating is essential throughout a significant portion of the year – the picture of energy use and IAP exposure is more complex.

IAP and energy use patterns relate broadly to many of the UN Millennium Development Goals (MDGs). Reduced exposure to IAP contributes to improving women's and children's health (Goals 4 and 5). It can reduce poverty (Goal 1) by enabling healthier populations to participate in economic activities.
In addition, transitioning to more efficient household cooking and heating practices can empower women, by freeing up their time (now spent collecting fuel) for human development activities (Goal 3); it can also allow more children, especially girls, to attend school (Goal 2). Moreover, switching to cleaner fuels and alternative cooking and heating patterns can reduce pressure on forests and allow crop residues (commonly burned for heating) to be used more efficiently as fertilizer (Goal 7).

Despite global recognition of IAP's enormous relevance to international development and global health, identifying the most effective ways to tackle the problem has proved daunting. Recent advances in intervention science – spanning a wide range of disciplines, from engineering to epidemiology and the social sciences – can help to fill the gap between advocacy and action. Yet, no intervention program can be sustained if it fails to take into account the social and physical complexities of household energy use and fuel combustion. We believe a comprehensive approach which brings together the concerns of multiple sectors is eventually needed for successful mitigation. To this end, World Bank, in cooperation with China's Ministry of Health and the Chinese Center for Disease Control and Prevention (China CDC) initiated in 2002 the project Sustainable and Efficient Energy Use to Alleviate Indoor Air Pollution in Poor Rural Areas of China. This multisectoral project drew on international IAP research and experience of the past two decades, taking stock of programs implemented in China and elsewhere.

The study aimed to test the viability of behavioral (health education) and technological (improved stoves and better ventilation) solutions to mitigate IAP in poor rural areas of China under real life implementation conditions. The central tenet was a multisectoral approach, incorporating concerns from the fields of health, energy, environment, education and poverty reduction. We hope that the lessons from this project will motivate research, policy and program responses in China and elsewhere toward large-scale, sustainable improvement in environmental, health and socioeconomic outcomes of household energy use.

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Acronyms and Abbreviations

ADB	Asian Development Bank
ARI	Acute Respiratory Infection
Al_2O_3	Aluminum Oxide
As	Arsenic
B	Behavioral Intervention
C	Control
$Ca\ (OH)_2$	Calcium Hydroxide
CaF_2	Calcium Fluoride
CaO	Calcium Oxide
CBOs	Community-Based Organizations
Celsius	C
CH_4	Methane
C_6H_6	Benzene
China CDC	China Center for Disease Control and Prevention
CI	Confidence Interval
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DALYs	Disability Adjusted Life Years
DFID	Department for International Development, U.K.
DME	Dimethyl Ether
ESCOs	Energy Service Companies
ESMAP	Energy Sector Management Assistance Program
ETS	Environmental Tobacco Smoke
F	Fluorine
FLO	Foreign Loan Office
GAVI	Global Alliance for Vaccines and Immunization
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Giga Watt (s)
g/MJ-d	Grams Per Megajoule of Energy Delivered to the Cooking Pot
H	Hydrogen
HDI	Human Development Index

IAP	Indoor Air Pollution
IEA	International Energy Agency
Kg	Kilogram
Kgce	Kilogram Coal Equivalent (Standard Coal Equivalent)
Kg/h	Kilogram (s) Per Hour
Km	Kilometer
KW	Kilo Watt (s)
KWh/m^2	Kilowatt-Hour Per Day Per Square Meter
LPG	Liquefied Petroleum Gas
MBTUs	Million British Thermal Units
MDGs	United Nations Millennium Development Goals
μg	Micrograms
μg/m^3	Micrograms Per Cubic Meter
Mg	Milligram
Mg/m^3	Milligrams Per Cubic Meter
MM	Millimeter
Million sq m	Million Square Meter
MW	Mega Watt (s)
NGOs	Non Governmental Organizations
NIOSH	National Institute for Occupational Safety and Health
NO_2	Nitrogen Dioxide
PM	Particulate Matter
PPP	Purchasing Power Parity
PPM	Part(s) Per Million
PV	Photovoltaic
PVC	Poly Vinyl Chloride
R&D	Research and Development
RE	Renewable Energy
RETs	Renewable Energy Technologies
RPM	Respirable Particulate Matter
S	Sulfur
S + B	Stove Plus Behavioral Intervention
SIDA	Swedish International Development Agency
SiO_2	Silicon Dioxide
SO_2	Sulfur Dioxide
TAG	Technical Advisory Group
UNDP	United Nations Development Programme
WHO	World Health Organization

Executive Summary

For more than half of the world's population, solid fuels (coal and biomass) provide the primary source of domestic energy. Their incomplete combustion, using poorly ventilated heating and cooking stoves, emits hundreds of health- damaging pollutants. IAP from cooking and heating is a serious health hazard throughout the developing world, especially in poor rural areas; IAP has been identified as a cause of a range of respiratory and other diseases. In 2000, IAP from household burning of coal and biomass resulted in more than 1.6 million deaths, nearly 3 percent of the global burden of disease.

Inefficient fuel use exacerbates energy wastage and environmental problems; moreover, fuel-gathering, traditionally borne by women, is a time consuming and laborious task. Substantial welfare gains at all levels (nationally, regionally and globally) can result from helping developing nations to improve appropriate use of solid fuels while reducing, at the same time, IAP and its health-related costs.

Rural China Context

China's large rural population – more than 900 million residents – suffers extensively from the ill health effects of exposure to IAP,[1] exacerbated by the growing use of contaminated coal. The country's energy transition to cleaner fuels is slow. Today, biomass accounts for 55 percent of rural energy use, while coal represents a growing share of 34 percent (14 percent higher than in 1990). In rural areas, energy consumption is accelerating sharply because of increased use of solid fuels, notably coal. Since electricity accounts for only 6 percent of the total rural energy consumption, these data suggest that most of the increased consumption is for heating and cooking. If so, exposure to IAP may be worsening, despite new technologies and government-supported stove interventions.

Data regarding interventions around the world and in China are generally inadequate for designing effective and sustainable reductions in IAP. Most past interventions were designed to conserve energy; reducing exposure to airborne pollutants and improved health were not the primary concerns. Where they focused more on health effects, the interventions were often implemented in artificial settings divorced from rural realities. Thus, epidemiological, toxicological, and, most importantly, intervention research on the health effects of IAP from solid fuels is at a relatively early stage. A stronger foundation of knowledge is needed to design appropriate interventions which simultaneously address energy conservation, health and environmental concerns, both affordably and sustainably.

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[1] *In 2004, based on the 2000 census, China's National Bureau of Statistics cited 69 percent of the population, or about 900.6 million, as rural.*

Concentration of pollutants at locations inside the house depends on energy technology (stove-fuel combination), house design (for example, house size and construction materials, room arrangement and number of windows) and stove use behavior (for example, whether fuel is dried before combustion). In addition to pollution levels, exposure depends on time activity budgets of household members (for example, time spent inside or near the stove and direct participation in cooking tasks) and alternative food drying techniques. In short, IAP exposure can be reduced using a wide array of technological, housing and behavioral interventions.

Project Summary

The World Bank, in cooperation with China's Ministry of Health and the China CDC in 2002, initiated the project "Sustainable and Efficient Energy Use to Alleviate Indoor Air Pollution in Poor Rural Areas of China." The project tested affordable household energy interventions designed to reduce IAP exposure. To the best of our knowledge, this study represents the first community-based intervention trial to have tested the combined effect of technological and behavioral IAP interventions, and their implementation in rural settings. Study design features and measurement instruments were selected or developed so that project results would be useful to energy and IAP health specialists and encourage policy makers and other stakeholders to be more proactive in proposing polices or implementing large-scale programs to effectively address IAP and its health effects.

It was anticipated that success in reducing IAP in these provinces would lead to significant improvements in the health of their rural populations, especially women and children, who typically are most exposed to the indoor household environment. The principal expected outcome was better understanding of how location-specific factors and considerations should be accounted for while designing and implementing IAP interventions.

The project was implemented in four provinces: Gansu, Guizhou, Inner Mongolia and Shaanxi. In at least two of these provinces, winter conditions are harsh. Household characteristics in the study areas portray rural populations living in considerable poverty, as reflected by low family incomes, illiteracy and other disadvantages. Despite rapid economic growth in the provinces, rudimentary household energy methods and practices in rural areas are a legacy of China's poverty and lack of capacity to handle such problems as IAP, even if informed of the health risks. Lack, or perceived lack, of affordable alternatives necessitates use of low combustion solid fuels and inefficient heating and cooking stoves.

The study measurements focused on documenting reductions in three indoor air pollutants: respirable particles, carbon monoxide (CO) and Sulfur Dioxide (SO_2). Baseline data were collected to provide an understanding of the day to day, seasonal and spatial variations in pollution. The technological, housing and behavioral determinants of exposure were also documented. This information was used to design the IAP interventions and provide the basis for evaluating their effectiveness. In addition, surveys were conducted on IAP-related knowledge and behavior and selected health indicators for women and children in the study households. The household energy use interventions were of two types: 1) alternative stove technology (including improved ventilation systems; and 2) health education and behavioral activities. In each case, the interventions were tailored to fit location-specific conditions.

Approximately, 500 households were selected from each of the 11 townships on a quasi-experimental community trial basis, for a total of 5,500 households. These households were then divided into three groups: stove plus behavioral intervention (S + B), behavioral intervention (B) and control (C). In the case of Inner Mongolia, only two groups were formed (B and C). Baseline data for all three sets of groups, collected through surveys and testing, provided the background against which to evaluate the energy, IAP and health-related effects resulting from the project interventions. Comparison of results for S + B and B against changes in the same indicators for C, where no interventions were conducted, provided estimates of the relative effectiveness of the various interventions, abstracting from exogenous trends (for example, temperature changes and energy prices) affecting household energy use in rural China.

The interventions took into account the energy needs for cooking and heating, housing characteristics, fuel use and such sociocultural factors as food types and storage methods. Between March and October 2004, alternative stoves were designed and tested for efficiency under both controlled conditions and actual household use to assess the role of user behavior in stove performance. Health education and behavioral interventions, including dissemination of educational materials through village discussion groups and visits to model homes, were also implemented in the project areas.

Post-intervention data were collected approximately one year after the stove technology and behavioral interventions were completed. Between December 2004 and April 2005, indoor levels of Particulate Matter (PM_4), CO, and SO_2 were again measured using methods identical to those employed to collect the baseline data. Follow-up surveys were also conducted on the efficiency of household energy use, knowledge of the IAP health risk, behavioral changes and IAP-related health indicators.

Analysis of the baseline and post-intervention data demonstrates relatively consistent evidence that stove interventions had IAP reduction benefits when heating was the main energy use.
The evidence for cooking stove interventions was less consistent. Fuel consumption for heating (versus cooking) is generally more stable and less intense when compared with cooking stoves. Therefore, the indoor air quality benefits of heating stoves are less susceptible to compromise from stove-handling behavior if the combustion is well separated from the living and sleeping areas and/or smoke is ventilated outdoors. The results of cooking stove interventions were more mixed because users tend to modify combustion patterns more regularly when cooking. To better succeed, cooking stove interventions require greater modification of user behavior or stoves which are robust to these behaviors.

Introduction of alternative stove-handling behaviors, as part of the health education program, led to increased IAP-related knowledge and changes in specific behavioral indicators based on self-reported data. With regard to indoor air quality, however, no measurable IAP benefits resulted from health education and behavioral interventions alone, that is, without alternative stoves. These findings may reflect that people’s behavior with regard to cooking and heating – activities central to daily life – may be little affected by their knowledge and concerns about long-term health outcomes, especially where infrastructure and household economic status limit opportunities for switching fuels and stoves. They may also reveal the need to improve the design of behavioral interventions. In more comprehensive interventions, health education can play a key role in encouraging the uptake and use of new technologies (for example, cleaner fuels and stoves) and reducing IAP exposure through specific routes (for example, bioaccumulation of Fluorine (F) in food dried over fire).

What Interventions are Needed?

China’s early stove interventions of the 80s and early 90s were motivated largely by energy conservation to reduce biomass use and its effects on land degradation and deforestation. There was also a shift toward greater consumption of coal for heating. It is only relatively recently that the health dimensions of household energy use interventions have been documented and used as input in designing and marketing new technologies.

There have been some advances in energy generation in China, supported in recent years by global warming concerns and the sharp rise in oil prices. In the last two decades, China has demonstrated some commitment to Renewable Energy (RE) sources, as well as cleaner energies (including the conversion of solid fuels to clean liquid and gaseous fuels suitable for cooking and heating). But the need for interventions in poor rural areas is immediate; it requires using all available options, including cleaner fuels, more efficient combustion technologies and fuel alterations. As biomass energy technologies continue to advance, it may be advisable for China to encourage rural areas to rely more heavily on renewable biomass energy rather than coal. The encouragement may need little prompting if the price of biomass gasified stoves falls sharply, which movement along the "experience curve" would likely allow. But increased biomass use would need to be accompanied by careful land management and land tenure initiatives.

Developing and Scaling up Interventions

International experience offers useful lessons. Market-based mechanisms are likely to be important for long-term sustainability and efficiency of interventions; yet, there are clear areas for public sector investment both to create and promote better technologies, and to deliver these technologies to the poorest households.

A clear area in the need of investment is research on and development of new technological options, assisting producers and distributors in moving along the "experience curve" for such technologies. Such options as cleaner coal (with lower Arsenic (As) and F concentrations) and improved stoves will be difficult to sustain without a marketing and delivery system which facilitates household access. As the poorest communities will continue to have the least ability to pay, most alternative household energy technologies mitigating IAP will not be marketable, and will therefore continue to require donor or government interventions. Even so, government-supported interventions may not be sustainable in the long run. Also critical are appropriately designed market interventions (involving the participation of the commercial fuel and stove sector), which have a chance of uptake after public interventions come to an end.

The options for promoting sustainable introduction of clean energy technologies are closely tied to developing countries' capacity for energy research, development, demonstration and deployment.[2] Paucity of training venues, technology and information exchange, and technology standards exacerbate the perennial challenge of funding. In addition, microcredit to foster locally-designed and implemented commercialization efforts is systematically lacking. Moreover, research is lacking on the relationship between renewable energy projects and the socioeconomic contexts in which they are embedded. Overcoming market failures cannot be resolved by private enterprises alone. Scaling up and improving the sustainability of interventions require better assessment of the supply and demand for alternative energy technologies, and

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[2] *For more details, see Kammen, D.M., R. Bailis and A. Herzog. 2002. Clean Energy for Development and Economic Growth: Biomass and Other Renewable Energy Options to Meet Energy and Development Needs in Poor Nations. Policy Discussion Paper, ESDG. New York: United Nations Development Programme (UNDP), and Ezzati, M., R. Bailis, D.M. Kammen, T. Holloway, L. Price, L.A. Cifuentes, B. Barnes, A. Chaurey and K.N. Dhanapala. 2004. "Energy Management and Global Health." Annual Review of Environment and Resources 29: 383-419.*

evaluation of the policies and programs that can optimally increase intervention coverage with a high degree of community effectiveness.

To this end, the public sector plays an important role in supporting Research and Development (R&D) of household energy use alternatives; introducing infrastructure and financial incentives which support the dissemination of new energy technologies; and education, training and awareness-raising activities. Rural residents' continued reliance on rudimentary stove and ventilation systems, despite the pervasiveness of IAP and greater household awareness of its health risks, calls for microcredit and other incentives to induce demand for new household energy technologies. These are all important considerations for high quality and comprehensive (and almost certainly intersectoral) programs on IAP interventions which go beyond raising concern and aim to alleviate a major cause of mortality and morbidity in poor rural areas of China and other developing countries.

1. Introduction

Fei Yu, Zuzana Boehmova, Enis Barış and Majid Ezzati

Indoor Air Pollution (IAP), resulting from the use of solid fuels in poorly ventilated heating and cooking stoves, is a serious health hazard in developing countries, increasing the occurrence of a range of respiratory and other diseases. Inefficient fuel use exacerbates the energy wastage and environmental problems; moreover, fuel-gathering is a time-consuming and laborious task traditionally borne by women. Substantial welfare gains at all levels (nationally, regionally and globally) can result from helping developing nations to reduce IAP and its health-related costs.

In this spirit, World Bank, in 2002, initiated a project in China to test affordable household energy interventions (improved stoves with better ventilation, health education and behavioral changes) designed to substantially reduce IAP and exposure to it.[3] The project was implemented in four provinces (Gansu, Guizhou, Inner Mongolia and Shaanxi) where rural poverty is still widespread. This Chapter explains why addressing IAP in rural China is of urgent importance. It introduces the nexus of household energy use and health, along with the complex environmental, technological and behavioral issues which must be factored into while designing sustainable solutions.

Rural Household Energy and IAP

Globally, nearly 3 billion people rely on solid fuels (biomass and coal) as their primary source of domestic energy. In many developing countries, biomass (wood, charcoal, crop residues and dung) accounts for more than 50 percent of energy consumption and as much as 90 percent in some lower-income ones. Evidence from certain countries indicates that the declining trend of household dependence on biomass has slowed, or even reversed, especially among poorer households (Ezzati et al., 2004). Estimated household reliance on solid fuels is heaviest in Africa, South and South-East Asia and the Western Pacific (Figure 1.1).

Heavy reliance by rural households on inefficient solid fuels for heating and cooking results in high emission levels of Carbon Monoxide (CO)[4] and Particulate Matter (PM)[5]

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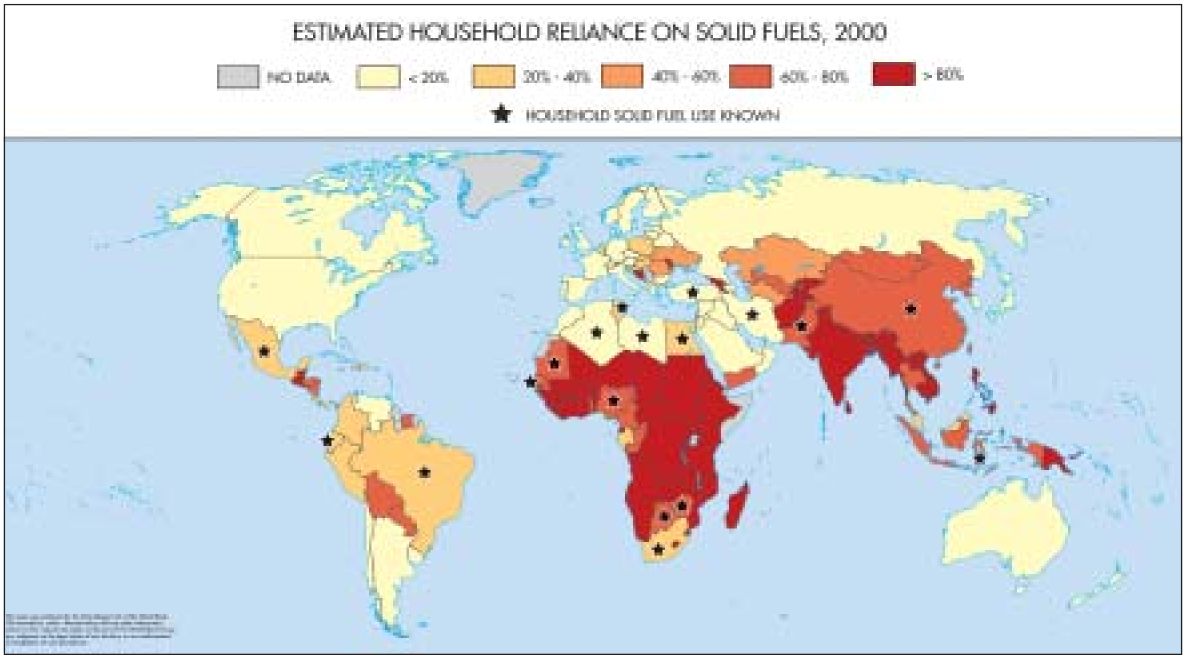
[3] *The project builds on World Bank-supported Comprehensive Maternal and Child Health VI Project, which succeeded in significantly reducing infant, child and maternal mortality rates in the project provinces. It also led to the observation that Indoor Air Pollution (IAP) was a major source of ill health among the rural poor.*

[4] *CO is an odorless, colorless toxic gas. At lower levels of exposure, CO causes symptoms which include headache, dizziness, disorientation, nausea and fatigue. At higher concentrations, CO poisoning is fatal.*

[5] *PM is the sum of all solid and liquid particles suspended in air when fuel is burned, many of which are hazardous. High concentrations and specific types of particles have been found to present a serious risk to human health. Of greatest concern are particles small enough to be inhaled into the deepest parts of the lung; these include* PM_{10} *(aerodynamic diameter less than 10 microns) and even finer ones, known as* $PM_{2.5}$ *(aerodynamic diameter less than 2.5 microns).*

Figure 1.1: Estimated Household Reliance on Solid Fuels by Country, 2000

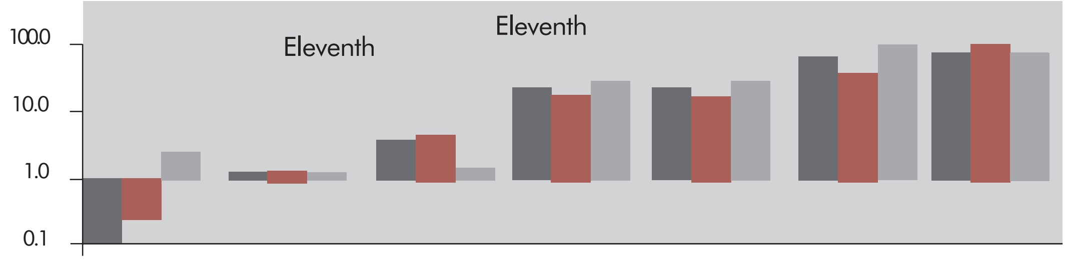


Note: Solid patterns represent countries for which estimates are based on model predictions.

Source: Smith et al. 2004.

(Figure 1.2). The main explanations for such heavy reliance are affordability (of fuel and/or start-up cost for stove) as well as energy infrastructure which determines whether people can buy specific fuels if they choose to do so. Liquid fuels, notably Liquefied Petroleum Gas (LPG) and kerosene, are usually more expensive than solid fuels, require more costly

Figure 1.2: Household-level Emissions by Fuel -type (per meal)



	Biogas	LPG	Kerosene	Wood Residues	Roots	Crop	Dung
■ CO	0.1	1	3	19	22	60	64
■ Hydrocarbons	0.3	1	4.2	17	18	32	115
■ PM	2.5	1	1.3	26	30	124	63

Note: Health-damaging pollutants per unit energy delivered: ratio of emissions to Liquefied Petroleum Gas(LPG) (data from K. Smith et al. 2000). Values are shown as Grams Per Megajoule of Energy Delivered to the Cooking Pot (g/MJ-d).

Source: Smith, Rogers and Cowlin 2005.

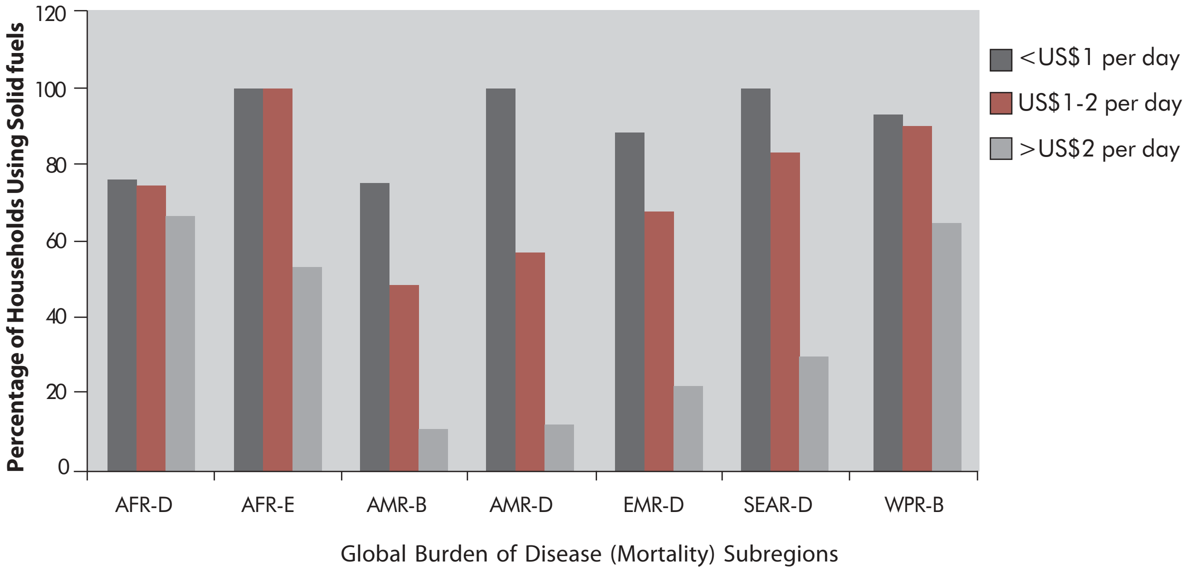
stoves and harder to obtain for people in rural areas or urban slums. Indeed, many forms of biomass are traditionally collected on an individual, noncommercial basis. As Figure 1.3 demonstrates, the relationship between income and reliance on solid fuels is strongly dependent on region.

But the transition to cleaner fuels with increasing incomes should not be interpreted as deterministic. Other factors, including alternative consumer desires, may be equally or more important than cleaner fuels. Further the energy options with increasing wealth and income vary: for example, a household may decide to consume more energy, switch to another form of energy or source of access, or use a mix of energy sources. The choice may be influenced by cultural context, energy infrastructure and policy considerations (Ezzati et al. 2004).

Rural China Context

Across China, residential energy consumption varies widely, reflecting differing access to energy sources, prices, climate, income and urbanization levels (Jiang and O'Neill 2004). Rural household consumption accounts for about 25 percent of the total national energy use (Wang and Feng 2001). From 1980 to 2004, rural household energy use per capita increased about 60 percent. Over this period, the composition of energy sources changed dramatically. The share from biomass fell nearly 30 percent (from 84 percent to slightly more than 55 percent), while that from coal increased 20 percent (from only 14 percent to 34 percent) (Table 1.1).[6]

Figure 1.3: Relationship between Income and Solid Fuel Use



Note: Abbreviations indicate WHO subregions: AFR = Africa, AMR = Americas, EMR = Eastern Mediterranean, SEAR = South-East Asia and WPR = Western Pacific. Corresponding letters (after each subregion) indicate mortality strata: B = low child mortality and low adult mortality, D = high child mortality and high adult mortality, E = high child mortality and very high adult mortality (WHO 2002).

Source: Blakely et al. 2003.

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[6] *The annual National Rural Household Survey, which included information on biomass energy use, was discontinued in 2000; data on biomass use provided by the Ministry of Agriculture provide rough estimates of magnitudes and trends.*

Over the past 25 years, rural Chinese households have transitioned toward commercial fuels (Figure 1.4). During the 80s, use of both biomass and commercial energy increased (the latter more rapidly than the former). During the 90s, rural use of biomass was relatively stable; only the highest household income group reduced use significantly (Jiang and O'Neill 2004). Use of agricultural residues (straw and stalk) remained constant, while fuelwood use declined because of restricted access to mountains and other reforestation measures.

Over the 1998-2004 period, rural energy consumption increased sharply. Data for 2004 show absolute and per capita increases of 31 and 28 percent respectively; straw, fuelwood and coal accounted for more than 90 percent of increased use. Fuelwood use increased 43 percent over the 1998 level, accounting for 25 percent of the rural energy supply in 2004; straw accounted for 30 percent. In total, biomass accounted for 55 percent of the rural energy supply, compared to 34 percent for coal (Table 1.1).

That the burning of solid fuels represented more than 90 percent of increased consumption over the period suggests that most of the increase was for heating and cooking.[7] A sharp increase in electricity consumption would have suggested increased use of consumer durables (for example, refrigerators or television sets); but, as Figure 1.4 illustrates, electricity contributed only marginally to meeting the surge in rural energy demand. The nature of increased demand thus indicates the likelihood of substantially greater exposure to IAP.[8]

Table 1.1: Rural Household Consumption by Energy Source, for Selected Years (percent)

	Energy Share (%)			
Energy Source	*1980*	*1990*	*1998*	*2004*
Total Biomass	84.3	77.4	56.7	55.5
Fuelwood	39.6	36.3	23.0	25.1
Straw and Crop Residues	44.7	41.1	33.7	30.4
Total Commercial	15.7	22.6	43.3	44.5
Coal	14.2	20.1	32.0	34.0
Electricity	1.0	2.2	8.1	6.0
LPG +	0.5	0.3	3.2	4.5
Rural Household Consumption per capita (Kgce)*	329.0	380.8	414.0	529.3

** Kilogram Coal Equivalent (Standard Coal Equivalent).*

Sources: Transportation and Energy Department, National Planning Committee of China; China Department of Agriculture, Technology and Education Office.

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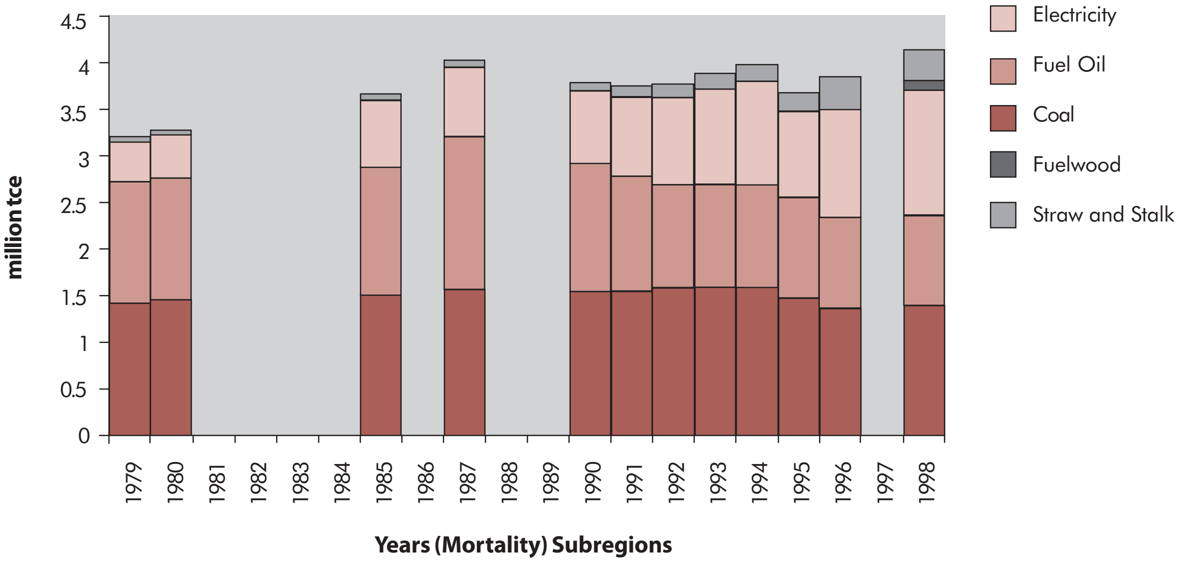
[7] *An additional reason could have been better reporting of data.*

[8] *It should be noted that this data is limited to rural household-energy use (rural industry is not included); thus, further research is needed. Preparations are under way to implement the China Residential Energy Consumption Survey II (C-RECS II). The aim is to use data from this fuel-scale survey to improve China's energy consumption statistics and provide input to the standards-setting process for household appliances to create reference year data on which future China Residential Energy Consumption Survey (C-RECS) surveys can be built. Survey content would be adapted and expanded from the smaller C-RECS-I survey conducted in 1999, which was limited to urban households. The survey has been jointly planned and conducted by China's National Bureau of Statistics; Lawrence Berkeley National Laboratory; Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences; and Technical Economic and Energy System Analysis Group, Tsinghua University.*

Figure 1.4: China's Rural Household Transition in Energy Consumption, 1979-98



Note: Data are from the 1999 National Rural Household Survey conducted by the China Rural Socioeconomic Survey Division, State Statistical Bureau.
Source: Jiang and O'Neill 2004.

Regional differences in rural household energy consumption reflect resource availability and climatic conditions. Reliance on biomass ranges from a high of 83 percent in North-East China to a low of 57 percent in North China. Provinces with extensive coal deposits (Guizhou, Hebei, Ningxia, Shanxi, Xingjiang and Yunnan) rely heavily on coal (Jiang and O'Neill 2004). The recent increase in the number of coal mines and the low price of coal, together with restrictions on wood gathering, have encouraged households to switch from biomass to coal. Households proximate to urban areas (Beijing, Shanghai and Tianjin) rely more heavily on electricity. Northern provinces use more energy than southern ones, reflecting colder weather conditions. (Air conditioning is not yet prevalent in rural areas.) It is noteworthy that 98 percent of households have electricity;[9] yet, in rural areas, electricity accounts for only 6 percent of total energy use (primarily for lighting). Nearly all households use a combination of energy sources, the most common being biomass, coal and electricity. In higher income households, preference has shifted toward more sophisticated sources, such as electricity or LPG (Jiang and O'Neill 2004).

In 1999, per capita expenditure on rural household energy was approximately 56 yuan (US$6.8) (Jiang and O'Neill 2004), representing 3.4 percent of the total expenditures and 2.3 percent of the total income. Energy expenditure increased with household expenditure: the share spent on coal declined, that spent on LPG increased and that spent on electricity remained constant. While coal consumption increased with income, biomass and electricity consumption were income inelastic – at least at this stage of development (Wang and Feng 2001). The reason may have been a government ban on harvesting fuelwood in certain forests.

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[9] According to the 2001 Rural Household Survey (State Statistical Bureau), 98.3 percent of townships, 97.8 percent of villages and 97.4 percent of rural households have access to the power grid (see also China Energy Statistical Yearbook 2000-02, China Statistics Press).

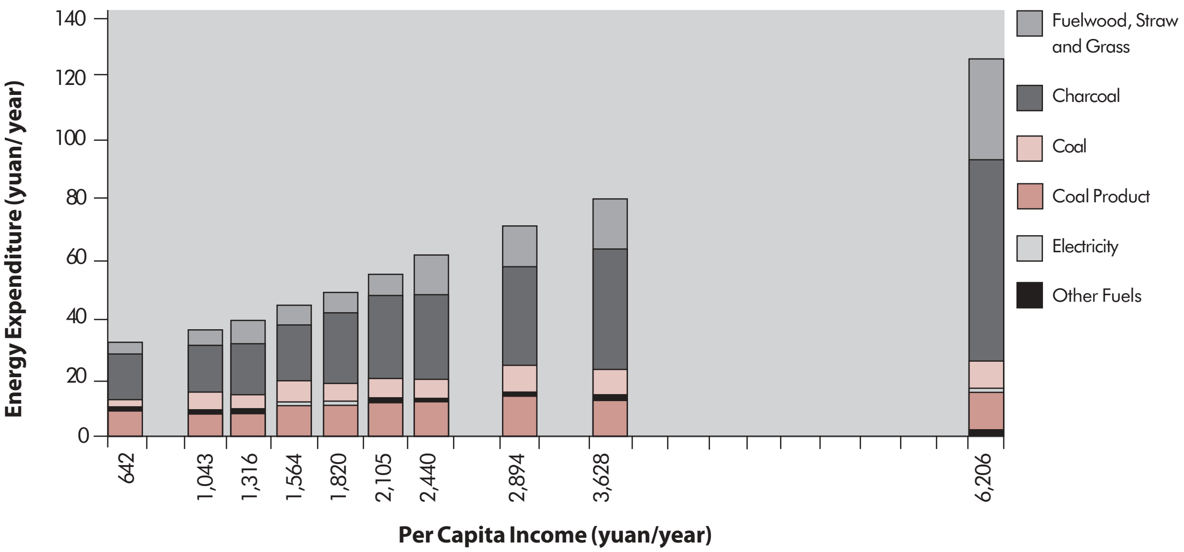
Thus, rural China appears to be in the early stages of energy transition; the process of substituting modern fuels for biomass is slow.[10] Concurrent with this transition, China is experiencing rapid growth in energy consumption, which is closely correlated with net income growth and improved access to electricity, coal and other fuels (Figure 1.5).

Over the past two decades, per capita net income of rural households increased fourfold in real terms. While rising net income has been accompanied by greater reliance on commercial energy to meet additional energy demand, the use of biomass continues. Nevertheless, the effect of China's policy interventions (as distinct from the general tendency of developing countries to switch to commercial fuels as incomes increase) is unclear. Whatever the trends and interventions, the fact remains that biomass continues to account for 55 percent of the rural energy, and coal for another 34 percent. In sum, the IAP occasioned by the continued burning of solid fuels for heating and cooking remains a serious problem in China.

Profiles of Project Provinces

In the four project provinces reported here, rural household energy use varied from 1998 to 2004. Energy use increased substantially in Guizhou and Inner Mongolia, grew moderately in Gansu and declined slightly in Shaanxi (Figure 1.6). In Guizhou, substantial increases in rural residential energy use could have been fueled by a tripling in the use of firewood and a doubling in the use of coal. In Inner Mongolia, the small increase was likely to have been fueled primarily by greater use of stalk.[11] None of the four provinces showed a clear trend toward increased reliance on coal relative to other energy sources.

Figure 1.5 (a): Rural Household Energy Expenditure by Fuel-type (deciles of per capita income)



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[10] *Education is a primary variable which bears on biomass use: As education levels rise, biomass use declines. Other variables include household size, occupation and geographic conditions (Jiang and O'Neill 2004).*

[11] *The figures show a surprising increase. One possible explanation is differences in reporting mechanisms; another is that it is a phenomenon deserving further exploration.*

Figure 1.5(b): Rural Household Energy Expenditure by Fuel-type (deciles of per capita income)

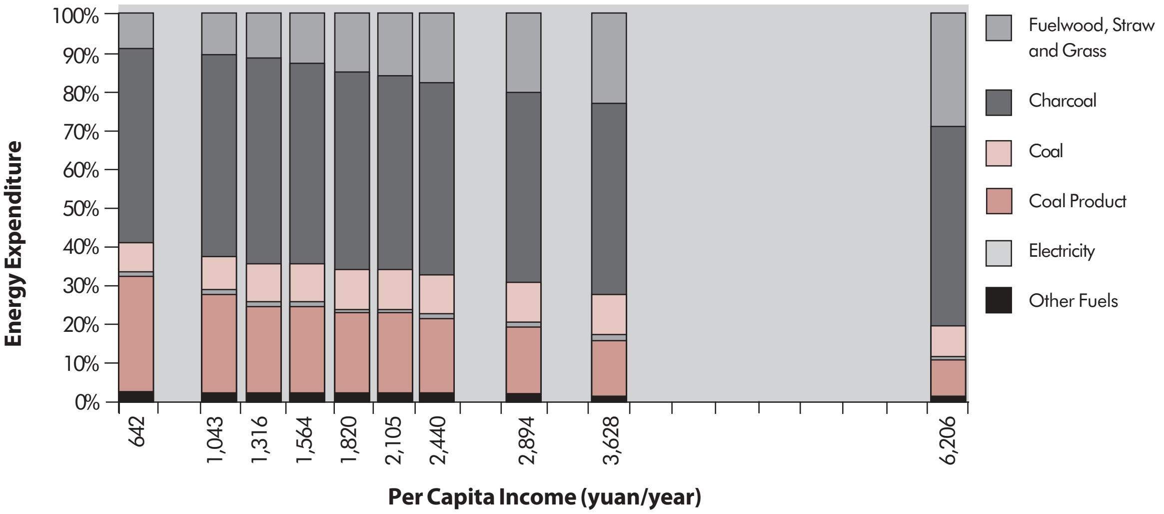


Figure 1.5(c): Rural Household Energy Expenditure by Fuel-type (deciles of per capita total expenditure)

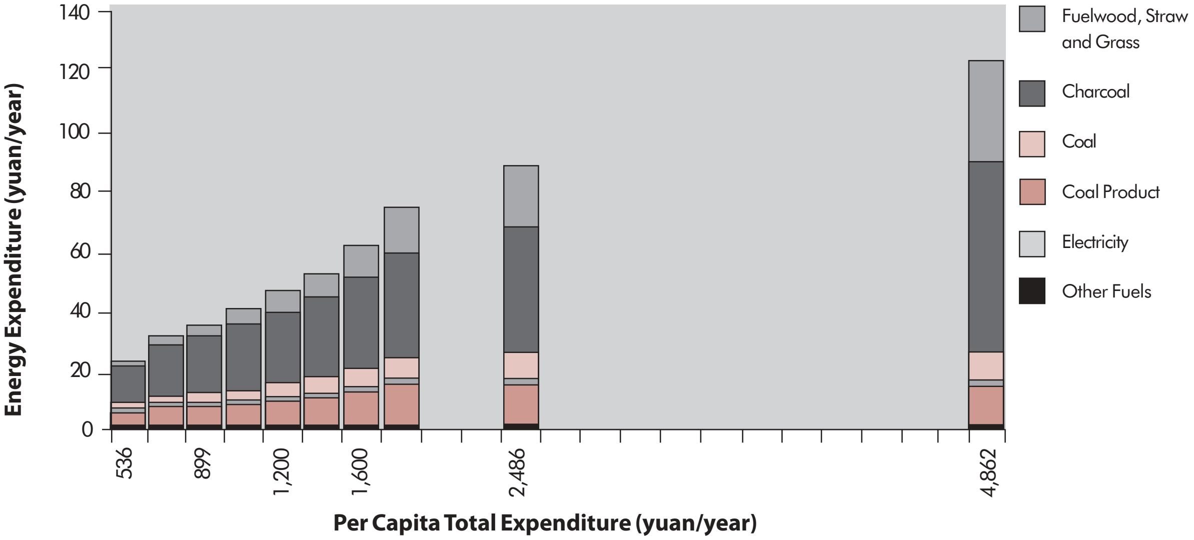
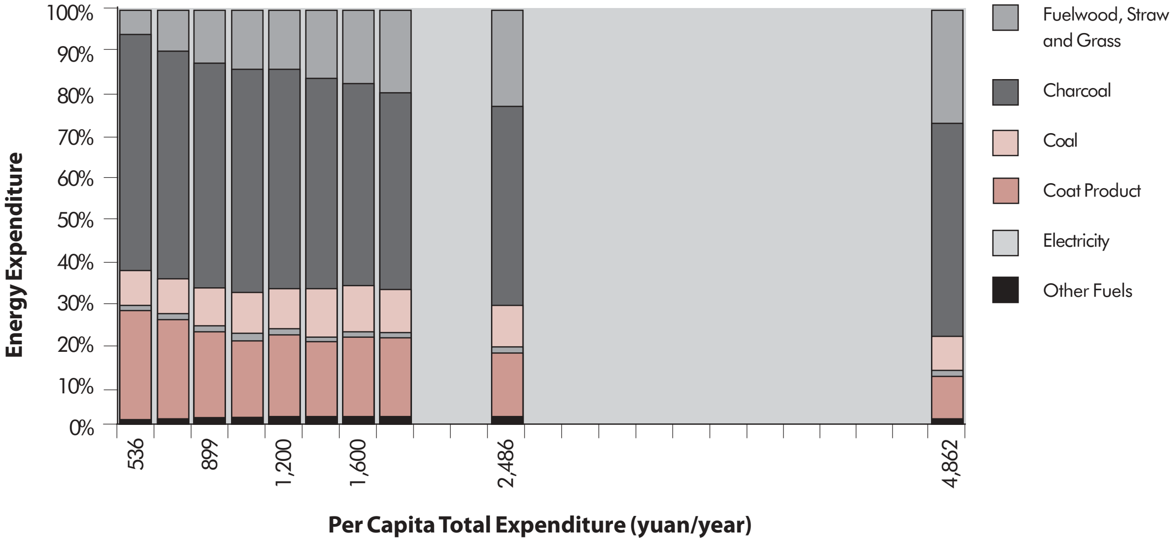


Figure 1.5(d): Rural Household Energy Expenditure by Fuel-type (deciles of per capita total expenditure)



Source : Jiang and O'Neill (2004). Reprinted with permission of Inderscience.

Health Risks and IAP

The burning of biomass or coal in open or poorly ventilated stoves results in the emission of hundreds of chemical substances, in the form of gases, liquids (suspended droplets) and solids (suspended particulates). These pollutants include CO, Nitrogen Dioxide (NO_2), particles in the inhalable range (below 10 μm in aerodynamic diameter) and other organic matter (for example, benzo[a]pyrene, Benzene (C_6H_6) and formaldehyde). In addition to the above pollutants, combustion of coal may release oxides of Sulfur (S) and heavy metal contaminants, including Arsenic (As) and F. Concentrations of inhalable particles, CO and Sulfur Dioxide (SO_2) in households reliant on solid fuels for heating and cooking, may be multiples of standards for ambient air pollution.

Detailed epidemiological and toxicological research on the health effects of IAP from solid fuels has only recently begun. Nonetheless, the growing consensus is that IAP is a causal agent of acute respiratory infection, chronic obstructive pulmonary disease, lung cancer (from coal smoke), asthma, nasopharyngeal and laryngeal cancers, tuberculosis, low birth weight and eye disease (for example, cataracts). A comprehensive survey conducted by the World Health Organization (WHO) in 2000 found that each year the first three of these diseases cause the death of more than 900,000 children under age five and more than 700,000 adults (WHO 2002). Globally, acute lower respiratory infection is the most common cause of mortality among children under age five. As Table 1.2 indicates, 98.5 and 98.7 percent of the respective deaths of children and adults from IAP exposure, caused by solid fuel use, occur in developing countries. Annually, IAP results in a loss of healthy life years equivalent to some 40.9 million Disability Adjusted Life Years (DALYs)[12] (WHO 2002).

For developing world regions, Ezzati et al. (2002) found that indoor smoke from solid fuels is a leading health risk factor. Globally, of the 20 leading health risk factors causing death, IAP ranks 11th (Figure 1.7); in terms of DALYs, IAP ranks eighth (Figure 1.8). For high mortality developing regions (that is, those with very low income), IAP ranks fourth in importance as a health risk factor. For low mortality developing regions, including China, IAP ranks eighth in importance as a health risk factor.

Table 1.2: Annual Mortality Caused by IAP Exposure from Solid Fuels

Country Grouping	*% of Global Population*	*Children Under Five Years*	*Adults*
High Mortality Developing Countries	*38*	*808,000*	*232,000*
Low Mortality Developing Countries	*40*	*89,000*	*468,000*
Demographically and Economically Developed Countries	*22*	*13,000*	*9,000*

Source: WHO 2002.

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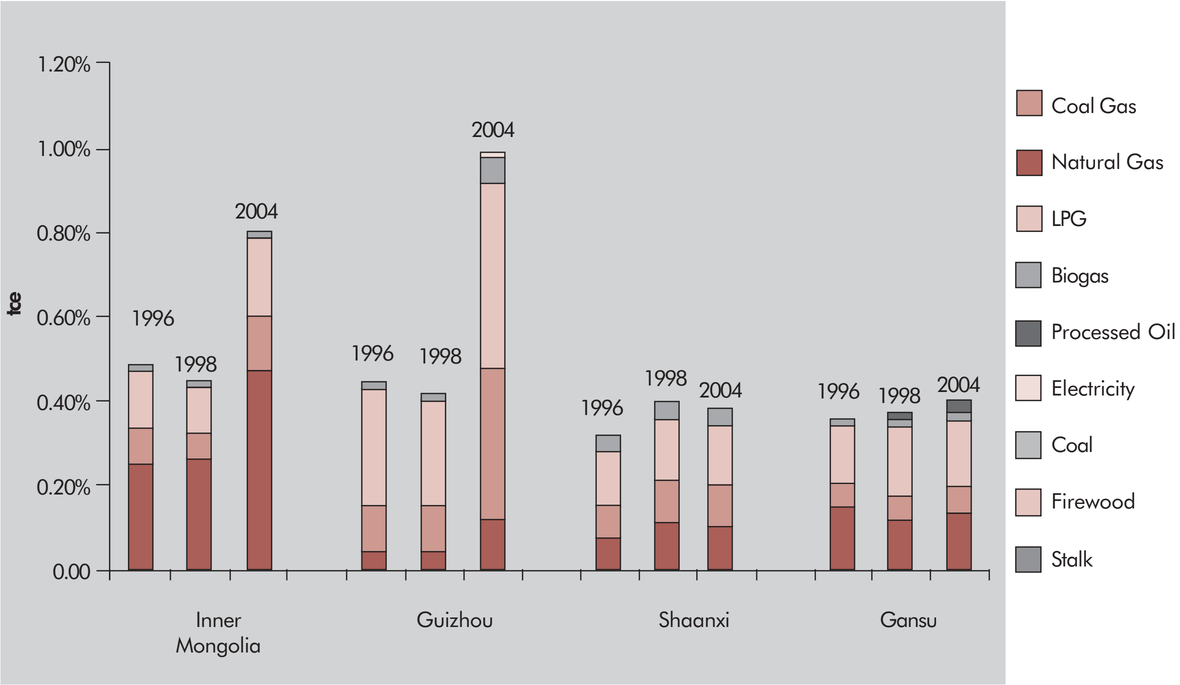
[12] *DALYs lost to mortality are the total discounted value of years lost to premature death across all causes and age groups. DALYs lost to disability are based on the incidence and duration of various types of disability multiplied by a weight which accounts for the severity of the disability compared to loss of life. Total DALYs result from the sum of DALYs lost to mortality and disability, adjusted by a discount rate so that future years of healthy life are valued at progressively lower levels and by age group weightings, so that years of life lost at different ages are given different relative values.*

Figure 1.6: Rural Residential Energy Consumption by Study Province (per capita) in Selected Years



Source: China Department of Agriculture, Technology and Education Office.

Women and children are at greatest risk since they spend more hours per day indoors in the vicinity of the cooking stove. Worldwide, the risk to women from IAP is nearly 50 percent higher than for men (Ezzati 2002). Risk is highest in South-East Asia, Western Pacific (including China) and Sub-Saharan Africa. Across the developing world, IAP is a serious health hazard, especially in rural areas where reliance on biomass and coal for heating and cooking, under poor combustion and ventilation conditions, is virtually universal.[13]

Challenge of Rural China

The global health risks from IAP noted in the previous section apply equally in China.[14,15] The Comparative Risk Assessment analysis estimated that, in 2000, IAP was the fourth leading health risk factor contributing to mortality in China, causing more than 500,000 deaths (WHO 2002). Indoor smoke from solid fuels was the fifth most important risk factor in terms of DALYs, accounting for 2.5 percent of the total lost healthy life years.

Virtually all of China's rural households – representing some 900 million of the country's total population of 1.3 billion,[16] rely on |biomass and coal to meet their daily heating and cooking needs. Extensive use of coal for heating and cooking emits high SO_2 concentrations, which are associated with adverse health effects.

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[13] *Reduction of IAP is reflected in the United Nations Millennium Development Goals (MDGs); solid fuel use is an indicator of environmental sustainability*

(Goal 7), while reduced IAP is related to many other goals, including the goals of reducing child mortality and promoting gender equality.

[14] *The WHO comparative risk assessment, conducted over a two-year period in 14 world regions, including the Western Pacific (of which China accounts for 85 percent of the population), provides an authoritative assessment of the health consequences of IAP in China (WHO 2002).*

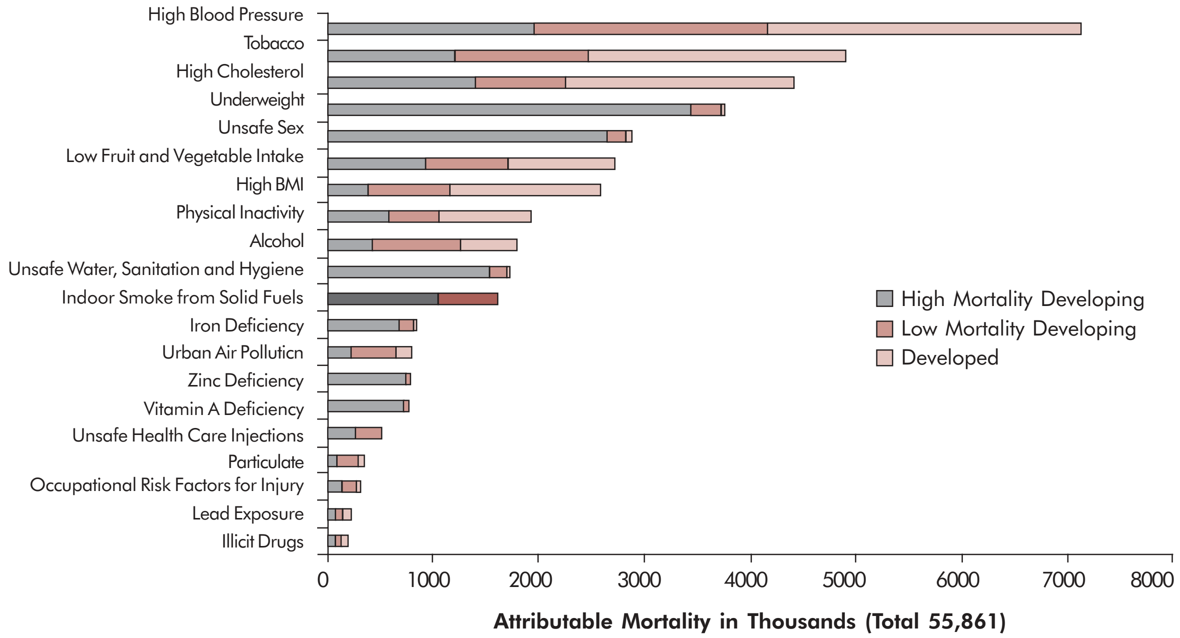
[15] *According to the Asian Development Bank (ADB), 17 percent of China's population still lives on less than US$1 per day (Key Indicators 2005). In 2004, China's per capita income was US$1,290 (World Development Indicators database, August 2005); based on Purchasing Power Parity (PPP), this translates into US$5,530. Rural income is about one-third of the national average.*

[16] *Based on the 2000 census, the National Bureau of Statistics of China in 2004 cited 69 percent (900.6 million) of the country's population as rural.*

Monitoring the health effects of improved stoves in Xuanwei County, Yunnan Province, before and after the intervention provides the most detailed evidence of the ill effects of coal smoke.

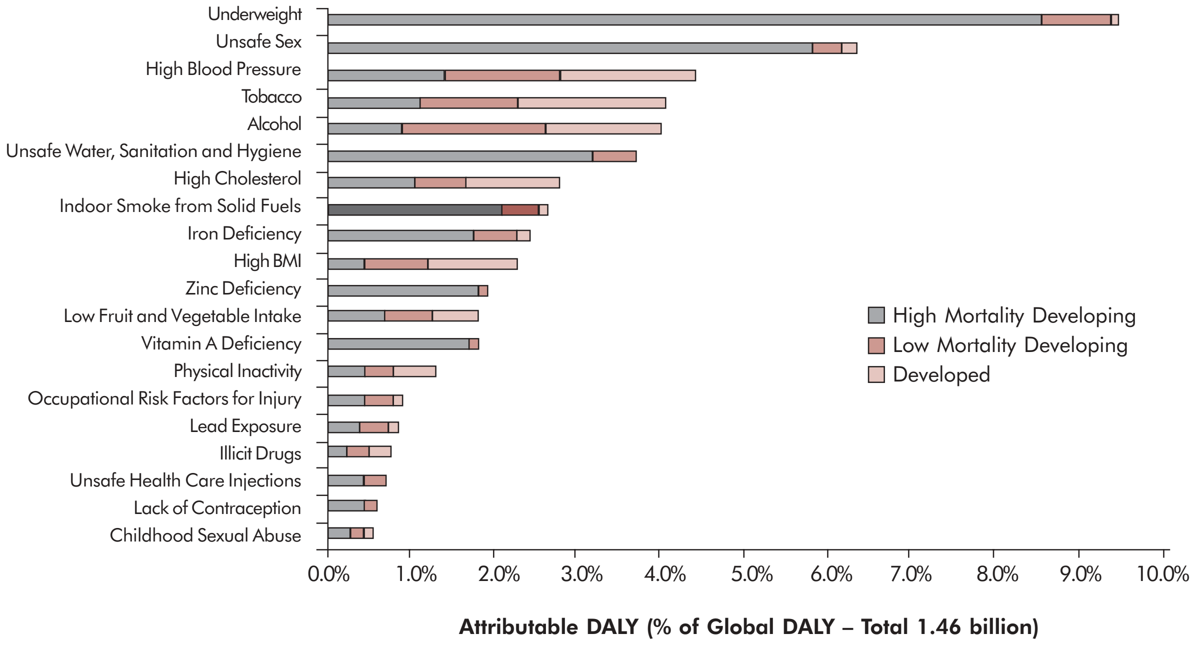
In Xuanwei, incidence of chronic obstructive pulmonary disease decreased noticeably after household coal stoves were improved (Chapman et al. 2005). Following the introduction of

Figure 1.7: Leading 20 Global Risk Factors for Mortality



Source: Ezzati et al. 2002.

Figure 1.8: Leading 20 Global Risk Factors for Loss of Healthy Life (Measured in DALYs)



Source: Ezzati et al. 2002.

improved stoves in the early 1980s, levels of household particles were reduced by a factor of three. Reduction in lung cancer, a decade later, was about 40 percent for men and 45 percent for women (Lan et al. 2000).

The health risks from coal use increase in those regions of China where coal is contaminated by F or As (or both). According to the Institute for Endemic Fluorosis Control, China CDC, F content of coal is high in 201 counties, affecting 35,000 villages and nearly 34 million residents. Some 17 million people are subject to dental fluorosis; incidence in children eight to 12 years old is high. Endemic Arsenic (As) poisoning from toxic coal occurs in eight counties (representing 42 townships and 142 villages or 333,905 residents). In Guizhou and Shaanxi provinces, exposure to As poisoning from burning toxic coal is high. In Guizhou, four counties (32 villages) are heavily exposed. Drying of corn and red peppers in households or sheds warmed by coal stoves results in high levels of contamination as pollutants are transmitted to food. In many areas, the fluorosis content of corn and red peppers exceeds the national standard (1.5 Milligram Per Kilogram [Mg/Kg]) (hundreds of times so for red peppers in Guizhou, Yunnan and Sichuan) (Yu 2005 and Finkelman, Belkin and Zheng 1999).

Environmental Dimension

Beyond the risk to human health, rural household use of solid fuels, particularly biomass, can indirectly lead to potentially irreversible environmental damage. For example, deforestation seldom occurs because of household use of biomass for heating and cooking. But foraging for biomass (for example, branches or young trees) in new growth areas following clearing (for example, for logging or agriculture) can hamper reforestation. Encouraging a shift to charcoal, which offers some health benefits compared to wood,[17] could lead to more severe environmental degradation because (given current charcoal production methods) more fuelwood is needed per meal when cooking with charcoal versus wood; even the most efficiently produced charcoal translates into net loss of energy.[18] Crop residues used for fuel rather than livestock fodder or soil nutrient can lower agricultural output.[19]

Household biomass use for fuel is potentially Greenhouse Gas (GHG) neutral (Smith, Uma and Kishore 2000; Bailis, Ezzati and Kammen 2003). If harvested sustainably and burned under ideal conditions, biomass fuel results almost entirely in the emission of water vapor and Carbon Dioxide (CO_2); water vapor is quickly incorporated into the hydrologic cycle with no measurable warming effect, while CO_2, the most common GHG, is absorbed by new plant growth through photosynthesis. At issue, however, is the degree of incomplete combustion typical of most household stoves in developing countries. In addition to water vapor and CO_2, hundreds of gaseous and aerosolized compounds are emitted, including CO, Methane (CH_4) and nonmethane hydrocarbons. Non CO_2 Greenhouse Gases (GHGs) are not absorbed by photosynthesis and remain in the atmosphere until they are broken down by complex natural processes.

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[17] *While charcoal is worse than other fuels with respect to Greenhouse Gas (GHG) emissions, it can lead to reduced concentrations of pollutants like PM (Bailis et al. 2004).*

[18] *Since most of the fuelwood energy is lost in the production process, charcoal users utilize more fuelwood than direct users (Kammen and Lew 2005).*

[19] *Soil degradation and erosion, along with disruption of water systems and soil nutrient cycles, can result in reduced agricultural productivity, damaged ecological systems and altered wind movements. Energy generated from biomass combustion using traditional technology releases many pollutants known as potential hazards to ecological systems. Energy harvesting, the process by which energy is captured and stored, and combustion add to the net flow and stock of Greenhouse Gases (GHGs), which contribute to climate change.*

Depending on time horizons and the GHGs measured, estimates of emissions for various stove-fuel combinations in developing countries indicate that both LPG and kerosene have a GHG effect comparable to, if not lower than, renewable biomass fuels. Further, the effect is far less compared to biomass fuels not used renewably. Because stoves fueled by liquid and gas (fossil fuels) are generally more efficient than those fueled by solid biomass, emissions per unit of energy delivered favors LPG and kerosene over most biomass fuels. Given current combustion technology and behavior, a shift to kerosene and LPG can reduce exposure to IAP and GHG emissions.

Nevertheless, the environmental implications of household use of solid sulfate fuels should not be understated. The burning of coal creates ambient air pollution (for example, aerosols) with local, regional and even global implications. Increased household energy use efficiency from echnological improvements benefits both households and the global community through reduced CO_2 and other emissions.[20] But the dual health and environment benefit should not occur at the expense of other priorities in developing countries, where many factors bear on the cycle of poverty.

China's Environmental Policies

In the 90s, China's policies to reverse deforestation and reduce soil degradation discouraged reliance on biomass and contributed likely to rural households' switching to coal. A comprehensive evaluation of 28 stove/fuel technologies commonly used in China found that the relative benefits of biomass and fossil fuels and policies promoting various fuel-types depend on whether all products of incomplete combustion are considered. While biomass-burning stoves rank well in terms of gases included within the Kyoto Protocol, they rank at best on a par with kerosene or LPG if the full range of gases emitted are considered. Biomass-burning stoves rank decidedly behind kerosene or LPG stoves if the biomass consumed is not renewed. Furthermore, the stove-type demonstrates a wide range of emission factors.[21]

China is a non-Annex 1 country under the United Nations Framework Convention on Climate Change, which means it has not agreed to binding targets for reduction of CO_2 and other GHG emissions under the Kyoto Protocol. As China is the world's second largest emitter of GHGs, its pledge to cut emissions is important.[22] If no measures are taken, the country is projected to experience the largest absolute growth in CO_2 emissions between now and 2025. China's five-year national development plan sets the objective of raising energy efficiency by 20 percent by 2010. The country's long-term goal is to reduce its overall coal dependency from 65 to 35 percent of energy generation by 2050.

China's primary concern, however, is with local problems, such as PM and SO_2 emissions. Acid rain, caused largely by the consumption of high-Sulfur coal, falls on some 30 percent of land. In an effort to encourage switching to cleaner burning fuels, the government introduced a tax on high-Sulfur coals. A system of emissions trading for SO_2, similar to that in the United States, is being pilot-tested. The government is applying stricter pollution controls on power plants, as well as policies designed to increase the share of natural gas in the country's fuel mix (EIA 2005).

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[20] *Ozone is not emitted directly, but is produced by the reactions of nitrogen oxides and hydrocarbons (known as volatile organic compounds) or CO. Elevated surface-level ozone concentrations are correlated with plant damage, as well as respiratory disease and premature mortality.*

[21] *"It is possible to implement policies with the best of intentions for alleviating the burden of collecting fuel, which may actually result in increased exposure of populations to health damaging pollutants and increased global warming contributions." (Edwards et al. 2004).*

[22] *This pledge was repeated at the Montreal meeting held in late 2005 to finalize the "rule book" for the Kyoto Protocol.*

The polluter-pays principle is being applied more rigorously. Initiatives under consideration include tax incentives for environmental protection, as well as preferential loans and subsidies for environmental-friendly products. The government has begun setting energy efficiency standards for household appliances. China's medium- and long-term energy development program for the 2004-20 period (recently approved by the State Council) includes building strategic reserves, energy conservation, fuel diversification, energy security, further exploration and environmental preservation.

IAP Interventions: What are the Knowledge Gaps?

While IAP has received increasing attention as a health risk to rural households, less is known about the design and dissemination of appropriate interventions.[23] Drawing lessons from international experience is hampered by lack of systematic studies on household energy interventions. While benefits of the interventions adopted may be known, the motivation for adoption, as well as long-term effects and sustainability, are generally not. Also, broader environmental and socioeconomic implications have not been sufficiently researched. To date, research has focused on improved stoves and fuels. Initial interventions in the early 80s were often marked by lack of detailed data on stove performance. Efficiencies and emissions, for example, were often measured in controlled environments (Krugmann 1987; Manibog 1984). More recently, research has shifted to monitoring stove performance under "actual use" conditions (Ezzati et al. 2004).

To design and disseminate appropriate interventions, researchers must ask:

- What factors determine human exposure and what are their relative contribution to personal exposure?
- What is the exposure response relationship between IAP and disease?
- Which determinants of human exposure can be influenced through any given intervention strategy, and to what extent?
- What are the effects of any intervention on human exposure and health outcomes, and how would they persist or change over time?
- What are the broader environmental effects of any intervention, its costs and the social and economic institutions and infrastructure required for its success?

Rural household exposure to IAP can be reduced through interventions in emissions source and energy technology, housing and ventilation and behavior and time activity budget (Von Schirnding et al. 2001). To this end, it is critical that further research be conducted on the complex interactions among the technological, behavioral, economic and infrastructural factors which determine the success of environmental health interventions, especially with such nonhealth dimensions as household energy (Jin et al. 2006).

These issues are especially important for female household members. Unless the details of the users' needs and behavior are considered during design, making energy cleaner may have contradictory results for women in certain aspects. For example, improved ceramic woodstoves with increased combustion efficiency may require that fuelwood be cut into smaller pieces and added more frequently, increasing women's workload and possibly exposing them to high-risk emissions during refueling.

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[23] *This section draws extensively on Ezzati et al. (2004) and Ezzati and Kammen (2002a, 2002b).*

Review of China's Stove Programs

The Chinese National Improved Stoves Program, a publicly-financed initiative of the Ministry of Agriculture initiated in the early 80s, aimed to provide rural households more efficient biomass stoves and, later, improved coal stoves for cooking and heating (Smith et al. 1993; Sinton et al. 2004). The primary motivation was to conserve energy and reduce time and labor needed to collect biomass, thereby affording household members more time to pursue human development activities.[24] Health considerations were not of primary concern.

The program extended to 860 counties (about 40 percent of all counties). Aided by independent provincial and county programs, commercial activity and word of mouth, improved stoves spread throughout China. The average subsidies for improved biomass and coal stoves were 26 percent and 10 percent, respectively. By the early 90s, 130 million improved stoves had been installed, and use of biomass eased in most regions. As the program wound down, the Ministry of Agriculture shifted its support to stove manufacturers and Energy Service Companies (ESCOs). From the mid-90s on, support for the stove industry was replaced by extension services and certification systems to standardize stoves. Development and dissemination of improved stoves was now left mainly to market suppliers, with some local government oversight. The Ministry claimed that, by 1998, 185 million of China's 236 million rural households had improved biomass or coal stoves. But degree of coverage varied widely by region (reaching only 22 percent of households in western provinces, compared with nearly 100 percent in eastern provinces and 70 percent in the central region).

Other agencies soon introduced their own stove programs. In the mid-90s, the Ministry of Health started a program to promote improved kitchens in poorer regions. It also initiated a program in areas where fluorosis from burning high-fluoride coals was endemic. In 1998, the National Development and Reform Commission (formerly the State Development Planning Commission) initiated the Yangtze River Valley Environmental Protection Project, which aimed to reduce soil erosion through reforestation; the project included provincial and county stove programs patterned after the Chinese National Improved Stoves Program.

In 2002, an independent review by a multidisciplinary team of U.S. and Chinese researchers found that China's improved household stove programs had succeeded in providing better stoves to most households in the targeted counties. The success reflected strong administrative, technical and outreach competence and local resources, supported by extensive national-level attention. Most biomass stoves were found to have flues and other technical improvements, although field efficiencies were less than expected at the design stage. By contrast, most coal stoves, even those using improved fuel (briquettes), lacked flues and thus could not be considered improved. In nearly all cases, PM levels after stove introduction were substantially higher than the national standard for indoor air. Thus, the benefits of improved biomass stoves were outweighed by the use of portable coal stoves without flues (Sinton et al. 2004).

In 2004, the Household Monitoring Project in China evaluated the National Improved Stoves Program (Sinton et al. 2004).[25] A survey of 3,476

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[24] Beginning with the Sixth Five-Year Plan (1981-85), the State listed development of fuelwood forests as part of the national reforestation program and rural energy development. Increasing fuelwood supply and fuel efficiency was considered a strategic necessity in rural development.

[25] Collaborating institutions were University of California (Berkeley and San Francisco), Tsinghua University, Renmin University and Chinese Center for Disease Control and Prevention (China CDC)(funding was provided by the Household Energy and Health Programme, Shell Foundation, London).

households was conducted which included measures of health, stove performance, socioeconomic factors and (in a subsample of households) indoor air quality. Three provinces (Zhejiang, Hubei and Shaanxi) were chosen to represent, respectively, high, medium and low adoption rates.

In January 2005, a widely attended workshop was held in Beijing to disseminate results of the National Improved Stoves Program review (China Energy Group and Smith 2005). The review concluded that:

- Despite extensive improved stove distribution, IAP caused by the incomplete burning of biomass and coal remains a critical factor threatening the health of rural residents; average particle levels in households often exceed the national IAP standard Micrograms Per Cubic Meter (150 $\mu g/m^3$) by a factor of two or greater (Smith 2005);[26]
- Since solid fuels will continue to dominate rural household energy supplies in the foreseeable future, improving the ways in which solid fuels are used, combined with widening access to and use of higher quality forms of energy, must be a key part of China's rural energy strategy;
- New technologies (developed mainly by the private sector) which offer potential for using biomass fuels in cleaner, more efficient ways should be encouraged on a large scale; direct government intervention should be limited to quality control, Research and Development (R&D) and assistance to the poorest areas; and
- Use of coal with toxic elements (F and As) must be discontinued; improved stoves with chimneys are urgently needed in areas using poisonous coals.

Other studies indicate that improved stove programs introduced by local health agencies have produced promising results. For example, a study conducted in Shaanxi (Ankang County) showed that improved stoves and installation of underground ventilation ducts reduced fluoride concentration of indoor air from 150 milligram(s) (mg)/m^3 to 3 mg/m^3, well below the internationally accepted standard of 20 mg/m^3. Fluoride contamination of food dried indoor, above the stoves, was also greatly reduced (from 1,342.2 mg/Kilogram(s) kg to 52.2 mg/kg in the case of chili peppers). Studies in Xuanwei and North-East Sichuan hold further testimony to the fact that improved stoves can significantly decrease IAP.

Lessons from these studies, together with models and designs for improved stoves, ventilation systems and pilot activities, have been incorporated into the project reported here. A major lesson is that improved stoves must be subject to more scientifically-based design criteria. Insufficient scientific analysis of the implications of fuel-saving cooking stoves may have resulted in increased exposure to health-damaging pollutants and increased release of GHGs (Edwards et al. 2004).[27]

Use of coal-heating stoves in winter months and greater substitution of coal for biomass in cooking may have undermined the indoor air benefits of improved biomass stoves. Although the thermal efficiency of commercial energy is generally higher than that of noncommercial energy, coal stoves used in rural areas are usually inefficient and more polluting than improved biomass stoves.

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[26] *For the households surveyed, a significant reduction (120 $\mu g/m^3$) in 24-hr, particle levels were recorded by switching from older to improved biomass stoves; winter measurements were invalidated by common use of multiple stoves and fuels, particularly unvented coal heating stoves.*

[27] *The focus on more efficient cooking stoves meant supplementary stoves for heating and attendant pollution. Improved flues and chimneys resulted in neighborhood and area pollution, which penetrated back into the indoor environment (see Edwards et al. 2004, p. 405).*

A new government program to reduce F and As poisoning from coal use includes an improved stove program which targets areas where disease from these toxins is serious. By 2010, 75-95 percent of households in high-disease areas (compared to 20 percent today) will have improved stoves.

Poverty in Rural China

Despite impressive economic growth over the past two decades, more than 100 million Chinese continue to live in acute poverty. More than two-third of China's rural poor live in the western provinces. Poverty is most severe in the north-western provinces (World Bank 2001).

Trends in Poverty Reduction

An econometric analysis of poverty trends in China included the following findings (Ravallion and Chen 2004):[28]

- In the 20-year period after 1981, the proportion of the population living below China's new poverty lines fell from 53 percent to 8 percent;[29] in 2001, incidence of poverty was 12 percent;
- Poverty reduction has progressed by fits and starts. Half occurred in the early 80s; after stalling in the late 80s and early 90s, reduction resumed in the mid-90s, only to stall again in the late 90s;
- Absolute inequality has increased, and relative inequality is higher in rural areas (Zhou and Wan 2004);
- Had inequality not increased and had the same economic growth rates prevailed, the overall poverty rate would be 1.5 instead of 8 percent;
- Most poverty reduction has occurred in rural areas, resulting from growth in primary agriculture; but growth has lagged in provinces where the greatest effect on poverty reduction would have been realized; and
- Increasingly, aggregate growth is derived from sources which bring limited gains to the poorest; thus, to maintain its past progress in combating poverty, China must effectively address the problem of rising inequality.

Analysis of the four provinces studied in this project reveals that, during the 80s and 90s, mean per capita income in rural areas increased by an average annual percentage of 3.9 (Inner Mongolia), 3.5 (Ganzu), 2.4 (Shaanxi) and 2.1 (Guizhou). Given the national rural rate of 3.4 percent, Shaanxi and Guizhou lagged by comparison. With the exception of Inner Mongolia, whose national per capita income ranking rose to 15, the project provinces remained low on the income scale. Over the same 20-year period, national incidence of rural poverty declined 6 percent annually. In Inner Mongolia, Ganzu and Guizhou, the rural reduction rate was equal to or higher than the national rate, while that of Shaanxi was lower (only 3 percent).

In 2005, the United Nations Development Programme (UNDP) reported that a large percentage of the Chinese population lives close to the poverty line (UNDP and China Development Research Foundation 2005). Each year, some 30 percent of rural

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[28] *See also Rural Survey Organization, National Bureau of Statistics, China (*Poverty Statistics in China, *September 2004).*

[29] *The long-standing official poverty line for rural areas is 300 yuan (Y) per capita per year at 1990 prices (US$0.66 per day in constant 1985 PPP dollars). The new poverty lines developed for the study were based on region-specific food bundles, valued at median unit values by province. These bundles were then scaled to reach 2,100 calories per capita per day. Allowance for nonfood consumption was based on the nonfood spending of households in neighborhoods, where total spending equaled the food poverty line in each province (separately for rural and urban areas). The national poverty line was derived from the means of the regional lines, yielding Y 850 per year for rural areas and Y 1,200 for urban areas, in 2002 prices.*

households fall back into absolute poverty.[30] According to a 2003 survey, 27 percent of poor households in the 11 western provinces are impoverished due to illness or injury.[31] In officially designated poor counties, more than 4 percent of residents are ill or weak, and access to medical care is limited.[32] Substandard health care services,[33] combined with lack of medical insurance and social security, frequent natural disasters and increased incidence of disease, are key causes of rural poverty.

Urban-rural Disparities

China's Human Development Index (HDI) improved significantly over the past three decades (from 0.52 in 1975 to 0.75 in 2003),[34] but the disparity between urban and rural improvement is significant. In 2003, the index for urban areas was 0.816, compared to only 0.685 for rural areas. Per capita disposable income in urban areas was 3.2 times that of rural areas. Life expectancy in urban areas was more than 75 years, compared to less than 70 in rural areas (eight years in the western provinces).

In the four project provinces, large urban-rural disparities were revealed for female life expectancy (10 years in Guizhou) (Table 1.3). Nearly 10 percent of rural residents had no formal education. In the western provinces, school enrollment was low and dropout rates high, in part, because of unaffordable school fees. In China's poorest villages, up to 50 percent of school-aged boys dropped out before completing primary school, particularly in minority ethnic areas where language is a barrier; nearly all school-aged girls in these areas did not attend school (World Bank 2001).

Table 1.3: Life Expectancy in Project Provinces

	Urban		*Rural*	
Province	*All*	*Female*	*All*	*Female*
Gansu	75.5	77.2	67.2	67.8
Guizhou	73.9	76.7	64.7	66.2
Inner Mongolia	74.1	76.5	69.3	70.4
Shaanxi	75.9	77.2	69.3	70.6
China	75.2	77.5	69.5	71.3

Source: UNDP and China Development Research Foundation 2005.

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[30] *National Bureau of Statistics, 2003.*

[31] *Statistics and Information Center, Ministry of Health, 2004.*

[32] *The third National Public Health Service Survey (2003) indicated that, for rural residents, 62 percent of two-week patients in western provinces did not see doctors because of economic hardship.*

[33] *Government per capita outlay for health care is more than five times higher in urban versus rural areas (Institution of Health Care Economy, Ministry of Public Health, 2003).*

[34] *The UN Human Development Index (HDI) is a comparative quality of life measure based on three basic dimensions of human development: Life Expectancy at Birth (LEB); knowledge as measured by the adult literacy rate and combined primary, secondary and tertiary Gross Enrollment Ratio (GER); and Gross Domestic Product (GDP) per capita at PPP in U.S. dollars; 177 countries were ranked in 2003.*

Health/Household Energy Nexus

That China's poverty is concentrated in rural areas bears on the health/household energy use nexus. During the 90s, household energy spending increased some 200 percent to more than RMB ¥300 by the end of the decade.[35] While middle- and upper-income quintiles spent more than the poor on energy in absolute terms, the poor faced immense difficulty absorbing increased costs for household energy.[36] Over a two-year period (2003-05), the price of ituminous coal increased nearly 50 percent; over the same period, the price of gasoline and diesel increased 34 and 20 percent, respectively.[37] Rural ousehold fuel prices, especially for biomass and low-grade coal, lagged fuel prices in urban areas and for industry, but national energy supply-and-demand pressures meant a significant increase in the cost of commercial fuel for heating and cooking.

In response to the energy crisis, the government has targeted cutting energy use per unit of Gross Domestic Product (GDP) by 20 percent by 2010.[38] Market pricing of fuel, thereby liminating the 20-30 percent or higher subsidies now enjoyed by consumers, offers one way to achieve this goal.[39] But the government hopes to exempt some 700 million farmers from price rise. Other measures include setting stricter standards for energy efficiency (for example, cars or buildings) and a mandatory labeling system for energy-using appliances. To date, no efficiency standards have been set for rural buildings.[40]

Projections for 2030 indicate that coal will continue to dominate as a primary energy source in China (Kato 2003). Currently, coal accounts for nearly 70 percent of China's primary energy, but increased use of oil, gas and hydropower, together with introduction of nuclear energy, is expected to reduce coal dependence to 60 percent. Over the next 25 years, China is projected to account for 20 percent of world incremental demand for energy and 50 percent of incremental demand for coal. Energy demand will pressure supply, meaning that prices will remain high or even rise, with the possibility that the poor may not have economic or physical access to cleaner fuels; thus, they would continue to depend on biomass and low-quality coal. Absence of countermeasures, emission of CO_2 and other GHGs would increase, compounding the climate changes already afflicting many parts of the world, including China. Addressing the poverty aspects of the health/household energy nexus requires a system of township-based targeting; the bulk of funding for IAP interventions must be directed to poor ownships within and outside nationally designated poor counties (World Bank 2001).[41]

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[35] Government of China, Compilation of Typical Survey Data of China's Rural Economy (1986-99), Office of Fixed Point Surveillance, Ministry of Agriculture.

[36] National Bureau of Statistics of China, Rural Household Survey in China, 2004. The Industry and Transportation Statistics Department, National Bureau of Statistics of China, is responsible for collecting and compiling China's energy statistics. The Bureau is endeavoring to improve the quality of its energy statistics, including data on residential energy use. Preparations are under way to conduct the second C-RECS II in collaboration with the Lawrence Berkeley National Laboratory.

[37] Beijing Energy Efficiency Center (www.beconchina.org).

[38] Statement by Chinese Premier Wen Jiabao at the Summit Meeting of East Asian Leaders in Malaysia, December 2005.

[39] In February 2005, the price of natural gas (US$ per Million British Thermal Units MBTUs) was US$4.55 in China, compared to more than US$7 in the United States. The gap was partially closed during 2005, as the government of China increased domestic energy prices five times. The China Daily (January 20, 2006) quoted Zhao Xaioping, Director, Pricing Department, National Reform and Development Commission (NRDC), as saying that the prices of oil, gas, coal and electricity would soon be liberalized by subjecting them to market forces.

[40] Labeling for energy efficiency was first introduced in 1999 for refrigerators; more information is available at World Energy Council (www.worldenergy.org).

[41] Since 1986, the government's county-based, poverty targeting system, has resulted in near-complete omission, even under the 8-7 Poverty Reduction Plan, introduced in 1994, to fund "the other half of the poor" residing outside designated counties. World Bank (2001) concluded: "The central and provincial governments should increase their assistance to the poor areas in support of a limited set of health services directed at the principal causes of morbidity and mortality. At a minimum, this should include increased public funding for the control of infectious diseases, overall disease surveillance and reporting, health information and education and the strengthening of the basic infrastructure of the health system in the poorest areas."

Project Context

As noted previously, World Bank initiated a project in China, in 2002, to test affordable household energy interventions – improved stoves, better ventilation, health education and behavioral changes – designed to substantially reduce IAP and exposure to it. Known as the Sustainable and Efficient Energy Use to Alleviate Indoor Air Pollution in Poor Rural Areas of China, the project was designed to add to the foundation of knowledge which will enable the development of sustainable interventions customized to local conditions.

The project was implemented in four provinces characterized by widespread rural poverty and (in at least two of the test areas) harsh winter conditions: Gansu, Guizhou, Inner Mongolia and Shaanxi (Figure 1.9). It is anticipated that success in reducing IAP in these provinces will lead to significant improvement in the health of the rural population notably omen and children, who typically are the most exposed to the indoor household environment (Ezzati et al. 2004).

The project is empirically based in order to build understanding and compile data and results potentially applicable to other areas of China and other developing countries.
A multidisciplinary team participated in the project. This report endeavors to capture the insights of each component, as well as the collective findings and conclusions.

Structure of this Report

This report is structured as follows. Chapter 2 describes the project goals and objectives and general methods used. Chapter 3 provides socioeconomic profiles for each of the four provinces studied, together with references to the counties and townships which served as the study

Figure 1.9: Map of China, Showing the Four Study Provinces

Source: Jin et al. 2006. Reprinted with permission of Elsevier.

sites; it also provides baseline data on levels of IAP, household energy use, behavior affecting exposure and health indicators related to respiratory disease. Chapter 3 also describes the stove and health education/behavioral interventions conducted as a part of the project. Chapter 4 discusses results of the interventions with regard to household energy use, IAP levels, knowledge and behavioral changes and health indicators. Chapter 5 considers alternative technological options for reducing IAP. Finally, Chapter 6 summarizes the project lessons and offers policy and program recommendations for future R&D studies.

2. Project Overview

Zuzana Boehmova, Fei Yu, Enis Barış and Majid Ezzati

This Chapter is divided into two sections: project description and project design. The first section considers the basis of the project in terms of its goals and objectives, expected outcomes and beneficiaries, components and implementation and management and partner organizations. The second presents the project's underlying rationale, its intervention model and hypotheses and site selection process.

Project Description

The purpose of this project was to evaluate the community effectiveness of relatively simple and affordable household energy interventions (alternative stoves, better ventilation, health education and behavioral changes) to lower exposure to IAP in rural China.[42] Further, the project aimed to facilitate implementation of these interventions and build local capacity for their supply and maintenance. The anticipated outcomes in project intervention areas were substantially lower levels of IAP and exposure to it, thereby helping to lower associated health risks. More generally, the expected outcome was advancing knowledge about location-specific factors and considerations in designing and implementing IAP interventions. Project results demonstrate the need for further research, notably in technology design and access and the interaction between technology and household behavior.

Objectives

Project objectives were to:

- Determine the scope and severity of IAP in the test sites of four Chinese provinces where rural populations are exposed to high levels of IAP because of climatic, topographic and socioeconomic reasons;
- Understand the technological and behavioral determinants of exposure;
- Determine the knowledge about health risks associated with IAP and potential interventions to reduce the level and degree of exposure;
- Test a variety of potential household energy interventions to reduce IAP and assess their health, energy, environmental, educational and poverty reduction benefits; and
- Evaluate the technical, sociocultural, organizational and economic feasibility of broader application of the interventions and their sustainability.

To gain broad support and interest, the interventions were designed to yield significant benefits at an affordable cost and be possible to implement within local institutions using local infrastructure. An important indicator of success

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[42] Project funding and technical assistance were provided by World Bank through financial support from the Energy Sector Management Assistance Program (ESMAP), Department for International Development, U.K. (DFID) and the Swedish International Development Agency (SIDA).

was the degree of end use. Major factors in this regard were economical, applicable and effective interventions; main fuel-types currently in use; more efficient fuel combustion; and local capacity for supplying and maintaining improved stoves.

Throughout its implementation, the project sought to demonstrate how household energy use and environment are linked to the ecology of rural communities; promote more efficient, environmental-friendly household cooking and heating devices (thereby easing the energy burden in rural areas); and demonstrate alternative household energy technologies and mainstream their use in World Bank projects in China and elsewhere.

The project was designed to contribute to better understanding of social and gender issues (through its focus on women and children); intersectoral linkages (notably health, energy use and environment); community involvement (by encouraging locally designed improved stoves and ventilation systems); and national and local capacity-building (through partnerships with the Institute for Environmental Health and Related Product Safety; China CDC; Foreign Loan Office (FLO), Ministry of Health; and local county governments and health offices).

Expected Outcomes and Beneficiaries

By introducing and making available new stove and ventilation designs, it was expected that the project would substantially improve fuel efficiency and reduce IAP in the participating households. Higher quality of indoor air would improve the health of household members, especially those who spend more time in the cooking vicinity. Through greater awareness of IAP health risks, household members would make risk-reducing changes in their energy use behavior and technology, resulting in reduced risk of burns. Throughout the project, communities, residents would benefit from high quality ambient air. With greater knowledge, local stakeholders, including Community-Based Organizations (CBOs), Non Governmental Organizations (NGOs), health personnel and microenterprises, would be empowered to improve local governance's handling of IAP-related health issues. Damage to local forest ecosystems would be mitigated, while revenue from a healthier, and thus more productive, labor force would increase.

At national and international levels, the project was expected to improve evidence-based policy-making. Project results would contribute to formulating or revising IAP standards and technical specifications for cooking and heating devices. In addition to strengthening national research and development capacity, the country's burden of respiratory illness and related health care costs would ease. Finally, the project would demonstrate the benefits of combining health, energy and environment to address IAP and contribute to the international body of IAP literature and knowledge management.

Components and Implementation

The project focused mainly on stove and behavioral interventions in townships of the targeted provinces and, to a lesser extent, small grants and awareness-building.[43] Specific interventions included distribution and installation of improved stoves and ventilation systems to test the effectiveness of new designs in reducing IAP and associated health risks. Behavioral interventions included health education, attitudes and practices to improve household energy use. The small grants component focused on building

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[43] *Detailed information on this logframe approach is available at http://wbln1023/OCS/Quality.nsf/Main/MELFHandBook/$File/LFhandbook.pdf*

capacity in four areas: 1) introducing household energy technologies and training local technicians in their use; 2) seeking ways to lower toxic substances from coal use; 3) encouraging development of low-emission, biomass-burning stoves for rural application; and 4) facilitating sustainable local responses to the IAP health risk. The awareness-building component developed training materials and trained health education and other local personnel in raising awareness about the health-related risks of IAP and methods to reduce them.[44]

The project was implemented in four phases. The first phase pilot-tested alternative stove designs and monitored multiple pollutants in homes that used coal or biomass for heating and cooking (implemented in Guizhou and Shaanxi). The second phase collected baseline data (from household, health and other surveys and tests on energy use, IAP and health) with which to design and evaluate IAP interventions (implemented in selected counties, townships and villages in Gansu, Guizhou, Inner Mongolia and Shaanxi). The third phase focused on the interventions (both technological and ehavioral). The fourth phase consisted of post-intervention data collection and evaluation of the intervention program's effect.

Prior to intervention, a feasibility study was conducted on: 1) market analysis and adoption of stove and ventilation designs based on existing knowledge and local conditions; and 2) field- and market-testing of stoves and ventilation devices. The main intervention study included supply and distribution of alternative stoves, market development, health education and training activities and policy considerations. This was followed by monitoring and evaluation, which focused on selected health indicator effects of the interventions; activities included baseline surveys and post-intervention measurements of indoor air pollutants. Other scheduled activities included: 1) strengthening of local institutional and technical capacities and development of IAP intervention strategies and policies; and 2) knowledge management through dissemination of project findings and publications in peer-reviewed journals (Annex 1).

Management and Participants

The project team, led by the FLO, Ministry of Health, consisted of staff from the Institute for Environmental Health and Related Product Safety, China CDC; Huaxi School of Public Health, Sichuan University; CDC provincial and county offices; and local hospitals in project townships. The team also included international experts from Sri Ramachandra Medical College and Research Institute (India), Harvard University and World Bank (Figure 2.1) (Annex 2). Provincial-level project teams were responsible for project programming and organization, monitoring, analysis and assessment of project outcome and community commitment. County- and township-level technical teams (experts, technicians and engineers from health care departments and local hospitals) were in charge of project planning and organization, training, development of health education materials and advising communities. Townships established teams to manage planning and implementation of project activities. Each project province and county set up a special project account and provided counterpart funds as an expression of commitment.

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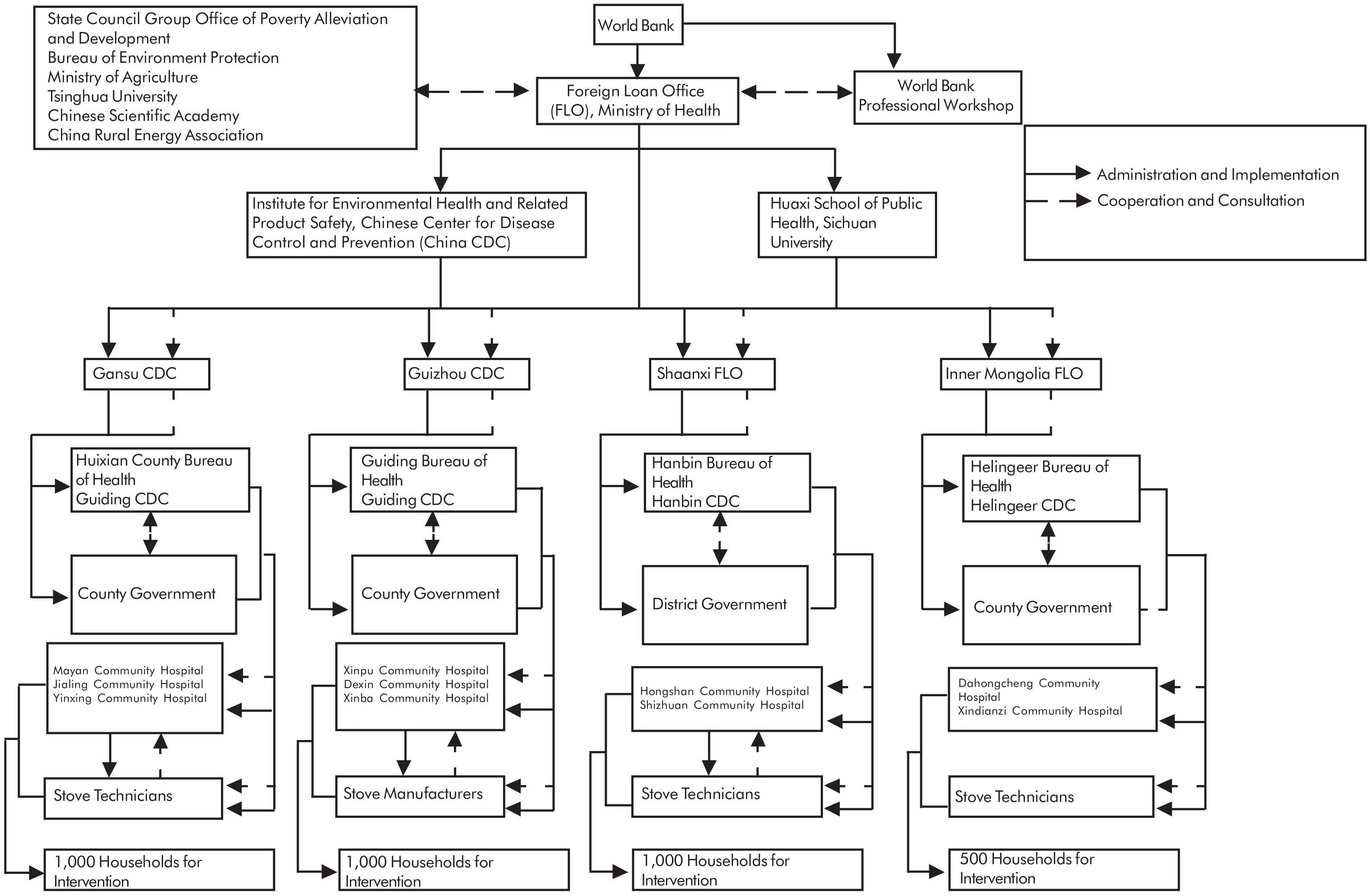
[44] *A fourth component on policy and regulatory framework development was to review and revise environmental, energy and health guidelines in the light of the field studies on energy use, IAP diffusion and household behavior. Given the intervention nature of the project, this component was not developed extensively; but follow-up activity in response to this report's recommendations is expected.*

Figure 2.1: Organizational Structure of IAP Project



Source: Chinese Center for Disease Control and Prevention.

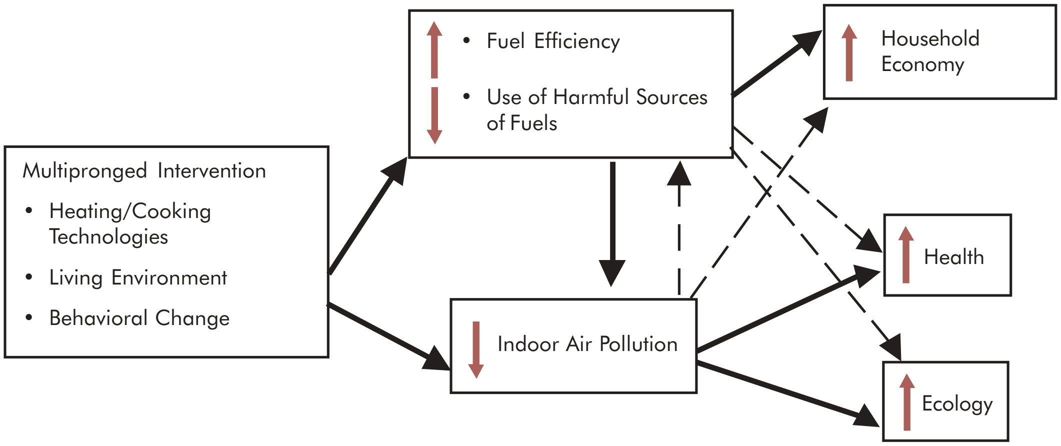
Project Design

This project draws on international lessons in household energy intervention, including programs in China, Mongolia, Kenya, Ethiopia and Tanzania (Ezzati and Kammen 2002a; Smith, Mehta and Maeusezahl-Feuz 2004). Such studies have emphasized exposure assessment, estimation of the health burden and effectiveness and technical feasibility of specific interventions. One important lesson is the need to field-test interventions in various socioeconomic, cultural, climatic and topographical settings and jointly assess the health, energy and environmental implications throughout the project cycle (design, implementation, monitoring and evaluation). Another lesson is the need to take account of the living environment and customary practices of low-income rural families. Low-cost, low-maintenance technologies are critical to facilitate affordability and sustainability. Access to technology and energy infrastructure must also be considered. To ensure uptake, maintenance and long-term use, direct subsidies to acquire improved stoves should be complemented by health education, market development and capacity-building activities. In addition to generating interest in new stove and ventilation technologies, health education is vital to encouraging behavioral changes (for example, food-drying practices). Detailed documentation of the effect of program interventions is needed to build local, national and international support to continue and expand on IAP-related initiatives.

Underlying Principles

Drawing on these lessons, this project adopted a holistic approach which combined technological interventions (stove and ventilation technologies) with behavioral ones (community-based health education, behavioral changes, market development and capacity-building) (Figure 2.2). To ensure effective and sustainable results, many organizations cooperated to provide training, outreach services, market promotion and logistical support for a wide range of provincial and local health officials, education specialists, engineers, administrators, stove producers and suppliers and others interested in reducing IAP. Finally, cultural, economic, environmental, and socioorganizational dimensions of the project were thoroughly appraised, and health education and technical training programs were adapted to local needs and conditions.

Figure 2.2: Intervention Model and Hypotheses



Note: Dotted lines indicate a secondary effect, which takes time to materialize.

Approach

The basic design approach was to test the post-intervention outcomes of household energy use interventions: IAP, energy, health and environment. From the four project provinces, 5,550 households (500 households from each of 11 townships) were selected to test the interventions. The 11 site townships were divided into three intervention groups:

- Stove plus behavioral intervention (S + B). This group included one township site from each project province (with the exception of Inner Mongolia) (1,500 households). These three sites were subject to the full range of stove and ventilation technology and behavioral (community education and behavioral changes) interventions, accompanied by institutional capacity-building at provincial, county and township levels. New alternative stoves were provided at approximately one-third market cost;
- Behavioral intervention (B). This group included one township site from each project province (2,000 households). These four sites were subject to a more limited range of interventions. They were not offered new stoves at subsidized rates, and the interventions focused on health education and behavioral changes; and
- Control (C). This group included one township site from each project province (2,000 households). These four sites were not subject to any interventions; rather, they served to indicate exogenous trends (for example, secular interannual fluctuations caused by varying winter temperatures or other factors which may have affected energy use) between project initiation and completion. In this way, baseline and post-intervention comparisons for each township subject to stove and behavioral activities or behavioral activities alone could be matched against baseline and post-intervention comparisons for the control townships, providing the basis for difference-in-difference analysis.[45] This provided the empirical evidence on the relative effectiveness of the interventions (Figure 2.3).

The project design included extensive data collection through household and health surveys, on-site measurement of multiple pollutants in the air and other media (for example, F in food dried over fire) and health examinations (especially for childhood respiratory diseases). Households were selected on a cluster randomized basis, subject to including women and children members.

Site selection Process

The project was carried out in low-income, rural counties of the four project provinces: Huixian (Gansu), Guiding (Guizhou), Helingeer (Inner Mongolia) and Ankang (Shaanxi) (Figure 2.4). In all four counties, the need for space heating was extensive, households relied heavily on solid fuels (coal and biomass) for heating and cooking and IAP was a serious problem. Additional site selection considerations were community interest in and local government support for the project.

The 11 townships sites were chosen based on their similar economic circumstances and household environments, including housing structure and food habits. Additional site selection considerations were degree of concentration of residents, status of transportation access and residents' willingness to participate (Table 2.1 and Figure 2.5).

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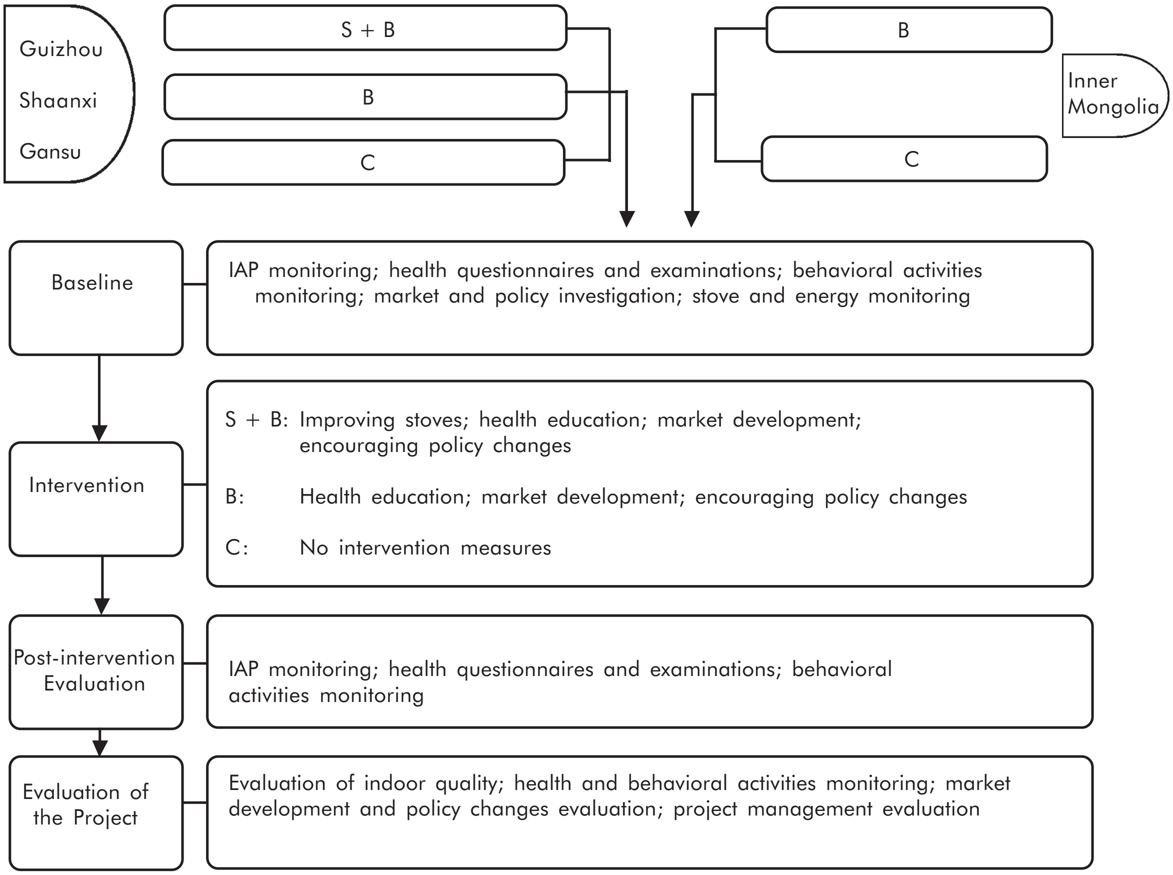
[45] *The mean difference between after and before values of the outcome indicators for each of the intervention groups was calculated; from this was subtracted the mean difference between after and before values for the control. The second difference (that is, the difference-in-difference) is the estimated project effect.*

Figure 2.3: Overview of Project Methodology



Note: S + B = stove plus behavioral intervention, B = behavioral intervention, C = control.

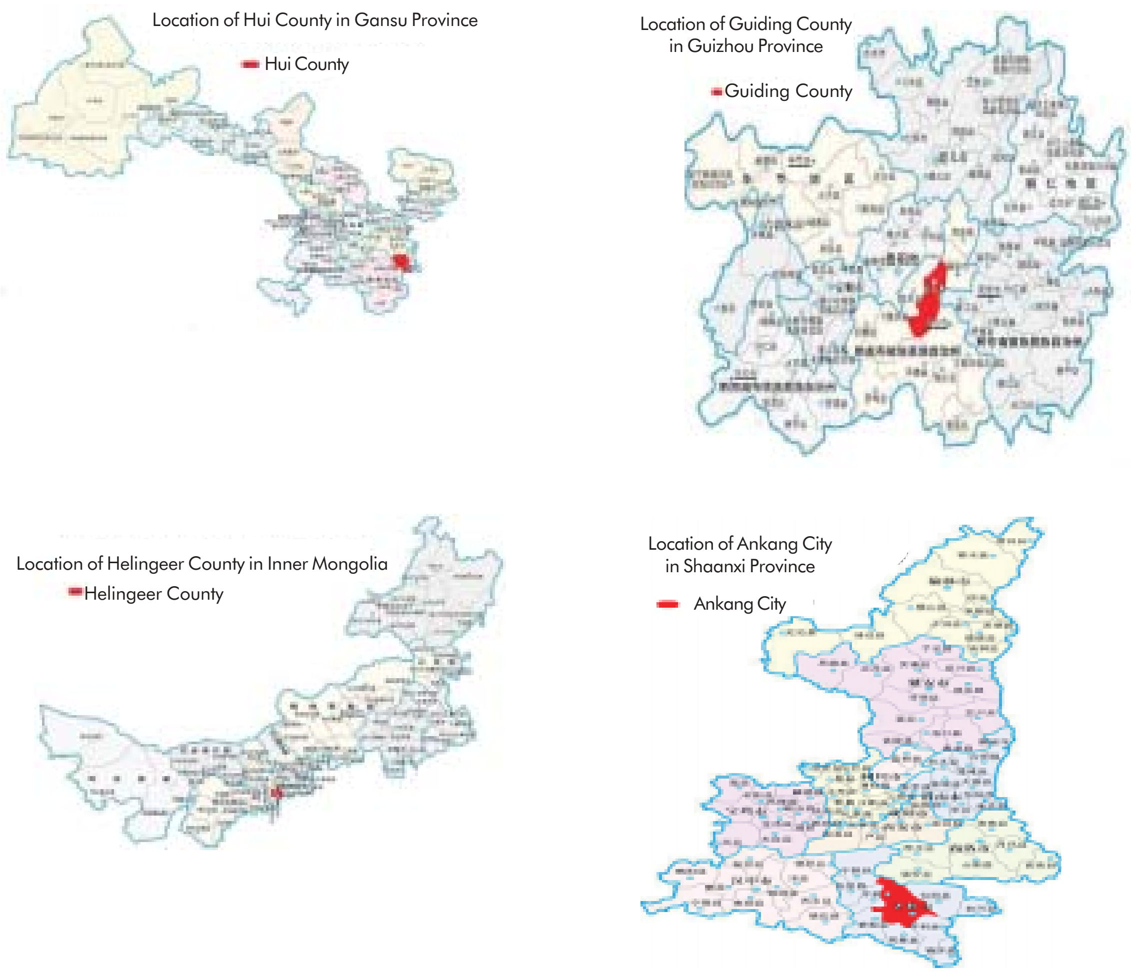
Table 2.1: Categorization of Selected Townships

			Intervention Group[1]	
Province	*County*	*C*	*B*	*S + B*
Gansu	Huixian	Yinxing	Jialing	Mayan
Guizhou	Guiding	Xinba	Dexin	Xinpu
Inner Mongolia	Helingeer	Xindianzi	Dahongcheng	--
Shaanxi	Ankang	Shizhuan[2]	Shizhuan[2]	Hongshan

[1] *C = control (no intervention), B = behavioral intervention, S + B = stove plus behavioral intervention.*

[2] *Shizhuan is effectively divided by a mountain, enabling the township to serve as a control (C) and behavioral intervention (B) group.*

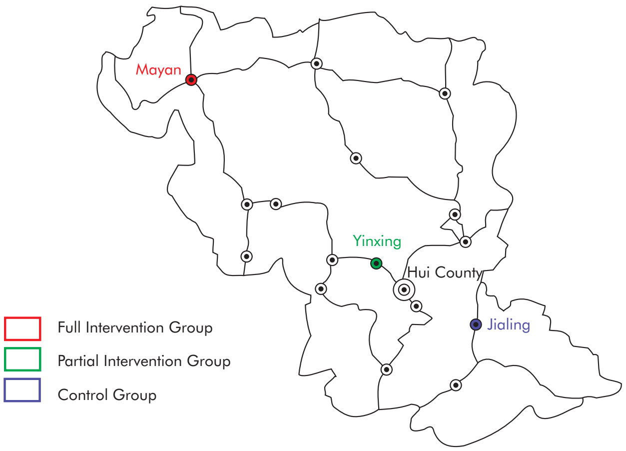
Figure 2.4: Location of Selected Counties in Project Provinces



Source: Chinese Center for Disease Control and Prevention.

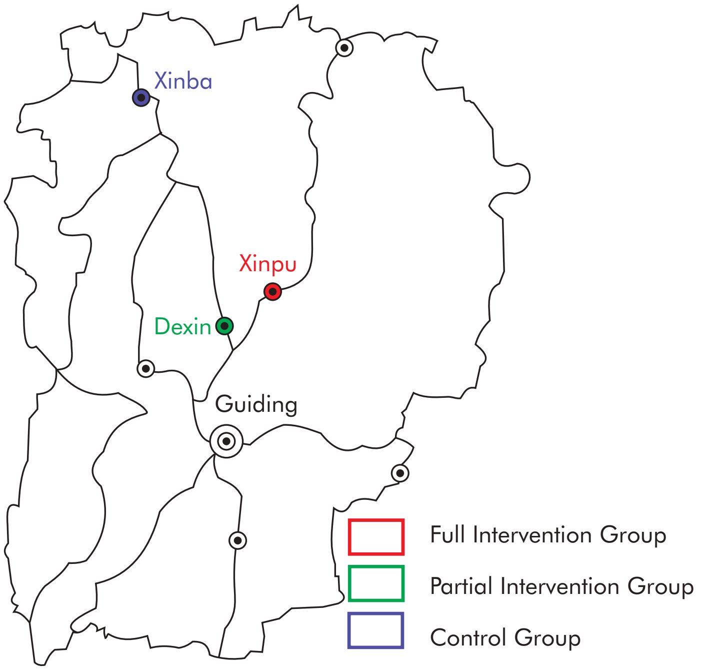
Figure 2.5: Location of Selected Townships in Project Counties

Huixian County (Gansu)

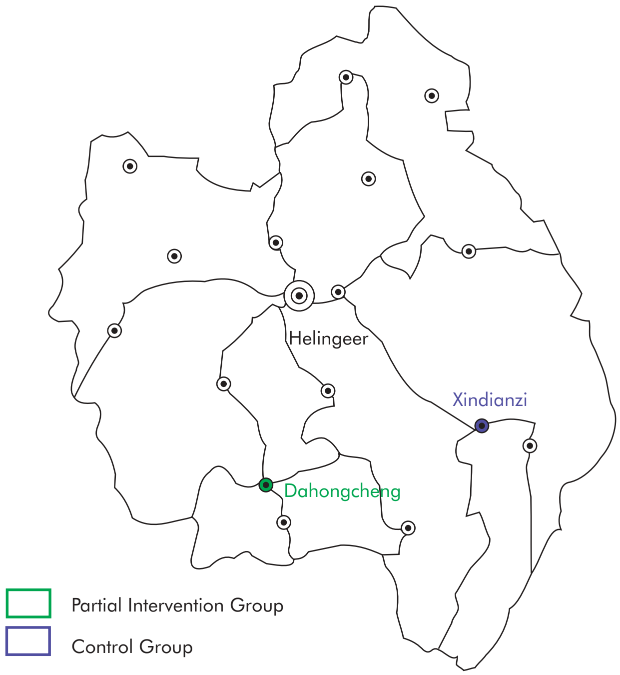


Guiding County (Guizhou)

IAP Project Groups in Guiding County

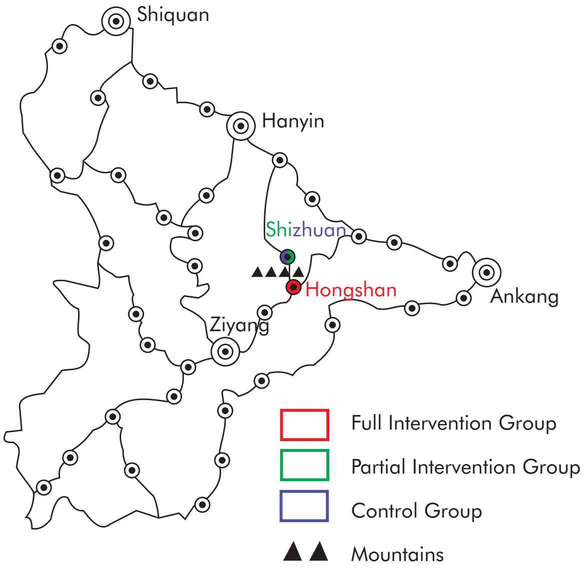


Helingeer (Inner Mongolia)



Ankang County (Shaanxi)

IAP Project Groups in Ankang City



Source: Chinese Center for Disease Control and Prevention.

A total of 5,500 households were chosen from the 11 townships (500 from each township). Household selection was based on several considerations:

- Inclusion of women (older than 18 years of age) and children (14 years of age or younger) in the household and at home;
- Length of time women had lived in the township (more than one year); and
- Voluntary participation of households.

The project areas had been included in earlier World Bank-funded Health VI initiatives; thus, many trained and experienced health, engineering and other experts were available to participate in the project. Furthermore, earlier or current environmental pollution investigations, epidemiological surveys, health examinations and health education programs provided information relevant to the project.

3. Foundations for Intervention Design*

Zuzana Boehmova, Fei Yu, Zheng Zhou, Enis Barış and Majid Ezzati

As discussed in Chapter 2, the household energy use interventions undertaken in this project were of two types: 1) alternative stove technology, including improved ventilation systems; and 2) health education and behavioral activities. Each was accompanied by capacity-building activities for local health, energy and related agencies and institutions. Both interventions were tailored to fit the location-specific conditions and general circumstances of the four project provinces and their respective counties and townships.

To provide a foundation for evaluating the interventions undertaken, baseline data were collected on IAP levels, household energy use, knowledge and behavioral characteristics and IAP-related health conditions. These data, summarized in this Chapter, contributed to the design of IAP interventions.[46]

General Design Considerations

Many factors bear on the design of IAP interventions. This section offers brief socioeconomic and demographic profiles of the four study provinces, highlighting the array of factors – from poverty and literacy to rural-urban disparities, economic trends and energy resources – which contribute to affordability and behavioral responses. Other relevant design considerations, also discussed in this section, are housing characteristics and household energy use behavior and time-activity patterns.

Provincial Profiles

A shared characteristic of the four provinces – and an important criterion for selection in this study – is economic status. Among China's 31 provinces, autonomous regions and municipalities, Guizhou ranks 31 (last) in terms of GDP per capita, followed immediately by Gansu at 30 and Shaanxi and Inner Mongolia at 25 and 15, respectively.[47,48] Despite the presence of more efficient fuels (for example, petroleum or hydropower), most rural households rely on inefficient energy sources and stove technologies (Guizhou and Shaanxi depend primarily on coal, while Gansu and Inner Mongolia rely more on biomass). For all study areas, the heating season lasts from November to

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[46] Portions of this Chapter draw from Jin et al. (2006).

[47] Profiles are based primarily on data from the China and provincial statistical yearbooks. Provincial GDP numbers are for 2004, while most other data are for 2003. Township data are based on household surveys conducted by provincial and county-level staff of the Health Bureau and China Center for Disease Control and Prevention (China CDC). Because women have primary responsibility for cooking and child care, most respondents were female household members.

[48] China Statistical Yearbook (2005).

** Portions of this text is from the article by project team members Yinlong Jin et al., "Exposure to indoor air pollution from household energy use in rural China : the interactions of technology, behavior and knowledge in health risk management,"* Social Science and Medicine*, 2006 June; 62(12):3161-76. Permission for reproduction of material was granted by Elsevier.*

late March, and IAP from household energy use (heating and cooking) is a health risk.[49] Other shared characteristics of these provinces and their counties and townships include high illiteracy rates (especially among females), a high percentage of ethnic minorities (including linguistic differences) and large rural populations heavily reliant on farming for their livelihoods (Table 3.1).[50]

offer potential opportunities for implementing health education activities.

In 2004, per capita GDP was nearly Y 6,000 (US$730), the second lowest provincial average in China. Rural net household incomes were a third or less of this amount, reflecting the low productivity, agricultural basis of farming communities. Provincial revenues per capita were also low, weakening the government's ability to support public services. However, the revenue position is improving as a result of strong GDP growth rates over the past few years. Gansu's accelerating industrial output reflects rapid growth of exports (including textiles, chemicals, minerals and nonferrous metals).

Table 3.1: Geographic and Environmental Features of the Study Areas

	Province (County)			
Feature	*Gansu (Huixian)*	*Guizhou (Guiding)*	*Inner Mongolia (Helingeer)*	*Shaanxi (Ankang)*
Altitude (m)	800-1,500	1,100-1,400	1,400-1,600	350-1,000
Summer Temp. (avg. C°), (daily min.-max.)	28 (19-35)	27 (19-33)	21 (20-22)	28 (23-41)
Winter Temp. (avg. C°), (daily min.-max.)	9 (–5-16)	8 (–1-15)	–10 (–13- –8)	5.5 (–8-11)
Average Rainfall (mm)	240-320	1,100-1,400	420	1,120
Average Number of Sunny Hours per Year	2,500	1,100	2,700	1,500
Population Density (persons per Km^2)	57	220	180	20

Source: Chinese Center for Disease Control and Prevention.

Gansu

Gansu has a population of approximately 26 million, some 76 percent of which live in rural areas. While the predominant ethnicity is Han, nearly 2 million people are of ethnic minority and are among Gansu's poorest residents. Education levels are low; illiteracy, at about 20 percent, is twice the national rate. The age structure of the population is relatively young. The province's five million primary and secondary school students

In terms of energy resources, petroleum and coal offer limited opportunities, but hydropower's potential is extensive (installed generating capacity

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[49] Final project report, China CDC (2006).

[50] Annexes 3.1 and 3.2 provide statistical overviews of the study provinces and counties, respectively, while Annex 3.3 provides data on socioeconomic and demographic characteristics of the study households.

is currently 30 million Kilo Watt (s) (KW). With regard to Renewable Energy (RE), Gansu's climate is suitable for the development of wind and solar power. Environmental improvement measures include meeting national air- and water-quality standards. In addition, 43 smog-control zones and 47 natural reserves have been established, the latter covering nearly 20 percent of the province. Forest protection is a priority.

The three townships selected for the study – Jialing, Mayan and Yinxing – are located in Huixian County. Of the four project counties, Huixian has the lowest GDP per capita (90 percent of its population is rural). Household survey respondents for this study indicated that nearly half of the households had family income of less than Y 1,000 (US$120) in the year prior to the survey. They also reported large family sizes (86 percent of families had four to seven household members). The respondents, 96 percent of whom were women, indicated illiteracy rates which approximated the provincial average for women.

Guizhou

With a population of 39 million, Guizhou is the most densely populated of the study provinces. Ethnic minorities (including Yao, Miao, Buyi, Dong and Tujia) account for 56 percent of the population, and the province is designated as an autonomous region. About 76 percent of residents live in rural areas.

During the 90s, Guizhou's economic growth lagged; more recently, it has matched or exceeded the national average. In 2004, the growth rate was 11.4 percent and GDP per capita reached Y 4,082 (US$495); yet this was the lowest provincial average in China. Furthermore, rural residents' net disposable income per capita was less than half the provincial average. Nonetheless, provincial data indicate a substantial drop in the level of poverty over the past decade, although it is still widespread in mountainous regions. Like Gansu, Guizhou has a weak fiscal position, which undermines support for public services; thus central government transfers are important. Despite fiscal constraints, poverty reduction projects over the last five years have included rural electrification and other infrastructure investments.

Guizhou's high illiteracy rate, especially in rural areas, reflects the unaffordable cost of sending children to school, compounded by the language difficulty of ethnic minorities. Some 40 percent of the province's labor force has only an elementary school education (most have not completed five years of schooling). The population's low education and literacy status hampers public health education.

The province has a subtropical humid climate and experiences ample precipitation, especially in mountainous areas. Agriculture, the main source of employment, accounts for only 20 percent of GDP, which largely explains rural poverty. Industrial output is increasing rapidly, supported by a sharp jump in energy production in recent years; the province has ample coal resources and hydropower potential.

The three townships selected for the study – Xinpu, Xinba and Dexin – are located in Guiding County. Compared to Huixian (Gansu), Guiding has a higher GDP per capita, yet, net rural household incomes are lower, reflecting larger families in the former. Of the four counties studied, Guiding has the highest percentage of population under 15 years of age. Household survey respondents, 70 percent of whom were women, reported a 35 percent illiteracy rate and a high percentage of residents with only a primary education. Some 75 percent of families in the three townships reported four to seven household members, and nearly 70 percent had family incomes of less than Y 1,000.

Inner Mongolia

Among China's provinces, municipalities and autonomous regions, Inner Mongolia (designated an autonomous region) is the third largest, yet, it has one of the lowest population densities (only 23.8 million residents in 2004). About 43 percent of residents live in urban areas, by far the highest ratio among the four project provinces. The Han ethnicity accounts for nearly 80 percent of residents, while Mongolians and other ethnic groups account for more than 20 percent.

By 2004, GDP per capita had risen to Y 11,387 (US$1,390); the region ranked 15 among the country's 31 provinces, autonomous regions and municipalities. However, rural households' disposable income per capita was less than 25 percent of this amount, and an estimated 800,000 people remained severely poor. The local government's fiscal position has strengthened rapidly, enabling support for critical public services. In 2004, local expenditure per capita was well above the national average. Published data show high enrollment ratios, including secondary schools. Illiteracy is estimated at about 12 percent.

Farming and animal husbandry engage more than 50 percent of the labor force, yet, account for only about 20 percent of the GDP. By contrast, the secondary industry engages less than 20 percent of the labor force yet accounts for more than 40 percent of the GDP. Transport and elecommunications services are well developed. In terms of energy resources, the region has the second largest coal reserves in China, as well as extensive hydropower and petroleum resources; the region is a net exporter of energy.

Inner Mongolia features a temperate continental climate with long, cold winters. Of the four study provinces, it has the coldest temperatures (only 80-150 frost-free days); thus, home heating requirements are intensive. In recent decades, the greenhouse effect and unscientific exploitation have aggravated drought, desertification and soil erosion. In an effort to revert cultivated land to grasslands and forests, the central government recently launched the Ecological Construction Project, one of the 10 projects in its western development campaign.

The two townships selected for this study – Dahongcheng and Xindianzi – are located in Helingeer County, with a 90 percent rural population. Net rural household incomes and literacy rates are the highest of the four counties studied. Still, Helingeer has high rates of infant and child mortality. Household survey respondents, 64 percent of whom were women, indicated a higher degree of education compared to the other study areas but a higher illiteracy rate compared to the provincial average. Compared to respondents in townships of the other study provinces, Helingeer respondents reported higher family incomes and smaller average family sizes.

Shaanxi

Shaanxi's population of 37 million is almost entirely of the Han ethnicity. Some 68 percent of residents live in rural areas. Like the other three study provinces, Shaanxi experienced rapid economic growth in 2004; that year, per capita income reached Y 7,790 (US$950). Rural household incomes were about 25 percent below the provincial average. Shaanxi's fiscal position reflects its low income ranking; on a per capita basis, local revenues were 40 percent less than the national average, with the result that local expenditures were significantly below the national average.

Rural poverty is widespread, education levels are low and illiteracy is high. Some 40 percent of females receive little education, and female illiteracy is prevalent in rural areas. But the situation is changing rapidly; primary education is nearly universal, and a reasonable percentage continues on to junior and senior high schools.

As in the other study provinces, the agricultural sector is the main source of employment, but accounts for only about 20 percent of the GDP. Secondary industry accounts for nearly 50 percent of the GDP and total output of major industries (electronics, machinery, pharmaceuticals, chemicals, energy and food) is increasing at nearly 20 percent annually. As part of the central government's western development strategy, transportation infrastructure is being extended; currently under construction is a new railway designed to resolve north-south bottlenecks. Shaanxi's extensive coal and gas reserves and hydropower potential are increasingly accessible.

Shaanxi's low winter temperatures require many heating hours per day, resulting in limited air exchange due to closing of windows and doors. For rural residents heavily dependent on coal for heating, IAP poses a serious health risk. As part of its effort to improve environmental conditions, provincial authorities have intensified efforts to protect and expand forest coverage (currently, nearly 29 percent). In 2003 and 2005, many thousands of rural households suffered a series of natural disasters (drought, floods and hailstorms), which caused extensive damage and economic hardship.

The selected study townships – Hongshan and Shizhuan – are located in Ankang County.[51] With 2.6 million people (more than 80 percent of whom live in rural areas), Ankang is the most populated of the four counties studied. Although infant mortality rates are low, household survey respondents reported the highest illiteracy rates (especially among females) of the four sets of townships, relatively low family incomes and large family sizes.

Housing Characteristics

Jin et al. (2005) provide basic information on housing characteristics of the households studied (Table 3.2). In Gansu, nearly 90 percent of houses have a wall separating the kitchen from the bedroom and living room areas, with separate entrances. In Guizhou, the most common housing design consists of cooking/living, sleeping and entrance/storage rooms connected by doors. Most houses have a separate cooking area reserved for special occasions. Cooking is usually done in one of the main rooms (cooking/living room), especially during the winter (heating season). In Inner Mongolia, older homes are constructed within a cave-like structure; a single room is used for cooking, living and sleeping (the cooking stove is connected to the bed for heating). Newer homes in the study area have a wall with windows and a door that connects the cooking and sleeping/living areas. In Shaanxi, most houses have a cooking area connected to the main house by a door, a living room with a ground stove (fire pit) used for heating and boiling water and one bedroom (sometimes equipped with a ground stove). Most houses have a small attic used only for storage.

Household Energy use Behavior and Time-activity Patterns

IAP exposure is affected by a variety of behavioral factors related to household energy, including ventilation practices and the time-activity patterns of household members. Table 3.3 summarizes key exposure-related behaviors in the four study provinces. The implications of these data for IAP interventions are discussed in the next section.

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[51] *As indicated in Table 2.1, Shizhuan serves as both a control (C) and behavioral intervention (B) group.*

Table 3.2: Housing Characteristics of Study Participants (percent households)

Characteristic	*Gansu (n = 1,518)*	*Guizhou (n = 1,508)*	*Inner Mongolia (n = 1,035)*	*Shaanxi (n = 1,580)*
Construction Material				
Mud, Wood and Tile	71.5	40.1	38.2	76.3
Brick, Wood and Tile	25.9	42.9	36.6	8.0
Other	2.6	17.0	12.7	15.7
Usual Cooking Location				
Specialized Kitchen	88.5	25.4	36.2	93.5
Bedroom	3.3	4.7	46.6	1.7
Living Room	7.9	67.6	16.3	4.6
Other Rooms	0.3	2.2	0.9	0.2
Other Characteristics				
Houses with Gaps between Wall and Roof	No Gap	22.4	No Gap	No Gap
Kitchens with Window	90.3	73.8	72.8	60.3
Kitchens with Ventilation Fans	0.9	0.9	10.2	2.3

Note: n = number of households in the sample.

Source: Zhou et al. (2006).

Table 3.3: Household Energy Use Behavior and Time-activity Patterns as Determinants of Exposure

Energy Use	*Gansu*	*Guizhou*	*Inner Mongolia*	*Shaanxi*
Cooking	• Affects primarily women who spend >2 hours per day cooking human/animal food • Some cooking/tea-making takes place on fire pan in the living and sleeping area in morning and nighttime, affecting all household members	• Affects primarily women who spend 2.5-3 hours per day cooking human and animal food • Cooking the main meal takes place in the living area, affecting other household members	• Affects all household members since all cooking takes place in the same room as living and sleeping • Women who spend >2 hours per day cooking human and animal food are particularly affected	• Affects primarily women who spend 2.5-3 hours per day cooking human and animal food • Some cooking and heating water takes place on the groundstove in the living area, affecting other household members
Heating*	• Affects all household members who spend time around the fire pan or on the heated bed, especially	• Affects all household members who spend time around the heating stove in the living area	• Affects all household members who spend time on the heated bed, especially children and the elderly, and women who	• Affects all household members who spend time around the ground stove in the living area • With no

Energy use	*Gansu*	*Guizhou*	*Inner Mongolia*	*Shaanxi*
	children and the elderly • Seasonal pattern (approximately four to six months)	• Chimney in most houses only goes to the attic and smoke disperses in the house through the porous separation of main floor and attic • Seasonal pattern (approximately six to seven months)	use the same stove for cooking • Seasonal pattern (approximately six to seven months)	chimney, smoke disperses in the house • Seasonal pattern (approximately five to six months) • Ground stoves in bedrooms no longer used because of concerns about CO
Food Drying and Storage	NA	• Food (chili and corn) is dried directly above the stove or in the attic above the chimney outlet. Most rice is stored in bags during drying • 54 and 81% of households do not wash corn/chili before eating	NA	• In the past, food was stored over the stove. Public health programs have promoted alternative behaviors to store food in bags and/or away from the stove

** Although the provinces have relatively similar heating seasons, the intensity of home heating is higher in the colder provinces, particularly in Inner Mongolia. In Guizhou, for example, increased humidity and cloudiness are the main feature of the heating season. Therefore, the stove is used for shorter daily durations and with less intensity than in Inner Mongolia. Similarly, windows may be left open in Guizhou during the heating season, but are closed and sealed in Inner Mongolia.*

Note: NA = Not applicable.

Source: Jin et al. (2006). Reprinted with permission from Elsevier.

Baseline Data

To build the technical foundation for designing IAP interventions and the basis for evaluating their effectiveness, the study included extensive surveys, interviews and testing to collect baseline data on IAP levels, household energy use, knowledge and behavior and IAP-related health symptoms.[52]

IAP Levels

Based on a pilot study conducted in January 2003 (Jin et al. 2005), which examined the relationship between pollutants and measurement points in four households in each of the study counties in Guizhou and Shaanxi, and a survey on household energy use

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[52] *This section draws on Jin et al. (2005).*

behaviors and time-activity budgets, an optimal combination of pollutants and measurement locations was selected to best characterize exposure conditions in each province. Pollutants were measured at two to three points in the cooking, living and sleeping areas (the main exposure microenvironments). In a few homes and for selected pollutants, measurements were made at additional points for comparison.

Measurement Design and Monitoring

Two designs were used to measure indoor air quality:

- Small sample of households and multiple measurement days: six households were selected from each province (four in Inner Mongolia) and monitored continuously over a four-day period, which enabled measurement of day-to-day variations; and
- Large sample of households and a single measurement day: 72-76 households were selected from each province and monitored over a 24-hour period.

Both designs conducted monitoring twice a year, corresponding to the middle (March) and late (December) heating season. Households monitored in March over a four-day period were also observed in December; for the larger set of households monitored over a one-day period in March, a subset was selected for one-day monitoring in December. Both designs selected households based on family income, energy use and housing characteristics. Measurements were taken by teams of investigators from the national China CDC, assisted by the Center's provincial and county staff and health workers.

Three key indoor air pollutants were monitored: respirable particles (PM_4 and PM_{10}; that is, particulate matter with a median aerodynamic diameter of less than 4 micrometers (μm)(and 10, μm respectively), CO and SO_2. Tests involving fluoride and As were also conducted (Annex 3.4).

Resulting Data

In all provinces, concentrations of Respirable Particulate Matter (RPM) exceeded current health-based standards and guidelines for PM in an outdoor environment.[53] Gansu and Inner Mongolia – the two provinces where biomass is the primary fuel – had the highest concentrations; high concentrations in Inner Mongolia reflect colder temperatures, longer heating hours and a housing arrangement which combines heating and cooking (Annex 3.5).

Except for a few observations in Gansu, Inner Mongolia and Shaanxi, 24-hour mean CO concentrations were consistently below health-based standards and guidelines.[54] Not observable from the data was the possibility that CO concentrations may have been higher during cooking and when bedroom doors and windows were closed at night. Guizhou had the lowest CO concentrations due to the type of coal and stove used and the configuration of chimney/attic ventilation.

Cost considerations limited SO_2 measurements to Guizhou and Shaanxi – the two provinces where coal is the primary fuel. SO_2 concentrations were higher than the WHO guideline value of 0.04 Part(s) Per Million (PPM) at all locations in both provinces; concentrations in Shaanxi were substantially higher than the corresponding points in Guizhou. Higher concentrations in Shaanxi were likely due to the type of coal used and lack of chimneys (in contrast to Guizhou).

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[53] *For example, for RPM, the U.S. Environmental Protection Agency requires that the 24-hr mean concentration of $PM_{2.5}$ be below 65 Micrograms per Cubic Meter (íg/m$^{3)}$ and annual mean concentration below 15 íg/m^3.*

[54] *For eight-hr exposure of CO, WHO guideline value is 10 Part(s) Per Million (PPM), while that of the American Conference of Governmental Industrial Hygienists is 25 PPM.*

Pollutant concentrations at various measurement points. Room concentration of pollutants were generally determined by whether the stove in that room was used for cooking or heating and the housing characteristics which affect dispersion.

The pollutant microenvironments for each province were as follows:

- Gansu. The cooking room had RPM levels 50-60 percent higher than the bedroom. CO concentrations were more even between the two rooms (about 5 PPM in March and 8.75 PPM in December, with concentration in the cooking room slightly higher in each period). Biomass use during short periods of intense combustion results in high levels of RPM in the cooking room, whereas slow-burning coal stoves for the heated bed yield low RPM levels but relatively high CO levels;
- Guizhou. The highest concentration of indoor air pollutants was the attic area, where the chimney ends. Concentrations in the bedroom were similar to or even slightly higher than in the cooking/living room. The bedroom is an important exposure microenvironment even though it has no stove and is connected by a door to the cooking/living room. Dispersion via the attic through the porous separation with the ground floor results in concentrations in the bedroom being similar to those in the cooking/living room;
- Inner Mongolia. Cooking and heating occur in the same room, making it the main exposure microenvironment; and
- Shaanxi. The cooking room, heated living room and bedroom all had relatively similar RPM concentrations. But concentrations of CO and SO_2 were highest in the heated living room reflecting the use of coal stoves. Pollutant levels in the bedroom were determined by a combination of direct emission and dispersion from other locations. High concentrations in both the heated living room and bedroom illustrate the important role of heating as a source of exposure in winter.

Pollutant concentrations in middle and late heating season. Pollutant concentrations according to the heating season (December or March) cannot be generalized across the four provinces. In Gansu and Shaanxi, average concentration of all measured pollutants were higher in December than in March at all measurement points. In Guizhou, average RPM concentration in the cooking/living room were nearly equal in December and March (about 300 $\mu g/m^3$); in the bedroom, however, average concentration in December were approximately one-third lower than those in March. By contrast, average concentration of CO and SO_2 were higher in December than in March in both the cooking/living room and bedroom. High humidity in Guizhou and the need to keep stored food dry explain, at least in part, interprovincial differences. In Inner Mongolia, where data collection began only in December 2003, baseline interseasonal comparisons were not possible.

Pollutant concentrations across multiple measurement days. Daily variations in IAP levels are reflected in household data subject to measurements over continuous days (Jin et al. 2005). Pollutant concentrations across multiple measurement days varied by a factor of 2-10.[55] Standard deviation of multiple measurements for the same household varied between 10 and 100 percent of their mean. With the exception of SO_2 in Shaanxi, variation was consistently less in December than in March.

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[55] *Minimum and maximum concentrations were calculated separately for each household and then averaged over all such households. The coefficient of variation (defined as the standard deviation divided by the mean) was also calculated for each household and then averaged over all households.*

Variability of pollution across households (interhousehold variation) was compared to variability across measurement days (interday variation) for the same household. In all cases, except CO in the cooking/living room in Guizhou during March, variation across households was greater than within households. This finding suggests that factors which determine pollution concentrations (for example, duration of stove use, quantity and quality of fuel and ventilation and stove use behaviors) are likely to vary more across households than day-to-day within households.

Data Implications for Household Energy Use Interventions

The IAP baseline data reveals the main exposure routes in the four provinces. These findings were used to design household energy use interventions, as follows:

- In households with separate cooking and living/sleeping areas and distinct cooking and heating stoves (that is, most households in Gansu and Shaanxi), the cooking stove is a year-round source of exposure for women and young children; thus, improvement in cooking stoves can reduce exposure. Heating during winter is possibly a greater source of exposure for all household members than cooking. Therefore, reducing exposure requires more extensive improvement in heating stoves than those used for cooking;
- In households with the same cooking and living areas and no physical distinction between cooking and heating stoves (that is, most households in Inner Mongolia), cooking is a year-round source of exposure for all household members. Heating during winter results in exposure periods which are equal to or exceed those caused by cooking. Thus, stove improvements should be accompanied by changes in housing arrangements which separate the main stove from the living area; and
- In households with a separate cooking area used only on special occasions (that is, most households in Guizhou), most cooking occurs in the living area, combined with winter heating. While reducing exposure does not call for changes in housing arrangements, it requires stove improvements which increase the chimney length to limit dispersion of pollutants inside the house (including those from the attic).

In summary, the baseline data indicate that IAP was a serious problem in all four provinces. On average, PM_4 levels exceeded the national standard by nearly 100 percent in Inner Mongolia and by about 70 percent in Gansu, Guizhou and Shaanxi.[56] SO_2 levels exceeded the national standard by 60 percent or more in Guizhou, Inner Mongolia and Shaanxi. CO levels exceeded the national standard by nearly 50 percent in Inner Mongolia and by 45 and 33 percent in Shaanxi and Gansu, respectively.[57]

Household Energy Use

Household energy use surveys, including general household and kitchen/fuel use characteristics, were conducted for all study households. While coal is the near-universal fuel for heating in Guizhou and Shaanxi, 18 and 52 percent of study households in the two provinces, respectively, use biomass as their main cooking fuel. Such multifuel and multistove use means that successful intervention programs must consider

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[56] *Chinese National Standard for Indoor Air Quality, China State Environment Protection Agency.*

[57] *Ministry of Public Health and National Institute for Environmental Health and Related Product Safety, China CDC;* Sustainable and Efficient Energy Use to Alleviate Indoor Air Pollution in Poor Rural Areas in China: Final Report, *Beijing, 2006.*

the various energy uses, combustion (stove) technologies and fuel sources (Tables 3.4 and 3.5). With regard to coal, for example, the type used in Guizhou may contain traces of As and F; the stone coal used in Shaanxi has high S concentrations and possibly traces of toxic trace elements (Finkelman, Belkin and Zheng 1999).

Table 3.4: Stove Characteristics of Study Households (percent households)

	Gansu			*Guizhou*			*Inner Mongolia*		*Shaanxi*		
	C	B	S + B	C	B	S + B	C	B	C	B	S + B
Stove Use/ Type	Pre- n = 509	Pre- n = 509	Pre- n = 500	Pre- n = 523	Pre- n = 501	Pre- n = 484	Pre- n = 527	Pre- n = 508	Pre- n = 508	Pre- n = 491	Pre- n = 581
Cooking											
Coal	44.7	23.0	27.8	–	–	–	–	–	100.0	100.0	100.0
Biomass Range	100.0	100.0	100.0	33.1	20.8	67.4	–	–	64	65.2	72.1
Stove-bed Device	–	–	–	–	–	–	87.1	96.7	–	–	–
Heating											
Coal	–	–	–	–	–	–	–	–	–	–	–
Biomass Range	–	–	–	–	–	–	–	–	–	–	–
Underground Stove	–	–	–	–	–	–	–	–	97.8	96.1	95.7
Kang	100.0	100.0	100.0	–	–	–	–	–	–	–	–
Stove-bed Device	–	–	–	–	–	–	87.1	96.7	–	–	–
Cooking and Heating											
Coal	–	–	–	100.0	100.0	100.0	75.5	51.6	–	–	–
Fire Pan	72.1	85.4	33.4	–	–	–	–	–	–	–	–

Note: C = control, B = behavioral intervention, S + B = stove plus behavioral intervention; blank (–) cells indicate that household members did not claim this stove type as their main stove.

Source: Jin et al. (2005).

Table 3.5: Fuel Characteristics of Study Households (percent households)

	Gansu			*Guizhou*			*Inner Mongolia*			*Shaanxi*	
Fuel Use/ Type	C n = 509	B n = 509	S + B n = 500	C n = 523	B n = 501	S + B n = 484	C n = 527	B n = 508	C n = 508	B n = 491	S + B n = 581
Cooking											
Coal	1.6	0.4	1.6	95.6	97.6	70.0	5.3	3.9	60.6	55.6	59.0
Biomass	98.4	99.6	98.4	4.4	2.4	30	94.7	96.1	39.4	44.4	61.0
Heating											
Coal	34.6	16.3	30.2	100.0	100.0	100.0	96.2	80.2	98.6	96.7	96.2
Biomass	65.4	83.7	69.8	–	–	–	3.8	19.8	1.4	3.3	3.8

Note: C = control, B = behaviorial intervention, S + B = stove plus behavioral intervention; blank (–) cells indicate that household members did not claim this fuel-type as their main fuel.

Source: Jin et al. (2005).

Table 3.6: Stove Use Hours in Middle and Late Heating Season

Living Area	*Mean Hours Stove Used (95% CI)* *March*	 *December*
Gansu		
Cooking	3.0 (2.7-3.3) (n = 96)	2.7 (2.1-3.4) (n = 33)
Living Room/Bedroom	2.3 (1.2-3.5) (n = 96)	4.1 (1.5-6.8) (n = 33)
Guizhou		
Cooking/Living Room	16.5 (15.8-17.2) (n = 96)	15.3 (14.0-16.5) (n = 32)
Inner Mongolia		
Cooking/Living Room/Bedroom		7.3 (6.1-8.4) (n = 65)
Shaanxi		
Cooking	8.4 (6.6-10.3) (n = 100)	9.6 (6.5-12.6) (n = 36)
Living Room	16.8 (13.7-19.9) (n = 25)	18.2 (16.1-20.3) (n = 30)
Bedroom	8.7 (6.7-10.7) (n = 98)	6.8 (2.8-10.8) (n = 24)

Note: CI = Confidence Interval; n = number of household days of observation.

Source: Household survey (self-reported figures).

Other relevant household energy use data includes hours of stove use and amounts of fuel consumed. Of the households studied, those in Shaanxi have the longest daily cooking and heating periods (Table 3.6). In Guizhou, where winter months are characterized by high humidity, keeping stored food dry is a priority. For this reason, warmer March temperatures may have systematically resulted in lower energy use (and lower pollution levels) in the living rooms in Shaanxi and Gansu, but not those in Guizhou. (It should be noted that the differences are not statistically significant.) Inner Mongolia has the highest quantity of fuel consumption (Table 3.7).

Knowledge and Behavior

In each township, approximately 150 households were selected to complete a household questionnaire on energy technology and IAP knowledge and behavior, which was linked to the health survey questionnaire (Annex 3.6).[58] In addition, data on energy use behavior were collected through field observation by key informants (village health workers, and village committees and leaders). Because cooking and child care are primarily done by women, the questionnaire focused mainly on female household members.

Across all provinces and sociodemographic groups, the majority of respondents were aware that smoke from cooking and heating is a health

Table 3.7: Quantity of Fuel Consumption (kg/month)

	Coal		*Biomass*	
Intervention Group	*Heating Season*	*Other Seasons*	*Heating Season*	*Other Seasons*
Gansu				
C	47 ± 78	7 ± 29	241 ± 162	201 ± 119
B	38 ± 81	3 ± 21	371 ± 136	258 ± 98
S + B	78 ± 148	3 ± 49	320 ± 178	256 ± 124
Guizhou				
C	366 ± 195	214 ± 138	65 ± 184	129 ± 238
B	326 ± 244	194 ± 183	25 ± 107	42 ± 142
S + B	282 ± 163	158 ± 142	162 ± 262	322 ± 332
Inner Mongolia				
C	232 ± 115	19 ± 80	257 ± 130	184 ± 104
B	247 ± 255	19 ± 86	369 ± 255	282 ± 230
Shaanxi				
C	256 ± 134	185 ± 106	104 ± 226	124 ± 177
B	243 ± 106	161 ± 102	116 ± 241	150 ± 188
S + B	229 ± 106	173 ± 109	103 ± 204	135 ± 280

Note: C = control, B = behavioral intervention, S + B = stove plus behavioral intervention.

Source: Household survey (self-reported figures).

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[58] *The household questionnaire was conducted by provincial and county staff of the Health Bureau and China CDC.*

hazard (Table 3.8). Respondents from Guizhou – a poor province whose population includes a high proportion of ethnic minorities and limited health education – had the least knowledge of the health risks associated with respirable pollutants from any source. In terms of age groups, respondents below the age of 40 had the greatest knowledge of health hazards. There was a slight gradient by education and income, with those of higher socioeconomic status generally having greater knowledge of risk.

Table 3.8: Knowledge of the Health Effects of Respirable Pollutants (percent respondents)

	Province			
Questionnaire Statement[1]	*Gansu (n = 463)*	*Guizhou (n = 476)*	*Inner Mongolia (n = 323)*	*Shaanxi (n = 479)*
Smoking is a health hazard	93.3	60.1	90.4	80.1
ETS is a health hazard	76.0	47.7	83.3	74.9
Smoke from burning fuel or from cooking is a health hazard	74.5	53.8	77.3	59.7
	Age Group (years)			
	< 40 (n = 1,226)	40-59 (n = 455)	≥60 (n = 60)	
Smoking is a health hazard	82.2	76.9	60.3	
ETS is a health hazard	71.7	65.0	52.5	
Smoke from fuel used for cooking or heating is a health hazard	67.5	60.3	58.3	
	Educational Level			
	Illiterate (n = 472)	Elementary (n = 760)	Junior High (n = 387)	Senior High and Higher (n = 63)
Smoking is a health hazard	71.5	82.2	85.4	92.1
ETS is a health hazard	60.2	70.0	76.9	82.3
Smoke from fuel use for cooking or heating is a health hazard	53.6	68.6	70.8	85.5
	Income Group[2]			
	< 1,500 (n = 137)	*1,500-2,999 (n = 442)*	*3,000-4,499 (n = 452)*	*≥ 4,500 (n = 684)*
Smoking is a health hazard	62.2	75.6	79.2	86.8
ETS is a health hazard	50.4	63.1	67.6	77.8
Smoke from fuel use for cooking or heating is a health hazard	55.6	65.0	61.9	62.2

[1] *ETS = Environmental Tobacco Smoke.*

[2] *Combined value of cash income and subsistence food.*

Source: Jin et al. (2006).

Regarding knowledge of the causes of IAP, only 16 percent (Guizhou), 12 percent (Shaanxi) and 5 percent (Gansu) of those interviewed knew that smoke from fuel combustion contains harmful components, including dust, CO, SO_2, fluoride, As and "other chemicals." The link to indoor air quality was only clear for respondents in Inner Mongolia, where recent efforts have encouraged the installation of ventilation fans (Table 3.9).

Even where knowledge of health risks exists, it must be coupled with knowledge about effective interventions (or solutions) from which individuals and households may choose. Table 3.10 illustrates that awareness about interventions for reducing indoor smoke was relatively low, except for ''improving stove and chimney'' in Shaanxi, where an improved stove program has been in place, and in Inner Mongolia, where efforts are under way to improve the design of the bed-stove configuration in newly constructed homes. In all four provinces, few respondents thought that improving stove-handling skill would reduce indoor smoke from energy use. Most respondents could not identify alternative fuels.

Chapter 4 (Annex 4.2) presents the energy/IAP knowledge and behavior survey data, combining

Table 3.9: Knowledge of IAP Sources by Province (percent respondents)

IAP Source	*Gansu (n = 463)*	*Guizhou (n = 476)*	*Inner Mongolia (n = 323)*	*Shaanxi (n = 479)*
Cooking	36.7	51.6	77.7	63.1
Heating	16.8	38.3	57.6	54.1
Smoking	16.0	42.4	71.5	55.7
Poor or Limited Ventilation	23.3	49.0	63.8	42.3

Note: *In the questionnaire, IAP was defined as the contaminated/polluted/bad air inside the house.*

Source: Jin et al. (2006). Reprinted with permission from Elsevier.

Table 3.10: Knowledge of Methods to Reduce Smoke from Energy Use by Province (percentage respondents)

Method	*Gansu (n = 463)*	*Guizhou (n = 476)*	*Inner Mongolia (n = 323)*	*Shaanxi (n = 479)*
Improving Stove	29.2	32.4	61.9	71.6
Improving Chimney	21.4	29.7	26.0	68.4
Improving the Skills of Stove Handling[a]	12.5	19.4	19.8	13.9
Improving Ventilation[b]	57.7	34.8	65.9	46.6
No Smoking Indoors	4.5	22.4	44.3	15.7
Spending Less Time Using Stove	6.9	17.6	10.8	8.3

[a] *Examples given to respondents included splitting wood into small pieces and cleaning ash regularly to allow better burning.*
[b] *Examples given to respondents included opening windows and doors.*

Note: n = number of households.

Source: Jin et al. (2006). Reprinted with permission from Elsevier.

pre- and post-intervention measurements for all study groups.

Gansu

In Gansu, women's IAP-related knowledge before the health education and behavioral interventions was similarly low among all three study groups. Only about 33 percent understood that cooking is a source of IAP, and less than 20 percent understood that heating is another source. By contrast, 70 percent or more understood that IAP is a health hazard. Consistent with the poor understanding of IAP sources, only about 30 percent and 20 percent, respectively, understood that improved stoves and improved chimneys could reduce IAP. Age, education and income differences did not yield consistent differences in understanding of IAP-related knowledge. Indoor use of fire pans was extensive, ranging from 70-85 percent of households in the control (C) and behavioral intervention (B) groups; only 33 percent of households in the stove plus behavioral intervention (S + B) group reported this practice. Age, education and income differences were not influential factors in explaining fire pan use.

Women's stove use and maintenance practices varied; they were poor regarding closing the stove door when in use, yet strong with regard to use of shorter wood and moderately good with regard to watering ash before removing. Some 80 percent or more women often open windows while cooking. Women younger than 30 years of age displayed similar practices as women over 30. The practices of women with a junior-high school education and above were moderately better than those with only primary schooling or less. Income differences did not appear to influence stove use behavior. Before the health education and behavioral interventions, children in Gansu had little knowledge of IAP sources, health effects and control methods; nearly 40 percent were often in the kitchen.

Guizhou

In Guizhou, 50-60 percent of women in the three household groups understood during the baseline period that IAP could affect health. Less than 20 percent understood the source of dental fluorosis, and almost none were aware that coal and unwashed food could be a source. Age of women was not a significant factor influencing understanding, but education was; the illiterate showed considerably less awareness of the IAP health effect than those with primary or higher education. Those with higher incomes also tended to be more aware of the risks. Most households dried corn and chili with coal smoke, and most (with the exception of S + B households) did not wash food before cooking. Age, education and income were not significant factors influencing the method of food treatment.

With regard to stove use and maintenance habits, 70 percent or more recognized that the stove mouth should be covered after adding fuel. However, only 25 percent or less understood the advisability of watering coal ash when removing. As in the case of food treatment, age, education and income were not significant factors influencing stove use and maintenance habits. Most households (70 percent or more) often open windows while cooking. Age and educational differences do not appear to strongly influence this behavior, but a greater percent of households with higher incomes open windows while cooking. Less than 10 percent of children exhibited knowledge of the source of IAP. But the health education group exhibited relatively strong knowledge about IAP pollutants, their effect and control methods; this knowledge was three times or more the percentage for the C group, perhaps indicating survey inconsistency.

Inner Mongolia

In Inner Mongolia, understanding the sources of IAP was high (60-80 percent). Cooking was identified as the primary source of IAP, followed by heating and bed aeration. Most women (50-75 percent) understood that improved stoves would lead to reducing IAP, but fewer (25 percent or less) understood that improved stove use would also reduce IAP. Age, education and income differences are not reflected in consistent differences in IAP-related knowledge. Some 90 percent of households have a stove-bed heating device, and most (at least in the B group) have no separation between the stove and bed. Again, age, education and income differences do not appear to influence household structures. Children had a relatively high understanding of IAP sources, and a relatively good understanding of the health effect of not separating the stove-bed areas.

Shaanxi

In Shaanxi, more than 60 percent of women exhibited understanding during the baseline period that improving stoves is a method for IAP control. However, less than 40 percent and 20 percent, respectively, understood that greater ventilation and improved fire-handling skills could reduce IAP. There was no consistent pattern with regard to age, education, or income. Only about 15 percent of households dry corn and chili in coal smoke, and an even smaller percentage store these foods near the stove. As in the case of IAP control, age, education and income do not appear to influence food treatment methods.

During cooking, some 50-70 percent of women – especially those below 40 years of age and those better educated and with higher incomes – often open windows. More than 90 percent understood that use of shorter wood contributes to reducing IAP; while more than 66 percent in the S + B group understood that the stove mouth should be closed after adding fuel, less than 40 percent in the B group did. Age, education and income did not bear significantly on stove use habits and maintenance. Among students, only 6 percent understood the source of IAP, but 40-50 percent understood the reference to pollutants and health effects. About 33 percent of students had heard of dental fluorosis, and about 25 percent were aware of prevention methods. Most students (70 percent or more) stayed out of the kitchen to avoid smoke inhalation.

IAP-related Health Symptoms

Baseline data on the health conditions and status of the project target populations were drawn from a comprehensive health survey questionnaire of all women and children aged eight to 12 in the target households (intervention and control groups) (Annex 3.6). Also, extensive health examinations were conducted for all women (above 18 years of age) and children (eight to 12 years old) in the study households. Furthermore, extensive testing was conducted of children under five for acute respiratory infection. The technical survey methods used and health examinations are outlined below.

Technical Designs

Health examinations were conducted regarding lung conditions, eye and nose infections, evidence of fluoric and As toxins and acute respiratory infection in children. Regarding lung conditions, a sample of 150 women and 150 children (eight to 12 years of age) was randomly drawn from the S + B and C groups. Experienced clinicians selected to conduct the lung examinations were trained and tested on the use of specialized equipment.[59]

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[59] *The health survey was designed according to the general questionnaire of the International Atmosphere Standard Consultant Committee (ATS-DLD-78) and modified to account for Chinese conditions. Surveyors (113 in total) were trained, based on the "Investigation Training Manual for Health Surveys" and "Investigator Manual for Knowledge Attitude Positive (KAP) Surveys."*

To test for fluoric and As toxins in household members, urine samples were taken from women and children (eight to 12 years of age). In both Gansu and Shaanxi, 100 persons were selected from each of the S + B and C groups. In Guizhou, fluoric presence was tested on a similar basis, but including the B group. In Inner Mongolia, urine testing applied to the B and C groups. Experienced clinicians selected to conduct the examinations were trained according to the "Diagnostic Criteria of Endemic Arseniasis" and "Clinical Diagnostic Criteria of Dental Fluorosis."

Acute respiratory infections among children (under five years old) were monitored extensively for all project household groups. Township clinicians, trained according to WHO standards for diagnosing acute respiratory infection,[60] conducted bimonthly examinations over a three-month period.

All questionnaire surveys and medical examinations were conducted after the subject (or his or her guardian) signed a consent form.

Resulting Data

The baseline, IAP-related health symptoms of the target households in the four provinces were serious (Table 3.11). During the three months prior to the baseline health survey, some 15 percent of women in the target households experienced IAP-related respiratory symptoms (for example, running nose and coughing with phlegm), 13 percent had IAP-related eye symptoms (for example, irritation) and 27 percent had IAP-related neurological-mental symptoms (for example, headache and dizziness). During the two-week period prior to the baseline health survey, some 20 percent of children aged eight to 12 experienced IAP-related nasal symptoms, 7 percent had pharyngeal symptoms and 4 percent had eye symptoms. Fifteen percent of children under five had symptoms of acute respiratory infection. In Guizhou, fluoride urine concentrations in women and children were 1.35 and .90 mg/L, respectively; 27 percent of children in that province were exposed to foods contaminated with fluorides from coal smoke.

Annex 4.3 presents in full the detailed baseline data for IAP-related health symptoms, combining pre- and post-intervention findings for all study groups.

IAP Interventions

The baseline data on IAP-related health symptoms underscored the seriousness of the IAP problem in the study areas, as illustrated by the finding that some 15 percent of children under age five suffer symptoms of acute respiratory illness. Baseline data on IAP concentrations illustrated the need for alternative stove technologies, including improved ventilation systems, while information on household energy use provided the fuel-specific, local design features for adapting these technologies. Baseline data on IAP-related knowledge and household behavior demonstrated the need for health education and behavioral interventions tailored to both local conditions and the general circumstances of the project provinces, counties and townships. The next sections describe the resulting stove and ventilation improvements and health education and behavioral activities implemented in the four study areas.

Selecting Alternative Stove Technologies

In response to the core IAP-related site problems, stove improvements were designed to increase combustion efficiency and reduce emissions. Combustion efficiency and emission

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[60] *"Management and Instruction Manual for Acute Respiratory Infection (ARI) in Infants."*

Table 3.11: Baseline IAP-related Health Data (percent of respondents/tested persons)

	Gansu			Guizhou			Inner Mongolia		Shaanxi		
Health Symptoms	*S + B*	*B*	*C*	*S + B*	*B*	*C*	*B*	*C*	*S + B*	*B*	*C*
Selected for Women	n = 593	n = 620	n = 653	n = 548	n = 550	n = 562	n = 545	n = 572	n = 578	n = 494	n = 499
Respiratory (in past three months)[1]	11.1	5.0	27.3	10.8	14.5	22.7	13.0	7.7	25.1	11.9	12.2
Eye (in past three months)[2]	14.0	7.6	23.3	9.5	13.5	21.2	7.5	3.2	21.1	13.0	9.2
Neurological-mental (in past three months)[3]	28.2	15.3	34.5	15.4	32.2	44.3	17.8	6.6	42.4	28.3	34.9
Selected for children 8 to 12 years-old	n = 730	n = 741	n = 770	n = 711	n = 739	n = 813	n = 623	n = 645	n = 855	n = 748	n = 773
Eye (in past two weeks)	4.5	1.5	4.2	1.3	3.8	5.7	2.3	2.8	11.4	3.6	2.3
Nasal (in two weeks)	14.3	6.5	22	11.1	23.2	18.8	14.6	11.5	40.9	32.2	28.5
Pharyngeal (in past two weeks)	6.0	2.6	10.5	3.5	4.7	10.6	5.3	4.7	14.7	6.7	3.1
Acute Respiratory Infection, Surveillance for Children Under 5 years-old	n = 600	n = 569	n = 885	n = 785	n = 792	n = 670	n = 1,084	n = 883	n = 1,022	n = 1,104	n = 1,109
Acute Respiratory Infection	42.3	51.5	53.8	24.3	43.7	39.3	30.2	21.0	23.1	15.4	14.9
Coughing, Phlegm and Hemoptysis	32.0	16.2	26.4	8.0	11.4	22.6	20.0	8.5	14.4	7.7	8.2
Dyspnea	5.2	1.9	1.1	0.8	0.8	0.9	0.1	0.9	0.3	0.1	0.0
Nasal Mucus	32.2	23.9	39.1	19.9	39.5	28.1	18.7	14.3	19.1	14.7	13.0
Pharyngeal	36.7	41.1	31.0	4.8	7.8	5.7	3.1	2.2	4.0	0.8	1.0
Eye	0.3	1.2	0.6	0.0	0.0	0.3	0.0	0.0	0.6	0.0	0.0

[1] *Respiratory symptoms in the past three months include running nose, nasal obstruction, sneezing continuously, coughing and coughing productive of phlegm.*

[2] *Eye symptoms in the past three months include irritation of both eyes lasting more than four hours, irritation of both eyes for more than five days in a week, itching (not irritation) of both eyes, watery eyes, engorgement of eyes, history of allergies affecting one or both eyes, discharge from one or both eyes causing eyelids to stick together in the morning.*

[3] *Neurological-mental symptoms in the past three months include continuous headache for more than four hours, more than five headaches in a week and dizziness.*

Note: S + B = stove plus behavioral intervention, B = behavioral intervention, C = control; n = number of observations.

Source: Household survey (self-reported figures).

tests of original and improved stoves were conducted in five to eight representative households for the S + B groups in Gansu, Guizhou and Shaanxi and the B group in Inner Mongolia (Table 3.12).

In total, 27 improved stoves, involving five stove-types, were pilot-tested. All were checked in the study households by scientists and engineers from the Institute for Environmental Health and Related Product Safety of the China CDC. Once selection was narrowed, the improved models were installed in 30-50 households in each province before large-scale installation.

Indexes for pyrology efficiency were determined based on the national standard (Testing Method for Household Use of Coal and Biomass Stoves [GB6412-86]). The amount of fuel needed to heat and vaporize a given amount of water was measured; tests were conducted under both controlled and local home conditions to measure ideal and actual performance, respectively. Pollutant emissions (PM_{10}, SO_2 and CO) were measured at given heights and distances from the stoves; each pollutant was continuously tested relative to the amount of fuel consumed. The analysis method and instruments used were the same as those described for IAP monitoring.

Stove and Ventilation Interventions

Some 2,500 alternative stoves were provided to households on a subsidized basis (S + B groups in Gansu, Guizhou and Shaanxi and B group in Inner Mongolia). In addition, some 200 households from the B groups chose to install new stoves at full cost. Improved ventilation systems complemented the introduction of new stoves (Table 3.13).

Pre- and Post-intervention Comparisons

Taking into account local fuel use, household conditions, housing structure and other factors, stove improvements were adopted in the study counties/provinces, as follows:[61]

Table 3.12: Types and Number of Stoves Tested

		Before Intervention		*After Intervention*	
Province	*Fuel-type*	*Stove-type*	*Number*	*Stove-type*	*Number*
Gansu	Biomass	Brick or clay stove	8	Coal/biomass two-fuel stove	8
Guizhou	Coal	Simple metal stove (Beijing stove)	6	Air-circular stove	6
Inner Mongolia	Biomass	Brick or clay stove-bed device	8	Improved stove-bed	8
Shaanxi	Coal	Separate coal and biomass ranges, basic underground chambers stove	3;2	Two combustion chambers for both biomass and coal, combustion chambers with improved insulation	2;3

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[61] *The detailed structures and technical parameters of the stoves are provided in the final project report of the China CDC.*

Table 3.13: Improved Stoves and Ventilation Systems Installed in Study Areas

	Intervention Group			
	S + B		*B*	
Study Area (county, province)	*Intervention-type*	*Number of Finished Devices Installed*	*Intervention-type*	*Number of Finished Devices Installed*
Guiding, Guizhou	Air-circular coal stove, chimney extends outdoors	500	Chimney extends outdoors	430
Hui, Gansu	Coal/biomass two-fuel stove, air-sucking heating-bed used with wood	500 500	Coal/wood-using stove, Heating-bed used with wood	71 29
Helingeer, Inner Mongolia	NA	NA	Separate stove-bed device	62
Ankang, Shaanxi	Coal-using stove, underground stove with chimney	469 469	Underground stove/ range using coal	91

Note: S + B = stove plus behavioral intervention, B = behavioral intervention.
NA = Not applicable.

Hui, Gansu. Cooking stove (Figures 3.1a, b). Most of the original brick or clay (biomass) range stoves had limited insulation with either no chimney or one whose diameter or height resulted in inappropriate ventilation. The new stoves are constructed of stronger material and are insulated. The size of the combustion chamber and chimney diameter and height are designed for appropriate ventilation.

Heating stove (Figures 3.1a, b). Most of the original brick or clay (biomass) heated beds had limited insulation and an opening for fuel inside the room, resulting in smoke. They had either no chimney or one whose diameter or height resulted in inappropriate ventilation. The new stoves are constructed of stronger material and are insulated. The fuel opening is outside the room with an airflow system to transfer heat through the bed-stove combination. The chimney diameter and height are designed for appropriate ventilation. A fire pan is sometimes used for heating, making tea and cooking small meals.

Guiding, Guizhou: Cooking and heating stove (Figures 3.2a, b). Original coal iron stoves were simple, enclosed metal containers with limited insulation and no door. Chimneys, equipped on some stoves, seldom extended outside the house. The new air-circular stoves have an internal metal combustion chamber and outer metal body, separated by air. They are insulated and have a multilayered upper door to fit variously sized cooking pots. The chimney extends outdoors.

Figure 3.1a: Original Biomass Range (left), Bed-heating Device (center) and Chimney (right), Gansu

Key Disadvantages:

- Poorly structured biomass range
- Incomplete combustion and heavy IAP
- No smoke tract for bed-heating device
- Poorly structured chimney and restricted exhaust

Figure 3.1b: Improved Biomass Range (left), Bed-heating Device (center) and Chimney (right), Gansu

Key Advantages:

- Improved structure of biomass range
- Clean combustion and efficient energy use
- Increased height of chimney with better ventilation
- Smoke tract for bed-heating device with safer and more efficient heating

Figure 3.2a: Coal Iron Stove (left) and Chimney (right), Guizhou

Key Disadvantages:

- Incomplete combustion
- Heavy IAP emission
- Stoves in serious disrepair
- Chimney extends only into the attic
- Released smoke used to dry food

Figure 3.2b: Air-circular Stove (left) and Ventilation System (right), Guizhou

Key Advantages:

- Complete combustion
- Lower IAP emission
- Adapted local customs
- High acceptance
- Chimney extends outdoors
- Chimney wind cap exhausts smoke

Helingeer, Inner Mongolia. Cooking and heating stove (Figures 3.3a, b). The original brick or clay (biomass) cooking stove was connected to a bed to create a bed-stove. Stove improvements are limited because they require changes in house design and construction to separate the cooking component from the heated bed. In some cases, stoves have been moved out of the bedroom, and ventilation fans have been installed in the kitchen.

Figure 3.3a: Original Biomass Stove-bed Device, Inner Mongolia

Key Disadvantages:

- Restricted ventilation resulting in heavy IAP
- Poorly structured with inefficient heat
- No barrier between stove and bed
- Safety hazard, especially for children

Figure 3.3b: Improved Biomass Stove-bed Device, Inner Mongolia

Key Advantages:

- Stove moved out of bedroom (if two or more rooms)
- Stove and bed separated by a barrier (if one room)
- Exhaust fan placed in kitchen
- Chimney extended outdoors
- Added smoke tract for more efficient heating; and
- Burns reduced for children

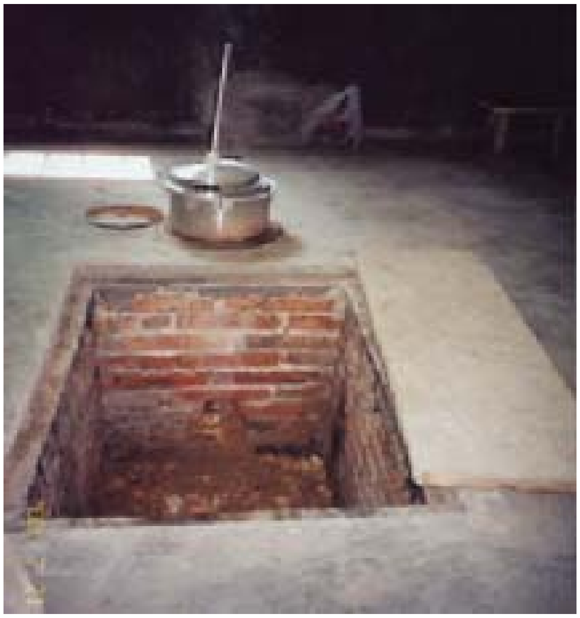
Ankang, Shaanxi. Cooking stove (Figures 3.4a, b). Construction similar to that of Gansu (see Figures 3.1a,b). Heating stove (Figures 3.4a, b). Coal stoves for heating were built underground, without chimneys. Stove improvements include better-insulated combustion chambers, with chimneys that extend outside the house above the eave.

Figure 3.4a: Original Coal Range (left) and Underground Stove (right), Shaanxi

Key Disadvantages:

- Incomplete combustion with heavy IAP
- Stove with no mouth ring or chimney
- No bed ventilation

Figure 3.4b: Improved Coal Range (left) and Underground Stove (right), Shaanxi



Key Advantages:

- Energy-saving
- More efficient heating
- Hot water supply
- Chimney extended outdoors

Table 3.14 summarizes the costs of the new stoves and ventilation devices for each study province.

Developing Health Education and Behavioral Activities

In all provinces, the following health education and behavioral activities were undertaken:

- ***Sources of IAP.*** Fuel, stove and behavioral sources of IAP exposure were emphasized. These included coal-types (for example, those with higher S or F content); stove characteristics (for example, lack of chimney or one not extending outside the house, bed-stove or heated bed without physical separation between fuel and living areas and poorly ventilated stoves and cooking ranges); and stove use behaviors (for example, not closing/covering the stove door or using too large pieces of fuel to allow for proper combustion);
- ***Health hazards of IAP exposure.*** Emphasis was on both the role of chronic exposure to IAP as a health hazard and specific diseases and symptoms familiar to the population (for example, respiratory diseases, eye and vision problems, dizziness, headache and CO poisoning). In provinces where coal contains specific trace pollutants (for example, F), the associated health outcomes (for example, dental and skeletal fluorosis) and routes of exposure (for example, deposition on food dried over fire) were also emphasized;
- ***Benefits of stove improvement.*** Fuel change and stove improvement to reduce IAP exposure were promoted. Local fuels and stoves were emphasized, as were stove quality and maintenance. In Guizhou, where it was possible to extend the chimney of existing stoves, use of a longer chimney was emphasized; and
- ***Alternative stove use and ventilation behaviors.*** Specific stove maintenance and stove use behaviors were presented as alternatives to the behavioral determinants

Table 3.14: Stove Intervention Costs by Province

Province	*Stove or Device Adopted*	*Total Cost (RMB ¥)*	*Household Portion*	*Intervention Group*
Gansu	Cooking Stove, Heating-bed Device	320-350, 370-420	120-150 (including partial materials and labor),	S + B
Guizhou	Air-circular Stove	300	100 (including transport and fittings, for example, chimney)	S + B
Inner Mongolia	Stove-bed Device	400	100-400 (including partial materials and labor)	B
Shaanxi	Underground Stove and Oven	585	185 (including transport, partial materials and labor)	S + B

Note: S + B = stove plus behavioral intervention, B = behavioral intervention.

Source: Chinese Center for Disease Control and Prevention.

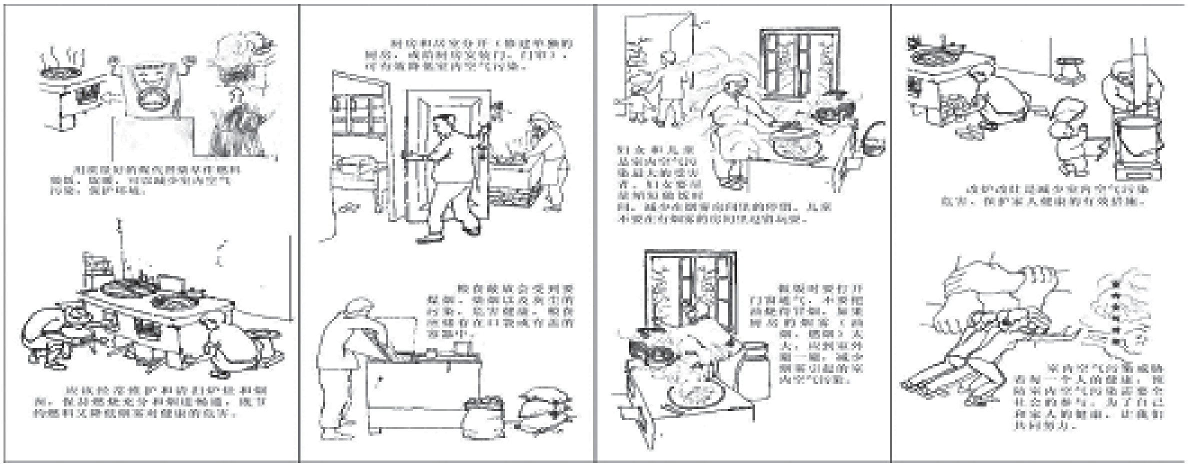
Figure 3.5: Illustrative Health Education and Behavioral Materials

School blackboard explaining how stove improvement helps health.

Poster explaining how to prevent fluorosis.

Village cadre distributing materials.

Villagers' group discussion.



Leaflet explaining stove use and behavioral habits which reduce exposure.

of exposure. These included fuel-handling, closing or covering stove doors and better ventilation of the cooking and living areas (subject to constraints of winter temperatures).

Health education and behavioral activities were extensive (Table 3.15). In addition to the 3,500 households and 5,000 students directly engaged, many more township residents (in the S + B and B groups) were reached through broad distribution of some 27,000 information leaflets. Some 5,850 students participated in a composition contest on IAP, its health hazards and ways to reduce the problem. An array of materials (bulletin boards, films, visits to model homes, manuals and village meetings) contributed to building awareness.

Table 3.15: Number of Households and Persons Involved in Health Education and Behavioral Activities

	Group			
	S + B		*B*	
Study Area (County, Province)	*Community (Households)*	*School (Persons)*	*Community (Households)*	*School (Persons)*
Hui, Gansu	500	1,000	500	450
Guiding, Guizhou	500	800	500	1,400
Helingeer, Inner Mongolia	NA	NA	450	460
Ankang, Shaanxi	500	530	500	330
Total	1,500	2,330	1,950	2,640

Note: S + B = stove plus behavioral intervention, B = behavioral intervention; NA = Not applicable.

Matching Key Messages to Local Realities

Health education materials were prepared separately for each province so that specific messages could be matched to local geography and climate, fuel and stove and sociocultural factors. Preparation and dissemination of the materials also took into account the roles of men and women in household energy choice, stove use and IAP exposure. Following is a summary account of the key messages conveyed and methods used for each province.

Gansu. Key message: *"IAP is caused by the improper ventilation of the old stove and use of fire beds and fire pans."* Health education training was provided to 50 and 30 persons in households in the S + B and B groups, respectively. Village meetings were held, led by township hospital officials, village cadres and doctors. IAP information (including the costs of not addressing the problem and the relative inexpensive options for reducing IAP exposure) was publicized. Women played a prominent role, holding family meetings to exchange skills and to discuss ways to decrease indoor smoke and the advantages of new stoves. Where possible, VCDs were played to demonstrate IAP health risks and methods to avoid them. Visits were made to model households, notably to Mayan township where women in model households demonstrated the use and maintenance of improved stoves. VCDs were also played in the local schools to educate students.

Guizhou. Key message: *"Coal used in heating and cooking contains fluoride, which harms health* *and leads to fluorosis."* The slogan "Prevent Fluorosis, Chimney Outdoors" was painted on the chimneys of more than 1,000 households. Health education activities were conducted mainly in community centers and primary and middle schools. More than 450 persons, mainly from households in the B group, were trained in health education. Village rules and pacts were made to reduce IAP, control fluorosis and change villagers' habits and behavior. Bulletins, films and addresses by specialists and country and township leaders outlined how to prevent and control IAP and fluorosis.

***Inner Mongolia*.** Key message: *"Use of a stove connected to the bed in one room leads to scalding of children and IAP, so stove and bed should be in separate rooms."* Village meetings were held, led by township hospital officials, village cadres and doctors. Twenty-seven persons received health education training. Bulletins and other IAP-related materials were distributed widely. Visits to model homes and women's small-group discussions contributed to better understanding of the IAP problem and options for reducing exposure. The county government reinforced the campaign by requiring new house construction to separate the bedroom and kitchen.

***Shaanxi*.** Key message: *"People suffer from fluorosis by using local bone coal with high fluoride content in underground stoves without flues."* Only 35 persons received health education training. Village working groups organized meetings of five to eight women at a time to discuss IAP health risks and ways to decrease indoor smoke. The advantages and proper use and maintenance of new stoves were described. VCDs and other educational materials were used.

4. Intervention Results*

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The changes which resulted from the stove and behavioral interventions discussed in Chapter 3 demonstrate the effectiveness of the project's heating-stove interventions in reducing IAP from coal and biomass fuels. Cooking stove interventions, whereby users modified combustion patterns more regularly (which included large fluctuations in combustion intensity), exhibited more mixed performance. When energy was used for heating, the fuel combustion pattern was more stable and less intense. The improved heating stoves (including the heated bed in Gansu and the underground stove in Shaanxi), which separated the combustion chamber from the indoor environment and/or ventilated smoke outdoors, were effective in reducing IAP and were not sensitive to user behaviors. Thus, well-designed and -constructed stove improvements can significantly reduce IAP exposure and its associated disease burden in China, where heating is a basic energy use for much of the population.

The following sections describe the outcomes which resulted from the project's alternative stove technology (including improved ventilation systems) and health education and behavioral interventions. Results are reported according to the four major outcomes: stove use and potential stove efficiency, IAP, IAP-related knowledge and behavioral indicators and IAP-related health symptoms.

Changes in Stove Use

In the project provinces and China generally, multifuel and stove use are common features of household energy because of fuel availability and multiple energy uses (for example, cooking and heating). Still the relative importance of fuels varies by project province. In Guizhou and Shaanxi, for example, use of coal for heating is nearly universal (a small proportion of households in Shaanxi use biomass). In Gansu and Inner Mongolia, biomass is the main cooking fuel, and coal plays a major role in heating (Table 4.1).

Because of the project's short time span, fuel use composition was assumed to remain largely unchanged throughout the project period. Stove and stove-ventilation data show improvements in technical characteristics (for example, whether a stove had a chimney or whether it extended outside the house) in the S + B group, as the intervention design intended.

Improvement in stove ventilation also occurred in the B group (for example, improved chimney in Guizhou and Shaanxi and reduced reliance on stove-bed device in Inner Mongolia).

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* *Portions of this text is from the article by project team members Yinlong Jin et al., "Exposure to indoor air pollution from household energy use in rural China: the interactions of technology, behavior and knowledge in health risk management,"* Social Science and Medicine*, 2006 June; 62(12):3161-76. Permission for reproduction of material was granted by Elsevier.*

Table 4.1: Baseline Fuel Use Among Study Participants (percent households)*

	Gansu			*Guizhou*			*Inner Mongolia*			*Shaanxi*	
	C	B	S+B	C	B	S+B	C	B	C	B	S+B
Fuel	n = 509	n = 509	n = 500	n = 523	n = 501	n = 484	n = 527	n = 508	n = 508	n = 491	n = 581
Cooking											
Coal	1.6	0.4	1.6	94.3	97.5	69.2	5.3	3.9	60.6	55.6	59.0
Biomass	98.4	99.6	98.4	5.7	2.5	30.8	94.7	96.1	39.4	44.4	61.0
Heating											
Coal	34.6	16.3	30.2	100	100	100	96.2	80.2	98.6	96.7	96.2
Biomass	65.4	83.7	69.8	0	0	0	3.8	19.8	1.4	3.3	3.8

** Figures are based on a survey question which asked household respondents about main fuel for cooking and heating.*
Note: C = control, B = behavioral intervention and S + B = stove plus behavioral intervention; n = number of observations.

Provincial Results

Intervention results by province were as follows (Table 4.2):

- Gansu. In the S + B group, stove and stove ventilation data showed improvement in stove technical characteristics (that is, presence or length of chimney), as a result of the intervention design. Among the B group, improvement in stove ventilation were noted (that is, chimneys extended higher above the ground). For all three groups, the percentage of households using coal stoves increased (although S + B and B showed larger increases than C);
- Guizhou. The S + B and B groups showed significant improvement in stove technical characteristics. In the S + B group, post-intervention, all households had chimneys extending outdoors (reflecting a dramatic increase of 88 percentage points compared to the baseline). The percentage of biomass range use declined in all groups;
- Inner Mongolia. Households in both groups (B and C) exhibited increased use of biomass ranges following the interventions. Reliance on the stove-bed heating device decreased for households in the B group, while it increased for those in the C group. In terms of separation between stove and bed, after installation of exhaust fans, B group households showed little change, while separation increased for C group households; and
- Shaanxi. S + B groups reported a sharp increase in the use of chimneys. In particular, all households in the S + B group had chimneys for coal and underground stoves, while most B group households did not have chimneys.

Table 4.2: Summary of Pre- and Post-intervention Stove Use

	Gansu						Guizhou						Inner Mongolia				Shaanxi					
	C		B		S + B		C		B		S + B		C		B		C		B		S + B	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Stove/ Fuel Use	n = 509	n = 504	n = 509	n = 473	n = 500	n = 469	n = 523	n = 458	n = 501	n = 456	n = 484	n = 377	n = 527	n = 490	n = 508	n = 454	n = 508	n = 437	n = 491	n = 458	n = 581	n = 414
Cooking																						
Coal Stove/Range[1]	44.7	57.0	23.0	47.4	27.8	75.3											100	100	100	100	100	100
Biomass Range[1,2]	100	100	100	100	100	100	33.1	27.9	20.8	16.9	67.4	23.6					64.0	63.4	65.2	68.4	72.1	16.7
Stove-bed Device												87.1	93.9	96.7	86.6							
Heating																						
Coal Stove																						
Biomass Range																						
Underground Stove[3]																	97.8	100	96.1	100	95.7	100
Heated Bed	100	100	100	100	100	100																
Stove-bed Device												87.1	93.9	96.7	86.6							
Cooking and Heating																						
Coal Stove[4]							100	100	100	100	100	100	75.5	92.9	51.6	73.4						
Fire Pan	72.1	71.7	85.4	85.2	33.4	33.3																

[1] In Gansu, the cooking range can use both biomass and coal. All households use the range with biomass, while a subset of households, reported under the coal range, also use the range to burn coal.

[2] In Guizhou, the biomass range is primarily used for large events (for example, spring festival) and for preparing animal feed. Coal stoves are used for both primary cooking and heating.

[3] In Shaanxi, less than 5 percent of households had no (underground) heating stove in the baseline survey.

[4] In Inner Mongolia, many households use coal in their stove-bed device (or use an additional coal stove) for nighttime heating because coal burns more slowly. Increased use of the coal stove in the post-intervention survey likely reflects the colder winter in 2004-05 heating season.

Note: All stoves used for a purpose are counted. Thus, if a household uses more than one stove and fuel for cooking or heating, numbers can total more than 100 percent; C = control, B = behavioral intervention, and S + B = stove plus behavioral intervention.

Energy Efficiency under Controlled Conditions

Under controlled conditions, fuel and heat efficiency of the new stoves increased significantly over that of the old ones (no data on actual user conditions were collected). In these tests, the fuel that new stoves consumed to vaporize a given amount of water under household conditions decreased 30-50 percent. With the exception of the new stove used in Shaanxi (where increased ventilation of the heating stove may have led to higher fuel consumption), heat efficiency increased 25 percent on an average.

Changes in IAP Levels

Air quality monitoring following the stove/ventilation interventions mirrored the techniques for collecting baseline data. With few exceptions, the same households were selected for post-intervention testing of RPM, CO and SO_2 levels. Two testing methods were used: 1) approximately 75 households (some 27 from each of the S + B, B and C groups) from each province were tested for one complete day in December 2004 and March 2005; and 2) smaller sets of households (some six from each province) were tested continuously over four-day periods in December 2004 and March 2005. The measurement points used were the same as during the baseline phase.

In addition to the above household measurements, pollutant levels from a small number of old and new stoves were measured under controlled stove use conditions equivalent to ideal stove use behavior. For these controlled

Table 4.3: Comparing Fuel and Heat Efficiency of Old and New Stoves

			Fuel Consumption (Kg/h)			*Heat Efficiency (%)*		
Province	*Stove-type*	*Fuel*	*Old Stove*	*New Stove*	*% Change*	*Old Stove*	*New Stove*	*% Change*
Guizhou	Air-circular	Coal	0.84	0.58	30	12	15	25
Gansu	Biomass	Biomass	3.84	1.88	51	13	17	31
Shaanxi	Underground	Coal	1.02	0.60	41	26	21	–19
Inner Mongolia	Stove-bed Device	Biomass	NA	NA	NA	9	13	19

Note: Heat efficiency equals weight of fuel needed to bring a fixed volume of water to boil.
Increased heat efficiency (%) equals heat efficiency of new stove minus heat efficiency of old stove divided by heat efficiency of old stove.
NA = Not applicable.

While both efficiency and pollutant emissions are related to the combustion process, they are separate characteristics; reducing pollutant emissions was the main goal of this project. Measurements under household conditions indicated that the new stove/ventilation technologies not only had higher fuel and heat efficiency, but considerably lower emissions (per unit of heat). With regard to environmental implications, the results were too mixed or limited to draw conclusions.

measurements, local fuel was used and scientists and engineers from the Institute for Environment Health, China CDC, operated the stoves. Concentrations of indoor air pollutants were measured at given distances from the stoves for the duration of combustion of an approximate fixed amount of fuel.

Changes under Controlled Conditions

Under controlled conditions, reductions in RPM concentrations were consistent and substantial; most were statistically significant, despite the small number of tests. For SO_2, the reduction in Shaanxi was substantial, reflecting high preintervention concentrations resulting from the type of coal used (Table 4.4).

Table 4.4: Change in Pollutant Concentrations under Controlled Conditions

Stove	*Fuel*	*RPM (μg/m^3)*	*CO (PPM)*	*SO_2 (PPM)*
Gansu				
Preintervention Cooking Range	Wood	3,400 (n = 7)	64.8 (n = 7)	NA
Post-intervention Cooking Range	Wood	60 (n = 7)	7.5 (n = 8)	NA
△		-3,340 (-98%) (p = 0.04)	-57.3 (-88%) (p = 0.04)	
Guizhou				
Preintervention (Beijing Stove)	Raw Coal	3,520 (n = 5)	14.5 (n = 5)	1.25 (n = 6)
Post-intervention (Air-circular Stove)	Raw Coal	420 (n = 5)	5.0 (n = 4)	1.14 (n = 6)
△		-3,100 (-88%) (p = 0.006)	-9.5 (-66%) (p = 0.08)	-0.11 (-9%) (p = 0.62)
Shaanxi				
Preintervention Cooking Range and Underground Stove	Stone Coal	1,240 (n = 6)	23.0 (n = 6)	7.96 (n = 5)
Post-intervention Cooking Range and Underground Stove	Stone Coal	90 (n = 4)	5.8 (n = 4)	0.92 (n = 4)
△		-1,150 (-93%) (p = 0.18)	-17.2 (-75%) (p = 0.01)	-7.05 (-89%) (p = 0.21)

Note: n = number of observations; △ = absolute reduction in pollutant concentrations

Source: Chinese Center for Disease Control and Prevention.

Changes under Household Conditions

The levels and changes in concentrations of pollutants under household use condition show substantially more heterogeneous stove performance than in controlled tests (Annex 4.1).[62] It should be noted that the proportional reduction in 24-hour household concentrations after the stove intervention may be lower than those in controlled tests for two possible reasons: 1) user skills and behaviors may lower the pollution-reducing effectiveness of a stove; and 2) twenty four-hour measurements consist of periods when the stove is burning intermittent with those when the stove is off. Therefore, proportional reduction in 24-hour concentrations may be less than those observed during burning periods.

With few exceptions, post-intervention RPM concentrations declined for S + B and B, as well as C (for example, B group in Guizhou during the December-January measurement period). Given the physical separation of the three clusters, it is unlikely that the decline in C was a consequence of contamination effects. Rather, it may represent determinants of indoor air pollutants external to the interventions. However, temperature appears not to have been the cause; data from the China National Meteorological Information Center indicate that average monthly temperatures were slightly higher during the post-intervention periods in Gansu, Guizhou and Inner Mongolia, and slightly lower in Shaanxi, compared with the same months during the baseline measurements, but not enough to explain the RPM reduction in C.

For rooms where heating is important (living room and bedroom), reduction in RPM concentrations were generally less, and with lower statistical significance, in late (March-April) versus peak (December-January) heating seasons. This was not the case for the separate kitchens in Gansu and Shaanxi, where reductions in RPM concentrations were similar during peak and late heating seasons. This result may be related to the seasonal nature of heating (living room and bedroom) versus a more stable pattern of energy use for cooking (separate kitchen). The pattern for the gaseous pollutants (CO and SO_2) was less consistent; concentrations declined in a smaller number of measurement points, and the proportional reductions were smaller.

Full Intervention and Control Comparisons

In Gansu, S + B consistently had a larger decline than C. This result was observed for both RPM and CO in cooking and living/bedrooms. The IAP reduction benefits of S + B were larger, with better statistical significance in the living/bedroom measurements than in the cooking room in December-January; the benefits of S + B were larger in the cooking room in March-April. Benefits during peak heating months (December-January) in the living/bedroom in all likelihood resulted from major design changes of the heated bed (Panel 1); cooking room reduction benefits resulted from new stove construction, with stable cooking patterns over time.

In Guizhou, S + B (with few exceptions) had larger reductions than C for all three measured pollutants in December-January, but smaller reductions in March-April, especially for RPM. None of the results in March-April were statistically significant. The March-April finding results largely from unusually high concentrations in the baseline measurements for C (621 $\mu g/m^3$ in the cooking/living room and 552 $\mu g/m^3$ in the bedroom),

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[62] *Annex 4.1 shows the levels and post-intervention changes in concentrations of indoor air pollutants under household use conditions. It provides the basis for difference-in-difference analysis by showing, for each province, the changes in IAP concentration levels for the intervention groups compared to the control groups.*

which leads to large observed post-intervention reductions in this group. Of the 33 measurements leading to these baseline estimates, nine were above 1,000 $\mu g/m^3$; six of these were measured in the same village within a two-day period. These outliers have a relatively large effect on the results.

In Shaanxi, the effects of S + B on various pollutants in different months were the least consistent among the three provinces; the only noticeable benefits compared to C were for RPM and SO_2 concentrations in the bedroom. This finding may reflect the improved combustion/ventilation of new stoves in the bedrooms, with low concentrations of RPM and SO_2, but not of CO, which is a crude indicator of total combustion. Reduction benefits in the bedroom were larger in December-January than in March-April, reflecting the seasonal nature of bedroom heating. In this province, C outperformed S + B in terms of change in concentrations of all three pollutants in the living room in December-January, although sample sizes were smaller because fewer households used their living room stove. Cooking room results had no consistent patterns or statistical significance.[63]

Other Relevant Comparisons

In addition to comparing results between S + B and C, comparing B and C, as well as S + B and B relative to changes in C are also relevant. In Inner Mongolia, where only B was undertaken, reductions in RPM and CO concentrations for the B group were greater than that of the C group, although none of the differences were statistically significant. With few exceptions, the B groups in the other three provinces showed no significantly different reductions in pollutant concentrations from those of the C groups. Of the five significant results, four indicated that B had smaller reductions than C, and one showed the opposite.

With regard to comparing results of S + B and B, S + B groups clearly outperformed B groups. In Gansu and Guizhou, S + B groups reported consistently larger reductions in concentrations of all pollutants than did B groups during the peak heating season; the differences were mostly statistically significant. In Shaanxi, the S + B groups reported larger reductions in all pollutants during the late heating period; one-third of the differences were significant.

Changes in IAP-related Knowledge and Behavior

Like changes in IAP concentration levels, changes in IAP-related knowledge and household behavior for S + B and B were the combined effect of stove and behavioral activities. With regard to B, the outcome understandably reflects behavioral activities only. Annex 4.2 provides pre- and post-intervention survey results for women and children in the study households. Because the survey questions varied by province, one should exercise caution in making interprovincial comparisons.

IAP-related Knowledge

Questions common to all provinces included the main sources of IAP, their health effects and control methods. Knowledge about fluorosis is relevant only for Guizhou and Shaanxi (Table 6.1, Annex 4.2).

With few exceptions, all groups showed post-intervention improvement in IAP-related knowledge. The process of completing the health survey likely raised respondents' awareness of the IAP problem. In some cases, S + B groups had larger improvements than did B groups, suggesting that the process of participating in stove improvements could have contributed to raising awareness of IAP-related knowledge.

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[63] *It should be noted that sample sizes were smaller for living room measurements because fewer households used their living room stove, which reduced the power of testing.*

In Gansu, women in the S + B group reported greater improvement in knowledge of health hazards and risk perceptions than those in the C group; most of these improvements were statistically significant. Differences between B and C groups exhibited no consistent patterns. With few exceptions, women in the S + B group demonstrated greater statistically significant improvement than those in the B group. Among children (with one exception), the B group demonstrated less improvement than the C group, and all results were statistically significant.

In Guizhou, women in both S + B and B groups reported greater statistically significant improvement than those in the C group. With few exceptions, the S + B group reported greater improvement than the B group; half of the differences were statistically significant. For children (except for the IAP health impact), the B group reported greater improvement than the C group, and the differences were mostly significant. These results suggest that both S + B and B groups benefited from behavioral interventions, with S + B groups benefiting more than B groups.

In Inner Mongolia, with few exceptions, women in B group demonstrated greater improvement in IAP-related knowledge (except with respect to heating as a source of IAP) than those in C group, but the differences were mostly insignificant. With regard to children, B group demonstrated statistically significant greater improvement than C group, except with respect to the IAP health impact.

In Shaanxi, women in the S + B groups reported greater improvement than the C group, although half of the differences were insignificant. There was no consistent pattern in the differences between B and C groups or between S + B and C groups. For children, B group demonstrated greater improvement than C group, and the differences were mostly statistically significant.

Behavioral Indicators

Questions common to all provinces mainly included stove use habits (for example, closing stove lid, using shorter wood, watering ash and opening windows). For children, the behaviors included avoiding smoke and staying out of the kitchen while cooking. Fluorosis prevention behavior was relevant only for Guizhou and Shaanxi (Table 6.1, Annex 4.2).

In Gansu, women in the S + B groups showed greater improvement than C groups in all cases; most differences were statistically significant. B group had greater improvement than C group in three out of four cases, but none of the differences were statistically significant. S + B groups demonstrated greater improvement than B group, and the differences were mostly significant. These results are consistent with increased awareness of IAP-related knowledge in Gansu province. For children, the differences between B and C groups were neither consistent nor significant.

In Guizhou, with the exception of "washing corn before cooking," women in both S + B and B groups had greater statistically significant improvement in food treatment behavior than those in C group. Differences between S + B and B groups showed no consistent patterns. In this case, participation in stove improvement appears not to have had any effect on food treatment behavior. In terms of stove use and maintenance habits, both groups reported greater statistically significant improvement than the C group. S + B and B groups showed no significant differences. No consistent patterns were shown for children.

In Inner Mongolia, women in B group demonstrated statistically greater improvement than C groups in all aspects, indicating that the interventions were effective in changing behavior. With regard to children, B group demonstrated greater statistically significant improvement than did C groups.

In Shaanxi, in terms of food treatment behavior, women in the S + B group demonstrated greater improvement than those in the C group, and the differences were mostly significant. Differences between B and C groups showed no consistent pattern. The S + B group exhibited greater improvement than the B group, and differences were mostly statistically significant. In terms of stove use and maintenance behavior, the S + B group demonstrated greater improvement than the C group, although the differences were mostly insignificant. The S + B group also reported greater improvement than the B group, but differences were mostly insignificant. Differences between B and C groups showed no consistent patterns. For children, B groups showed greater statistically significant improvement than C groups in behavior changes to reduce IAP exposure.

Health education and behavioral activities may have led to incremental IAP knowledge, but it was insufficient to convince households in B group to incur the full cost of a new stove. It may be that more intensive health education and behavioral activities continued over a longer period, or alternatively, if the cost of stove improvement were to fall, one might observe more benefits from such activities. It should be noted that the cost of the stoves for the B group was approximately one-quarter of per capita annual net income in rural areas.

Overall, the interventions had some effects in changing stove use habits, but the results were more consistent and had more statistical significance for S + B groups than for B group. Again, stove and ventilation improvement interventions may have facilitated IAP-related behavioral changes. One exception is Inner Mongolia, where the interventions were effective in improving IAP-related behavior in the B group. The interventions were generally less effective for B group than for S + B groups. This finding suggests that behavioral intervention alone is insufficient to change behavior or even awareness. This finding is consistent with others regarding IAP concentrations, which found no IAP benefits from behavioral interventions alone. This may reflect that people's cooking and heating behaviors, which are central to daily life, may be little affected by their knowledge and concerns about long-term health outcomes, especially where infrastructure and household economic status limit changes in fuels and stoves (Jin et al. 2005). Another possibility may be that behavioral change effects may not have been large enough to lead to observable improvement in pollution levels, whereas stove improvement resulted in larger, more measurable effects. As noted previously, the sample sizes for pollution measurements were small (20-30 per group), which limited the power of testing. If behavioral changes caused any changes in pollution levels, they may have been too small to be detected.

In terms of improving understanding of IAP-related knowledge among women, the interventions were effective in all S + B groups, but mostly ineffective in B groups, with the exception of Guizhou. As noted above, participation in stove interventions may have improved awareness of IAP-related knowledge. In the case of school children, the interventions were mostly effective, except for Gansu.

IAP-related Health Indicators

Many of the health effects of IAP exposure in rural China involve chronic conditions with heterogeneous definitions (Lan et al. 2002); however, this study was not designed to detect health benefits, which require substantially longer follow-up and more accurate diagnostic criteria. Because of the project's short time frame, rigorous collection of results and subsequent analysis were not feasible. But given the frequent health complaints by women in the study provinces (for example, headaches and lacrimation), we decided to include a set of symptoms to gauge any improvement in this area (Table 6.2, Annex 4.3). This section briefly evaluates the effectiveness of interventions by comparing symptoms change in intervention and control groups for each study province.

In Gansu, the differences in IAP-related health symptoms (for example, dyspnea, nasal mucus and eye irritation) between women in S + B and C groups were mixed and mostly insignificant. For children, S + B groups reported worsening symptoms compared with C groups, although the differences were insignificant. S + B groups reported less increase in symptoms than B groups, and the differences were mostly significant. For children under age five, changes in the incidence of symptoms of acute respiratory infection showed no consistent patterns for S + B or C groups. B groups reported mostly significant reductions in the incidence of all symptoms of acute respiratory infection. Heterogeneity of the project groups may have accounted for this contradictory result.

In Guizhou, with regard to IAP-related respiratory, eye and headache/dizziness symptoms, the differences between women in S + B and C groups showed no consistent pattern, while the B group reported greater statistically significant reductions than the C group for all symptoms. Urine fluoride results showed no consistent pattern. With regard to eye and nasal symptoms among children, both S + B and B groups not only reported less increases than the C group, but also less reduction in pharyngeal symptoms; most of the results were statistically significant. For children under age five, both S + B and B groups reported mostly greater statistically significant reductions in all symptoms of acute respiratory infection than C groups.

In Inner Mongolia, with regard to respiratory, eye and headache/dizziness symptoms among women, the B group had greater statistically significant reductions in symptoms than the C group. Lung function showed no consistent pattern. In terms of IAP-related eye, nasal and pharyngeal symptoms among children, the B group had statistically greater reductions for all symptoms than the C group. With regard to symptoms of acute respiratory infection, children under age five showed no consistent pattern.

In Shaanxi, with regard to IAP-related respiratory, eye and headache/dizziness symptoms among women, both S + B and B groups reported greater reductions than C group; however, only the differences between the S + B and C groups were statistically significant. In terms of urine fluoride, the S + B group reported greater significant reductions than did the C group. Differences between the B and C groups showed no consistent pattern. In terms of IAP-related eye, nasal and pharyngeal symptoms among children, S + B groups reported greater reduction than C groups, which were mostly significant. The B group showed no consistent pattern. For children under age five, with few exceptions, both S + B and B groups reported reduction in symptoms of acute respiratory infection post-intervention, and the increases were greater than those reported by the C group.

Summing up, the health effects of the interventions varied by province. Among women and children (eight to 12), they appear to have been more effective in Guizhou, Inner Mongolia and Shaanxi, and less effective in Gansu. In terms of symptoms of acute respiratory infection among children under age five, the interventions were more effective in Gansu and Guizhou, and less effective in Inner Mongolia and Shaanxi. Self-reporting of health data may have resulted in measurement error, as well as systematic bias (for example, those in the intervention group may have changed their reporting behavior after the health education program). Symptoms of acute respiratory infection among children under age five were obtained through evaluations by health professionals; but because of the short duration of monitoring, it is likely that only a small number of diagnosed cases were acute lower respiratory infection.

The short follow-up period for all health outcomes may have limited changes in symptoms which occur gradually or lag. In addition, heterogeneity among study groups may have been a serious problem in assessing health effects. In some cases, S + B groups reported significant increase in certain symptoms, while the C group showed either no significant change or reduced symptoms. It is doubtful that the interventions resulted in increased symptoms. Group-specific factors unrelated to the interventions may have affected the health of the respondents. Alternatively, the intervention program may have affected the reporting behavior of S + B and B groups differently from the C group.

Findings and Implications

Results demonstrated that heating stove interventions were effective in reducing IAP from the burning of coal and biomass fuels (Table 4.5). When energy was used for heating, fuel combustion occurred in a more stable pattern and with less intensity. Therefore, the new heating stoves, which separated the combustion chamber from the indoor environment and/or ventilated smoke outdoors, were effective in reducing IAP and were not sensitive to user behaviors (for example, new heated bed in Gansu and underground heating stove in Shaanxi). Because heating is the main energy use throughout much of rural China, well-designed and -constructed stove improvements can significantly reduce IAP exposure and associated disease burden.

Results of cooking stove interventions were more mixed because cookers modify combustion patterns actively and regularly, leading to relatively large fluctuations in combustion intensity. The inconsistent findings on pollution reduction in Guizhou may have been related to this factor because the same coal stove was used for cooking and heating (cooking was the primary use in March). Furthermore, a major aim of the interventions in Guizhou was to reduce exposure to Fluorine (F) deposited onto food dried or stored over the attic chimney. Thus, the interventions may have put less emphasis on the ambient concentrations of the three indicator pollutants used in this analysis. A small number of attic measurements demonstrated that reduction in concentrations of all three pollutants in S + B were about 10 times that in C.

No IAP reduction benefits resulted from health education and behavioral interventions alone, despite the relative extensiveness of the program. Introducing alternative stove handling behaviors (as part of the health education program) led to changes in specific behavioral indicators (for example, covering stove door or top after fuel is added), based on self-reported data; but these changes had no measurable benefits for indoor air quality. Two reasons account for this finding. First, awareness of health risks and interventions cannot lead to changes in fuel and stove choices without sufficient physical and financial access to alternative fuels and stoves. Second, the specific behavioral changes reported by participants may not have been sufficient to lead to reduced emissions, given the central role of cooking and heating in daily life. Nonetheless, health education can play a key part in more comprehensive intervention programs by encouraging the uptake and use of new technologies (for example, cleaner fuels and stoves) and reducing IAP exposure through specific routes (for example, bioaccumulation of F in food dried over fire).

One should also note the study's limitations. First, the relatively small sample size for pollutant measurements (owing to measurement costs) limited the statistical power of our analysis. However, one feature of the findings was consistency of reductions for different pollutants, seasons and locations for some provinces (for example, S + B in Gansu) versus inconsistent and opposite evidence on benefits in other cases (for example, B); sample size is less likely to have affected consistency of results.

Table 4.5: Summary of IAP Concentration Changes

	PM_4			CO			SO_2		
p-value	*≤ 0.05*	*> 0.05 and ≤0.1*	*> 0.1*	*≤ 0.05*	*>0.05 and ≤0.1*	*> 0.1*	*≤ 0.05*	*>0.05 and ≤0.1*	*>0.1*
December-January Measurement Period									
S + B									
Gansu									
Cooking Room			↓	↓					
Living/Bedroom	↓			↓					
Guizhou									
Cooking/Living Room			↓			↓			↓
Bedroom			↓			↓			↓
Shaanxi									
Cooking Room			↑			↓			↑
Bedroom	↓					↑	↓		
Living Room	↑					↑			↑
B									
Gansu									
Cooking Room		↑		↑					
Living/Bedroom			↑		↓				
Guizhou									
Cooking/Living Room			↑			↓			↓
Bedroom		↓				↓			↓
Inner Mongolia									
Cooking/Living/Bedroom			↓			↓			
Shaanxi									
Cooking Room			↑			↓		↑	
Bedroom			↓			↓		↓	
Living Room			↓			↓		↓	

		PM_4			CO			SO_2	
p-value	$\leq$ 0.05	> 0.05 and $\leq$0.1	> 0.1	$\leq$ 0.05	>0.05 and $\leq$0.1	> 0.1	$\leq$ 0.05	>0.05 and $\leq$0.1	>0.1
March Measurement Period									
S + B									
Gansu									
Cooking Room			↓			↓			
Living/Bedroom			↓			↑			
Guizhou									
Cooking/Living Room			↑			↑			↓
Bedroom			↑			↑			↑
Shaanxi									
Cooking Room			↓			↓			↓
Bedroom			↓			↑			↓
Living Room			↓			↓	↓		
B									
Gansu									
Cooking room			↑			↑			
Living/bedroom			↓			↓			
Guizhou									
Cooking/Living Room			↑			↑			↑
Bedroom			↑			↑			↑
Shaanxi									
Cooking Room			↑			↑			↑
Bedroom			↓		↑				↑
Living Room			↑			↑			↑

Note: $p \leq 0.05$ is statistically significant at 5 percent level, $p > 0.05$ and ≤ 0.1 is statistically significant at 10 percent level, $p > 0.1$ is statistically nonsignificant; ↓ = larger reduction or smaller increase, ↑ = smaller reduction or larger increase; S + B = stove plus behavioral intervention, B = behavioral intervention.

Second, with regard to the community randomization design used (to avoid or limit contamination of the C group by the health education intervention), differences in environmental and socioeconomic factors (even between townships in the same county) may have occurred, despite efforts to select similar villages and households. Such differences would mean that the study design is only partially randomized and that there may have been differential secular trends in pollution before and after interventions in various townships. For example, substantially higher biomass use for cooking in the S + B group in Guizhou may have influenced the IAP effects of stove interventions.

Third, day-to-day fluctuations in temperature or other factors which determine household energy use behavior may have resulted in variability in the number of stove use hours and, hence, pollution across measurement days. This variation would be equivalent to measurement error in "usual pollution" for each household and reduce the statistical significance of the findings. Converting pollutant concentrations to per hour stove use, based on the self-reported number of stove use hours each measurement day, did not change the findings.

Finally, the study did not include long-term follow-up on the benefits of the interventions. Over time, it is possible that user behavior would improve, leading to better performance for both interventions; at the same time, stove deterioration could lead to a reduction in the observed performance of the new stoves.

This study's findings are consistent with observational studies in China and Kenya.[64] The emerging evidence has two implications for scaling up intervention programs. First, stove programs must emphasize design and construction to ensure that solid fuel combustion is isolated from the living and working environment (to the extent possible) and is robust to user behavior. This, in turn, requires facilitated multiple purposes of energy use, including cooking and heating, and how they may affect stove performance and human exposure. Evidence on alternative stove limitations also means that sustained and robust reduction in IAP exposure requires strategies to initiate and disseminate alternative fuels. Since macroeconomic and infrastructure factors are likely to limit large-scale switching to petroleum-based fuels, an important area for future research is preprocessing of solid fuels into cleaner ones. The next Chapter discusses available options.

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[64] *Alternative cooking stoves have more variable performance than cleaner fuels; the stoves are affected by design, construction and maintenance; and ventilated heating stoves (China) have observed health benefits.*

5. Alternative Energy and Technology Options

Fei Yu, Zuzana Boehmova, Enis Barış and Majid Ezzati

The previous Chapter discussed the various technological IAP interventions which were tested as part of this project. Additional household energy use options have other environmental and economic implications. This Chapter discusses selected options, with emphasis on RE sources, as well as current trends in alternative energy generation, both worldwide and in China.

Overview

Energy is essential to meeting the most basic household needs, whether cooking, heating, lighting, or boiling water. Growing environmental concerns in both the industrial and developing world, combined with the sharp price rise in fossil fuels – particularly oil and natural gas – over the past few years, have increased interest in alternative energies for electricity generation and transport. Although alternative fuel sources still meet only a small percentage of global energy demand, the more commercially viable ones are growing rapidly. In addition, developing countries now emphasize the development of distributed power – localized power generation – driven by the necessity to provide relatively cheap and reliable power in the absence of developed electricity grids, which are expensive to build and maintain. This trend could have a significant effect on alleviating poverty and improving public health, as one chief obstacle to rural energy supply is the distance from power centers and insufficient energy infrastructure in these areas.

Although advanced (high-tech) energy innovation in developing nations is certainly needed, energy transformation in poor areas will take years to achieve and require substantial investment in technology R&D. Therefore, we also address simpler alternative energy options applicable to existing cooking and heating equipment in rural areas.

Global Energy Mix

In the near future, oil, gas and coal will continue to dominate the aggregate global energy markets; notwithstanding hydroelectric power, and the share of RE sources will remain relatively small. At the same time, there are outliers; for example, 77 percent of France's electricity is generated by nuclear energy, while 20 percent of Denmark's is derived from wind power (Parfit 2005). Around the world, coal (which remains abundant relative to oil and gas reserves) continues to dominate electricity generation; however, natural gas is making inroads. Moreover, solar power is being discussed as a potential solution to bring electricity to rural communities in the developing world which lack power and generators.

If oil and gas prices remain high, there will be additional incentive to diversify away from these fuels as primary energy sources. This, in turn, could spur technology breakthroughs that make alternative energy more attractive in terms of cost. In the meantime, both government legislation and market forces will determine the extent to which the energy mix changes over time. Currently, the three most commercially viable sources of alternative energy whose costs compare favorably with coal and natural gas are nuclear, hydropower and wind power. Other promising sources include solar, geothermal renewable biomass-based systems and modified coal.

Energy Technology Context in China

China's continuing economic growth, increasing energy needs and strained resources will affect its domestic and global energy markets alike, including worldwide fuel availability and pricing. The country's rapid growth in energy use will contribute to climate change and exacerbate environmental problems. At the same time, China's energy concerns are accelerating the development of alternative energy technologies, especially renewable or clean energy.[65] Under the 2005 Renewable Energy Law enacted last year, the government "encourages economic entities of all ownerships to participate in the development and utilization of renewable energy, and protects legal rights and interests of the developers and users of renewable energy on the basis of law." This law creates the regulatory framework for RE development, provides economic incentives and financial support for R&D and promotes construction of RE facilities through discounted lending and tax preferences.[66]

China is now beginning to utilize the country's massive flow of RE sources, from biofuels to wind and solar power. Exploitable onshore wind resources alone could provide 253 Giga Watt (s) (GW) of electric capacity, while offshore resources could provide three times that amount.[67] China is already the largest producer of solar thermal energy for hot water, boasting 60 percent of the world's installed capacity. And with the Renewable Energy Promotion Law, the government has committed to producing 15 percent of the country's power from clean energy sources by 2020.[68] Still, reaching that goal will require an ambitious level of public and private investment – up to Y 1.5 trillion (US$184 billion) by some estimates.

Although China is second worldwide in total energy consumption, electricity consumption per capita remains low (Figure 5.1); since 2002, the country has experienced annual electricity shortages, mainly in coastal cities. China's Eleventh Five-Year Plan (2006-10) sets the expansion of electricity generation capacity at about 8 percent per year.

With soaring oil prices, alternative energy becomes financially viable, although renewable sources currently represent only 6 percent of China's total energy consumption. By 2020, China's government plans to generate 18 percent of the country's energy consumption from renewable sources (Table 5.1).

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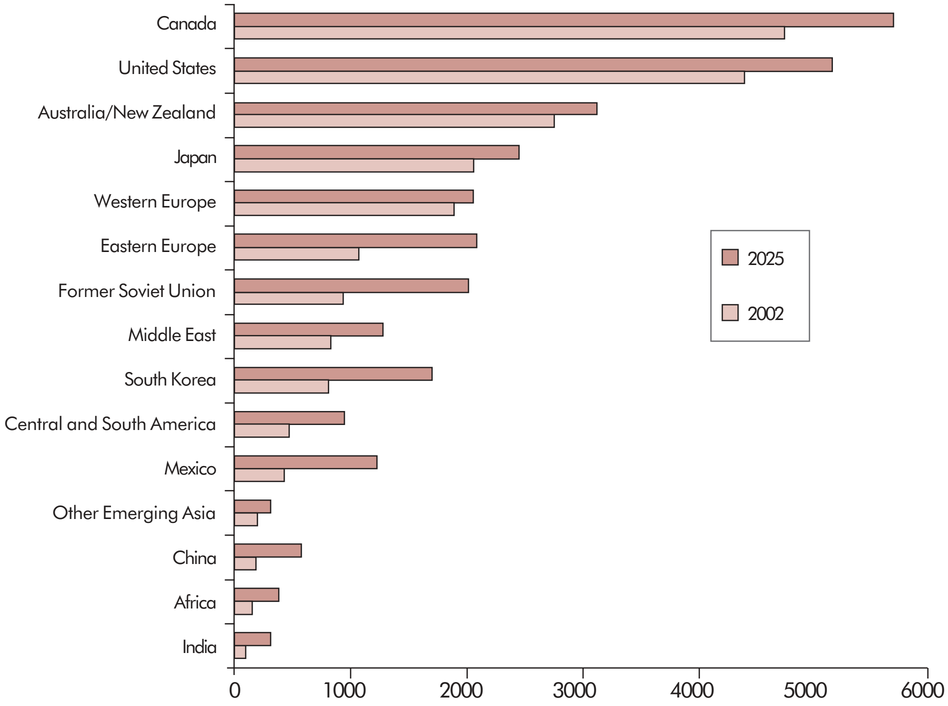
[65] *In a November 7, 2005 speech, President Hu Jintao noted: "Prioritizing the exploitation and use of renewable energy is the only way for the world to deal with its growing energy… China attaches great importance to the development and utilization of renewable resources, making them a key driver of economic and social development"; see Yinglin Liu, "China's Top Leaders Stress Importance of Renewable Energy" (available at www.worldwatch.org).*

[66] *Cong, Hu, "Legislature Passes Renewable Energy Bill."* China Daily, *March 1, 2005.*

[67] *"China's Wind Energy Potential Appears Vast," November 2005 (available at www.worldwatch.org).*

[68] *"China: World Bank to Help Scale up Use of Renewable Energy," June 17, 2005 (available at www.worldbank.org).*

Figure 5.1: Residential Sector Electricity Consumption by Country Group (per capita)



Source: EIA (2005).

Table 5.1: China's Increasing Renewable Energy Capacity

Renewable Technology	*2004*	*2020 (Projected)*
Hydroelectric Power	108 GW	290 GW
Wind	760 MW	30 GW
Solar Thermal	65 million sq m	300 million sq m
Solar Photovoltaic	65 MW	2 GW
Biomass	Development of 20 GW capacity	

Source: National Development and Reform Commission (Mid- and Long-term Development Plan for Rural Energy).

Alternative Energy Options for China

Over the next two decades, a range of advanced, alternative energy options relevant to China may become applicable to household energy use. These are described below.

Hydropower

Water-generated power, primarily from large-scale dams, accounts for about 20 percent of global energy production; of all the world's RE sources, hydropower is by far the greatest contributor. In 2004, global hydroelectric production grew 5 percent, with Asia representing half of that growth.[69]

Hydropower enjoys a number of advantages. In addition to sustainability, it can handle both seasonal and daily peak loads. At times of peak demand, water releases from the reservoir through a turbine, generating hydroelectricity; during periods of lower demand, excess electrical capacity can be used to pump water into a higher reservoir, storing electricity for later use.

The disadvantages of hydropower generated by large-scale dam projects are its potentially damaging effects on wildlife and downstream agriculture, possible displacement of local population and high GHG emissions compared to other renewable sources. Another drawback is the large amount of infrastructure required for household distribution.

Current hydropower growth is mainly in developing countries, including China, India and Iran. In addition to its enormous and controversial Three Gorges Dam project on the Yangtze River, China is developing other large hydroelectric projects. China's hydroelectric reserves stand at 700 million KW, 40 percent of its total conventional energy sources. Although China's hydropower exploitation potential ranks first in the world, its utilization ratio remains low (24 percent). Over the next 20 years, the country plans to utilize hydropower more rapidly; at the same time, the adverse environmental effects of large projects must be taken into account.[70]

Wind Power

After hydropower, wind power is far more developed than most other alternative energy industries. Over the past decade, wind technology has improved significantly; its importance has grown rapidly, especially in Europe, where political incentives to develop RE have been strong.

Wind power has many advantages. First, it is a clean and truly RE source. Second, it is scalable in that it can not only be used to generate power in a local area or even at an individual level; but it can also generate large amounts of power which can be added to an electricity grid system. Third, it is becoming more cost-competitive; wind farm construction cost is lower than that of many types of traditional power plants. Finally, in land-based wind farms, once the wind towers are built, the surrounding land area can be used for agriculture or other purposes.

The most significant disadvantage is that the wind required to drive the turbines can be intermittent and does not always blow when electricity is needed. However, rapid expansion of the wind energy industry is likely to continue as new and improved turbine technologies begin to generate more electricity, thereby resolving past problems which limited power generation. Newer technologies which reduce noise and environmental pollution can lessen the negative effect on bird populations[71] Perhaps, more importantly, wind power can accelerate the move toward distributed energy – energy supplied on a local scale rather than a national grid – which may greatly benefit remote rural communities, especially in developing countries. A key question is how many turbines are necessary to provide sufficient energy for a household's energy needs, depending on their cooking, heating and other requirements.

In China, wind power currently accounts for only 0.17 percent of the total installed energy

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[69] *"BP Statistical Review of World Energy," 2005 (available at www.bp.com).*

[70] *"Priority Given to Efficient Hydropower."* China Daily, *October 29, 2004.*

[71] RPS Energy News *(available at www.rpsplc.co.uk).*

capacity, but its potential is immense. According to some estimates, China's electricity generated by wind energy could reach 14 percent of global wind energy output by 2020.[72] While off-grid wind power can produce clean, relatively cheap power for villagers, the effect of these units on China's energy sector is small compared to what grid-connected wind farms could achieve. Several regions, including Inner Mongolia, already have rural wind energy programs which play an important role. But lack of developer incentives has kept the wind power market far from achieving its potential.[73]

Solar Energy

Solar power, available in many part of the developing world, is a renewable natural resource whose energy conversion process is emission-free. Solar energy is of two types: Photovoltaic (PV) and solar thermal. Solar energy technology is scalable, meaning that it can be used for domestic heating purposes or large-scale commercial electricity generation. Yet, mainstreaming of solar power is still a long way off; currently, solar power accounts for less than 1 percent of the global energy.
Unlike wind power, broad scale use of solar energy is more expensive than fossil fuels. China is well endowed with solar energy resources. Nearly 67 percent of the territory receives more than 4.6 Kilowatt-Hour Per Day Per Square Meter (KWh/m$^{2)}$ solar radiation per day.[74]

Photovoltaic

Solar PV cells, which involve converting solar power into electricity, have become more widespread in powering houses and businesses in some regions; as with wind power, technology developments have greatly reduced costs. In recent years, global PV production has grown at roughly 20 percent annually; some studies forecast that, within the next decade, costs could decline to about US$1.50 watt (W), reportedly the borderline cost at which this energy source would be competitive with other technologies (Kammen 2004). Broader-scale adoption will likely depend on technological breakthroughs which can reduce the cost of PV and that of other fuels. Adoption may also be contingent on increased government support. Beyond cost, the greatest barriers to increasing large-scale solar power generation are the amount of land required for massive electricity production, and the intermittent nature of the energy source (solar systems cannot work at night or in bad weather).

PV power generation could play an effective role in serving many remote rural areas of China. The cost of producing PV power in rural China would be far less than that of developed countries.

Solar Thermal

In the developing world, solar thermal energy has been used in many small cities and rural households to heat water for washing, crop drying, space heating and solar cooking. In the developed world, it is used in millions of domestic hot water systems. It is most applicable in areas which feature high solar insolation – the total energy per unit area received from the sun – such as the Mediterranean Region or Australia.

On a small scale, solar ovens are relevant for rural cooking needs. The cookers include an insulated box made of wood, metal, plastic, or cardboard, whose open top is covered with one or two glass plates. Light enters through the glass and

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[72] *"Wind Energy Has Huge Potential." Xinhua News Agency, May 15, 2004 (available at www.china.org).*
[73] *Debra Lew and Jeffrey Logan, "Incentives Needed to Energize China's Wind Power Sector" (available at www.pnl.gov).*
[74] *World Energy Council (available at www.worldenergy.org).*

is absorbed and reflected by foil-covered walls as infrared radiation (heat). The glass top blocks the infrared rays, capturing the heat in the box. As long as the sun shines, food can be steadily cooked in pots on a bottom metal plate, and the oven can heat several liters of water or food to more than 300°C within an hour (Kammen 1995). The drawback of this technology is the issue of adaptability. Since the cooking process is significantly slower than the one using traditional fuels, preparing meals requires changes in planning and behavior. In addition, villagers have reported that the cooking process causes food to taste different than what they are accustomed to.

Currently, China, India and Japan control 75 percent of the market for solar thermal collectors and supplementary equipment.[75] To date, this emergent industry has concentrated principally on small-scale use.

Geothermal Energy

Derived from the earth's natural heat, geothermal energy is used to generate electricity and as a source of heat for direct use, such as space heating for greenhouses, aquaculture and with heat pumps. For heat production, hydrothermal (hot water and steam) resources are commonly used for district heating. Electricity generation from geothermal sources can occur at various temperatures (from below 100 °C to high temperature steam plants at steam temperatures above 300 °C).[76] For commercial use, a geothermal reservoir capable of providing hydrothermal resources is necessary. Usually located at depths of 1,000-4,000 meters and consisting of steam or hot water, natural steam or hydrothermal resources are easiest to exploit. Some 16 countries including China, the United States and Israel – now use geothermal energy for aquaculture. The main challenges to widespread geothermal use include high cost and technological issues: Drilling for new resources typically accounts for half the costs.[77]

LPG and Gaseous Fuels

Gaseous fuels, including natural gas, are among the cleanest household energy sources. Worldwide production of LPG (a derivative of natural gas and oil processing and crude oil refining) continues to grow at an annual rate of 2.6 percent, driven by increasing use in China, India and the United States.[78] In developing countries, LPG is a primary household cooking fuel. Together with kerosene, LPG is more energy-efficient than traditional biomass; but unlike kerosene, LPG produces significantly less air pollution and poses no risk of poisoning or fire. Therefore, substitution of traditional biomass fuels by LPG presents several advantages: 1) less air pollution when burned; 2) lower emissions of GHG pollutants when used in traditional stoves; and 3) reduced dependence on gathering of biomass fuels and, thus, less deforestation. Despite these significant potential advantages, the relative costliness of LPG makes it inaccessible to most of the world's poor (Smith, Rogers and Cowlin 2005). Similarly, in China, supplies of domestic natural gas (and oil) are limited. Since imported LPG prices track international oil prices, importing LPG is likely to continue to be costly in China;

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[75] *STP 2005: Solar Thermal Power, CST Concentrated Solar Thermal Energy (edition 1), 2005 (www.the-infoshop.com/study/abs32125-solar-t-power.html).*
[76] *U.S. Department of Energy (www1.eere.energy.gov).*
[77] *World Energy Council (www.worldenergy.org).*
[78] *World LP Gas Association,* Annual Report 2005 *(www.worldlpgas.com).*

therefore, it is not a viable alternative for poor rural areas.[79]

Modern Biomass

Modern biomass typically substitutes for conventional fossil-fuel energy sources. It includes forest wood and agricultural residues and biogas and biofuels from energy crops, including plant oils and plants containing starch and sugar. With regard to household energy, electricity generated via advanced conversion methods, such as production in biomass gasifiers, is especially promising. Worldwide, including the developing country context, biomass gasifiers are being used extensively. Other modern biomass-derived fuels include Hydrogen (H), ethanol from ligno-cellulosic biomass and methanol (wood alcohol), discussed in the next section. The competitiveness of these concepts depends, in large part, on the development of oil prices (Faaij 2006).

Advantages of Changing or Processing Fuels

In rural areas of many developing countries, access to technologically advanced or expensive alternative energy options remains limited. Given the severity of IAP in China and other developing countries, low-tech options affordable to poor rural communities are needed now. Under such conditions, the following become the best available alternatives: 1) improved combustion by altering or replacing cooking and heating devices; 2) change in fuel; and 3) preprocessing fuel (for example, biogas, coal gasification, briquettes, or cleaner coal). These options are discussed both generally and with special reference to China in the sections that follow.

Substituting polluting fuels with cleaner ones to meet cooking and heating needs should have an especially high priority (Zhang and Smith 2005). This is applicable to poor households, which will continue using traditional stoves but may be able to replace traditional solid fuels with ones that emit fewer indoor air pollutants. Among alternative fuel-cooker combinations are briquettes or pellets, kerosene, LPG, biogas, or ethanol. Some of these technologies have already had a significant effect on local patterns of energy use, economic activity and the environment. With respect to rural household use, several developing countries are conducting biofuel stove tests. The advantage is that biofuel is produced locally, often at competitive prices.

Biomass Preprocessing

While biomass fuels are likely to remain the chief energy source for most poor people, improved stoves and cleaner technology can reduce fuel requirements and lessen adverse health and environmental effects. Because biomass and bioenergy rely on locally available resources, they hold advantages for alleviating poverty and mitigating climate change. Furthermore, the energy production stages of more sophisticated biomass-based products provide potential local employment opportunities. Regarding land degradation, if bioenergy stocks are planted on degraded soil, they have the prospect of bringing long-term improvements to land quality and fertility. Growing biomass can also provide various ecosystem services, including the halting of soil erosion and preservation of the hydrological cycle (Kammen, Bailis and Herzog 2002).

Another possible improvement in biomass technology can be attained by compacting loose fibrous or granular material into briquettes or pellets. Standardizing size and moisture content, and radically amplifying energy density, can greatly enhance fuel efficiency. Although examples of competing successfully against charcoal or fuelwood are rare, in Kenya, one private company has succeeded in briquetting charcoal dust

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[79] *In 2001, LPG imports accounted for nearly 33 percent of consumption.*

on a commercial scale (Kammen, Bailis and Herzog 2002).

Role of Charcoal

Although more polluting than clean fossil fuels, charcoal burns cleaner and produces less IAP than wood and raw biomass (Bailis, Ezzati and Kammen 2003). Compared to fossil fuels, charcoal is easier to transport and distribute on a large scale since expensive infrastructure, including refineries and processing, is not required. However, current inefficient production methods, which use minimal technical inputs, are harmful to the global environment and destructive to forests. Thus, without land management policies which promote sustainable production, the public health benefits from household charcoal use would come at a large environmental cost. Technological and policy tools for switching to sustainable harvesting, as successfully demonstrated in Brazil and Thailand, are necessary to reduce potential adverse effects, including GHG emissions (Ezzati et al. 2004). In this way, charcoal can become a more suitable option for households for which clean burning cooking fuels, such as ethanol and natural gas, are inaccessible or unaffordable.

Fuel Conversion Technologies

A variety of procedures can convert solid biomass into cleaner energy forms (for example, gases, liquids and electricity); these include methods to generate bioethanol and biodiesel, which are highly relevant in developing countries. Another pertinent technology relies on synthesized hydrocarbons (Fischer-Tropsch liquids), produced from a gaseous feedstock, including gasified biomass. This mixture of CO and H is called a synthesis gas (syngas), and the resulting hydrocarbon products are refined to produce the desired synthetic fuel. Two cooking fuels which can be produced from biomass via the Fischer-Tropsch synthesis are synthetic LPG and kerosene (Larson and Jin 1999).

Another option is tri-generation technology, which combines clean cooking fuel, hot water for heating and electricity from corn stalks and uses microturbines in a bioenergy experiment. Unfortunately, its disadvantage is low market viability and risk of acute CO poisoning. Specific environmental policies encouraging technological strategies, such as crop residue-based tri-generation, would be necessary (Henderick and Williams 2000).

A technology which converts coal into a clean fuel, known as Dimethyl Ether (DME), provides an opportunity for coal-rich areas. Produced from any carbonaceous feedstock, including natural gas, coal, or biomass, DME's characteristics as a household fuel resemble those of LPG (Larson and Yang 2004); it can be used for various sectors, including household cooking and heating. But using DME as a fuel requires that it be produced at low cost in large quantities. Other technologies involving the preprocessing of coal, a procedure applicable mainly to coal-abundant China, are discussed in the next section.

Applications in Rural China

Advanced biomass and coal technologies are particularly relevant to this project as these two fuels account for nearly 100 percent of the household energy used for cooking and heating in rural China. In this context, converting solid fuels to clean liquid and gaseous fuels offers significantly greater potential than certain types of improved stoves to reduce harmful emissions. Even when successful, improved stoves still emit concentrations of indoor air pollutants well above standards set for outdoor air in developed countries (Ezzati and Kammen 2001).

In recent years, China has encouraged greater use of coal and discouraged biomass (with the exception of dung), on the basis that biomass use degrades the soil and contributes to deforestation. However, advances in clean, Renewable Energy

Technologies (RETs) could call this policy into question. If used efficiently and sustainably (that is, through rotational planting), biomass is less harmful to the environment than coal. Furthermore, if biomass technologies continue to advance to the point where clean fuels are produced at a cost competitive with traditional fuels, the energy/health/environment equation would change in favor of more, not less, biomass use (Larson and Jin 1999).

Improving Stove Fuel Quality

To improve fuel quality and reduce dangerous emissions resulting from cooking and heating, so-called "honeycomb" coals have been used in urban and rural Chinese households for decades. The shape of the coal enables a more effective and balanced air supply, leading to increased combustion efficiency (Zhang and Smith 2005). Another means by which high efficiency and low emissions can be achieved is fuel pelleting. These technologies improve portability and increase efficiency at low emission levels (Zhang and Smith 2005).

In addition, given China's extensive coal reserves, use of coal-derived DME could present a promising option for producing clean synthetic fuels from coal. A production technology, known as oxygen-blown gasification, generates synthesis gas from coal; though not yet used in China's energy sector, it is already well established in the country's chemical processing industry (Williams 2001).

For coal-derived gases to become a commercially viable fuel in China's poor rural households, technology testing would be needed. China's first commercial DME fuel production plant was constructed in mid-1990s. A recent study suggests that national policies which ensure that Independent Power Producers can sell electricity to the grid, would facilitate growth of a coal-DME industry in China. While coal gasification technologies can be successfully implemented, they are not competitive at the present cost. But this technology might become more interesting financially should the prices of other fuels continue to rise (Larson and Yang 2004).

Bioenergy Options

Rural China offers numerous opportunities to better utilize bioenergy resources. According to some estimates, about half of the total crop residues could be available for energy use after serving as fertilizer, animal fodder and industrial feed. The current role of crop residues in household energy use is mostly in inefficient, high emission equipment (Zhang and Smith 2005). With regard to synthesized hydrocarbons (Fischer-Tropsch liquids), China has sufficient agricultural residues to produce enough liquid fuels to meet the needs of a significant fraction of its rural population; but this process is capital-intensive (Fischer 2001). In short, biomass technologies leading to clean fuels for rural household cooking and heating, have not advanced to the point of mass commercialization.

Fluoride-Sulfur Neutralization

As discussed in Chapter 1, 201 counties in China have coal deposits with high fluorine content, affecting 35,000 villages and nearly 34 million people. Furthermore, coal containing As is high in some provinces, including Guizhou and Shaanxi. Throughout China, low-quality coal deposits have high SO_2 content. Fluoride-sulfur elements can be reduced by washing coal or adding fixing agents. The washing procedure is expensive, ineffective in removing organic Fluoride, requires considerable amounts of water and may result in secondary contamination through wastewater. The preferred technology is to add fixing agents to the coal to capture Fluoride and S during combustion, capturing the elements' residue in the coal ash instead of releasing it into the atmosphere. Fluoride-Sulfur fixing additives include CaF_2

(Calcium Fluoride), CaF_2-CaO-Al_2O_3 (Calcium-Fluoride-Calcium Oxide-Aluminum Oxide), $Ca(OH)_2$ (Calcium Hydroxide), and CaF_2-CaO-SiO_2 (Calcium Fluoride-Calcium Oxide-Silicon Dioxide), which decompose at a higher heat than normal coal fire temperatures.

Laboratory and industrial-scale tests in China indicate that addition of the equivalent of 5 percent Lime (CaO) to coal significantly reduces Fluoride emissions and SO_2 emissions to a lesser extent. Experimentation with various additives, including shell-calcium, has been conducted to improve SO_2 results.

In Guizhou and Shaanxi, where coal is the primary household fuel, the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, has conducted Fluoride-Sulfur fixing tests. One such test involved coating bone coal with Calcium-radical, Fluoride-fixing absorbent (dolomite or limestone). In another test, the same fixing agent was added to powdered coal, which was

Table 5.2: Comparison of Indoor Air Concentrations of Fluoride after Fluoride-fixing Treatment

Group	*F Content (mg/m^3)*	*Student t Test*
Briquette Added with Absorbents (a)	0.086 ± 0.041	a:b
Control Briquette (b)	0.184 ± 0.091	$P < 0.05$
Bone Coal Coated with Absorbents (c)	0.046 ± 0.029	c:d
Control Bone Coal (d)	0.324 ± 0.259	$P < 0.01$

Table 5.3: Comparison of Indoor Air Concentrations of Sulfur Dioxide after Fluoride-fixing Treatment

Group	*SO_2 Content (mg/m^3)*	*Student t Test*
Briquette Added with Absorbents (a)	0.16 ± 0.07	a:b
Control Briquette (b)	1.17 ± 1.09	$P < 0.05$
Bone Coal Coated with Absorbents (c)	0.28 ± 0.19	c:d
Control Bone Coal (d)	1.13 ± 0.49	$P < 0.01$

Table 5.4: Comparison of Indoor Air Concentrations of Respirable Particulate Matter after Fluoride-fixing Treatment

Group	PM_{10} Content (mg/m^3)	Student *t* Test
Briquette Added with Absorbents (a)	0.310 ± 0.235	a:b
Control Briquette (b)	0.588 ± 0.867	$P>0.05$
Bone Coal Coated with Absorbents (c)	0.139 ± 0.035	c:d
Control Bone Coal (d)	0.311 ± 0.185	$P< 0.05$

Source: Tables 5.2, 5.3 and 5.4 Chinese Center for Disease Control and Prevention.

subsequently formed into coal briquettes. Preliminary results showed that coating bone coal with the fixing agent reduced indoor Fluoride concentrations by 86 percent. Adding the fixing agent to coal briquettes reduced Fluoride emissions by 74 percent. Levels of SO_2 and RPM were also reduced, although less significantly (Tables 5.2-5.4).

More widespread applications of the Fluoride-Sulfur fixing agents in Ziyang County (Shaanxi) and Longli County (Guizhou) yielded similar results. The low costs of the fixing agent and process offered a cost-effective way to reduce the health risk from indoor air concentrations of Fluoride and Sulfur Further tests are required to verify this conclusion.

Alternative Cookers and New Stove Design

In some developing countries, simple cookers (in addition to the solar cookers described above) and electricity-powered equipment play an important role. In China, small-scale digesters, using animal and human waste as feed material, are widely used. In Nepal, more than 80,000 households use CH_4 from biogas digesters for cooking; the most popular model ($6m^3$) costs US$300, one-third of which is subsidized.

Unlike fuel preprocessing, which occurs outside the household, another solution is to change the nature of the fuel directly in the cooking and heating area. This method utilizes gasifier stoves, which are designed to promote secondary combustion, achieve high combustion efficiency and, therefore, use biomass more efficiently. While increased combustion efficiency is easily accomplished using small electric blowers, certain models are designed to spur combustion via a natural draft.

In China, biomass gasifier stoves commonly have two levels. The biomass is consumed in two stages: 1) it is ignited in the lower part of the stove, where it produces gas under anaerobic combustion at a certain temperature; and 2) the gas is conveyed to the second level, where an open flame is used for heating and cooking (Figure 5.2). These stoves exhibit higher heat efficiency and lower pollutant emissions. Crop residues, branches and other biomass may be used as fuel. Still in the early stages of market development, biomass gasified stoves may provide an important advance over traditional heating and cooking stoves.

Figure 5.2: Biomass Gasified Stoves

Gasified stoves for cooking. *Gasified stoves for heating and cooking.*

Source: Chinese Center for Disease Control and Prevention.

China is also developing coal gasified stoves, which are now available. As in the case of biomass gasified stoves, heat efficiency is higher than traditional biomass stoves or air-circular coal stoves. However, their cost (RMB ¥450-600) is more than twice that of traditional stoves. With increased units and movement along the experience curve, the cost should become more competitive and affordable in poor rural areas.

Scaling Up Issues

Behavior, economic resources, community and regional infrastructure (both physical and institutional) all bear on the likelihood that alternate household fuels and improved technologies will be adopted at the local level. Table 5.5 summarizes the barriers to adopting selected technology options.

Although the health, welfare and environmental benefits of cleaner fuels are substantial, the long path from R&D to market transformation requires support (Chapter 6). In the 80s and early 90s, for example, China's National Improvement Stove Program was supported extensively by district-level research, training and education/promotion programs; major subsidies were extended to counties, households and technical institutions (Sinton et al. 2004). In Inner Mongolia,

Table 5.5: Household Fuel Choices and Barriers to Adoption

	Energy Source						
Selected Determinant of Adoption	*Electricity*	*Bottled Gas*[1]	*Kerosene*	*Charcoal*	*Coal*	*Fuelwood*	*Crop Residues, Animal Dung*
Equipment Costs	Very high	High	Medium	Low	Low-medium	Low or zero	Low or zero
Nature of Payments	Lumpy	Lumpy	Small	Small	Small, zero if gathered	Small, zero if gathered	Small, zero if gathered
Nature of Access[2]	Restricted	Often restricted, bulky to transport	Often restricted in low-income areas	Good, dispersed markets and reliable supplies, though prices and supplies can vary seasonally	Good, dispersed markets and reliable supplies	Good, dispersed markets and reliable supplies, though prices and supplies can vary seasonally	Variable; depends on local crops and livestock holding. High opportunity where residues are used as fodder and/or dung is used as fertilizer

[1] Includes LPG, butane and natural gas.

[2] Nature of access refers to the ease with which households can choose the fuel if they are willing to pay for it, determined by physical and institutional infrastructure (Ezzati et al. 2004).

Sources: Kammen, Bailis and Herzog (2002) and Ezzati et al. (2004).

introduction of some 130,000 small-scale wind energy systems was achieved through careful planning and creation of an effective regional and local infrastructure for manufacturing, sale, maintenance and training. Limited government subsidies helped to support individually purchased household systems.

In Kenya, by contrast, local and international agencies promoted introduction of the improved-efficiency ceramic stove, known as the Kenya Ceramic Jiko, largely by supporting research and refinement rather than through direct subsidies for commercial stove production and dissemination. Expanded numbers and types of manufacturers and vendors led to increased competition, spurring innovations in materials used and production methods, thereby overcoming initial design flaws and high costs. Today, there is a widespread wholesale and retail network for the Kenya Ceramic Jiko, and prices have fallen to a third or less of their original price.

Kenya has been at the forefront of PV systems without significant aid, subsidy, or other support (Kammen 2002). More typically, however, R&D support in developing countries is low and unreliable, reflecting tight fiscal realities. Moreover, training venues, technology and information exchange and technology standards are usually lacking.

China has achieved widespread rural dissemination of RETs (and fuel efficiency technologies more generally) through a mix of national standards, R&D support and encouragement of local innovation and entrepreneurship (Kammen et al. 2002; Lu 1993). Still, that IAP persists as a serious health risk and that rural households continue to rely on cooking and heating stoves lacking the most rudimentary fuel efficiency measures (for example, flues) indicate the gap yet to be closed.

What Factors Undermine Adoption?

The chain from R&D of alternative household energy technologies to market transformation is long, and many factors thwart progress along the way. R&D tends to be underfunded, in part, because industrial countries have largely resolved the problems of household IAP and domestic cooking and heating requirements. In addition, alternative household energy technologies have the characteristics of a public good; thus, it is difficult to appropriate costs to end users or narrow the benefits to those who buy the results. As such, private returns are less than social ones, resulting in suboptimal investment in basic R&D. The consequences of this market failure are that significant social benefits (including health and environment) remain unrealized. The problem is especially acute in developing countries, where other pressing priorities (for example, infrastructure, education and primary health services) often take priority.

The chain is further weakened by persistent poverty. In rural areas of many developing countries, per capita income is one-third (or less than) already low national averages. Fuel gathering in poor rural areas, largely done by women and children, is undervalued. Thus, affordability is an important constraint to adoption of new alternatives.

Entrenched use of traditional technologies also blocks adoption of alternatives; continued reliance on traditional energy options is common in areas with low population densities and deficient infrastructure (for example, roads, electricity and communications). Community and regional energy infrastructure (both physical and institutional) are important, but often overlooked, components of successful intervention programs (Ezzati et al. 2004). New energy technologies, including cleaner coal, are difficult to sustain without marketing and delivery systems which facilitate household access. Accessibility (and quality) of energy resources is a key determinant of energy use (Jiang and O'Neill 2004). Trained workers to construct, install and maintain new energy technologies are also essential (Jin et al. 2006).

In industrial countries, small-scale decentralized energy systems are typically outside the purview of academic or research institutes. Such initiatives as the Renewable Energy Policy Project and Renewables for Sustainable Village Power Program are helping to fill the information gap.[80] Still, sustained investigations of the technical, socioeconomic, health, environmental and policy issues surrounding household energy technology alternatives are scarce. In developing countries, the capacity for such investigations is limited (von Schirnding et al. 2001; Ezzati and Kammen 2002a, 2002b).

International Lessons

Despite differing circumstances and determinants, common lessons can be drawn from international experience in advancing and promoting technologies for household energy use (Kammen 2002):

- Technologies should be researched and tested under local conditions;
- Mechanisms are needed to overcome the initial cost barrier (for new technologies, cost is invariably high for the first units installed);
- Decisions must be made on the role of market-based mechanisms and where to direct grants and subsidies (that is, to research, infrastructure, training, interdisciplinary capacity-building and local sustainability versus directly to users);
- The involvement of local institutions; rationalization of taxes and tariffs; incorporation of quality control and standards mechanisms; and facilitation of financing, warranties, training and other mechanisms are needed to protect and encourage end users; and
- The focus should not be limited exclusively to poor rural populations, who are least able to pay for new energy technologies; these technologies achieve greatest market penetration in areas where fuels are purchased rather than collected (for example, straw and fuelwood), as fuel savings are realized in direct monetary terms rather than time saved.

Regarding the last point, poor rural communities may not attract viable ESCOs whereby private companies or government utilities enter into contractual agreements with community members to provide them hardware or services. Thus, the hardware or services offered must be affordable, match local preferences and be capable of being operated and maintained by households and local technicians. Establishment of revolving funds or other mechanisms may be needed to assist households in meeting the upfront costs of technical hardware. Fee-for-service energy companies are another option; but to reiterate, the incentive to include poor rural communities as clients may be limited.

Research Direction

China's National Improvement Stove Program and follow-up activities have provided extensive

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[80] *Information on the Renewable Energy Policy Project and Renewables for Sustainable Village Power Program is available at www.repp.org and www.rsvp.nrel.gov, respectively.*

information on dissemination approaches, institutional arrangements and local technology development strategies (Lu 1993). However, further research is needed on the technical, economic, political and commercial factors which bear on energy R&D and market transformation. The obstacles facing rural households and potential ESCOs, in particular, must be better understood.

It should be noted that China's National Improvement Stove Program was not designed as a pro-poor program (Sinton et al. 2004). It was cofunded with the counties; since participation depended on local officials' willingness to devote limited resources, the program was implemented mainly in better-off counties. In rural China, the types of institutions, market policies and training opportunities needed to develop community or household-scale energy services are largely absent. International development assistance, combined with supportive policy, regulatory and institutional measures at all levels of government, is necessary to create the conditions conducive to energy innovation and implementation.

Finally, since household demand for energy use interventions appears relatively weak (Larson and Rosen 2002), further research and information are needed on IAP health risks and the potential benefits of interventions. Long-term studies are required to determine sustainability, as well as energy, health and environmental effects.

6. Summary and Recommendations

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The issue of IAP provides an important opportunity to design and field-test community-based solutions to mitigat its health, social, environmental and economic effects. The study presented in this report was designed to add to the foundation of knowledge which will enable the development of sustainable IAP interventions customized to local conditions. Because IAP exposure is a major health risk requiring public and community involvement, effective interventions must encompass both technological and behavioral elements.
To the best of our knowledge, this study represents the first community-based trial designed to test the combined effect of technological (improved stoves and better ventilation) and behavioral (health education and behavioral changes) interventions in rural settings under actual conditions of program implementation. The study's empirical evidence of the relative effectiveness of these interventions will contribute to a better understanding of how household energy technology, health education and behavioral interventions interact in reducing exposure.

This Chapter briefly summarizes the study, offers implications of the main findings and highlights design limitations. It then draws together lessons which can be applied to future projects and suggests recommendations and areas requiring further research and testing.

Study Summary

As discussed in Chapter 5, review of earlier household energy projects in China and elsewhere revealed that most efforts were directed primarily at energy efficiency and reduced use of biomass fuels, not reducing IAP or exposure. For example, the Chinese National Improved Stoves Program of the 80s, prompted by environmental conservation objectives, focused on achieving greater fuel efficiency to meet cooking requirements.

Since 1980, rural China's residential energy use has increased significantly; over the past six to eight years, solid fuel consumption has increased about 30 percent. As indicated in Chapter 1, biomass now accounts for 55 percent of rural household energy use, while coal – whose importance as an energy source is accelerating – accounts for 34 percent. These trends, together with rural households' continued reliance on traditional, poorly ventilated cooking and heating stoves; low-quality coal; and inappropriate customs (for example, smoke-drying of corn and other produce) have meant that IAP continues as a major health risk. This is especially true for the severely poor, who can least afford stove alternatives, better quality fuels and medical attention when afflicted by respiratory and other IAP-related illnesses. Thus, reducing household exposure requires practical, carefully designed stove technology alternatives and health education and behavioral interventions.

Approach

As discussed in Chapter 3, the study in four Chinese provinces focused on reducing IAP as characterized primarily by three indoor air pollutants: respirable particles, CO and SO_2 (the role of fluoride in dried food was also considered). Baseline data were collected to provide an understanding of day-to-day, seasonal and spatial variations in pollution. The technological, housing and behavioral determinants of exposure were also documented. This information was used to design stove and behavioral (health education) interventions tailored to local conditions in the four study provinces (Gansu, Guizhou, Inner Mongolia and Shaanxi). In addition, surveys were conducted on IAP-related knowledge and behavior and selected IAP-related health indicators for women and children in the study households.

The interventions took into account the energy needs for cooking and heating, housing characteristics, fuel use and sociocultural factors (for example, food-types and storage methods). Between March and October 2004, alternative stoves were designed and tested for efficiency under both controlled conditions and actual household use to assess the role of user behavior in stove performance. Health education and behavioral interventions, including dissemination of educational materials through village discussion groups and visits to model homes, were also implemented in the project areas.

Post-intervention data were collected approximately one year after the stove technology and behavioral interventions were completed. In December 2004 and March 2005, indoor levels of respirable particles, CO and SO_2 were again measured using methods identical to those employed to collect the baseline data. Follow-up surveys were also conducted on the efficiency of household energy use, knowledge of the IAP health risk, behavioral changes and IAP-related health indicators.

Implications of Findings

Analysis of baseline and post-intervention data demonstrates relatively consistent evidence that stove interventions had IAP benefits when heating was the main energy use. The evidence for cooking stove interventions was less consistent (Gansu was the only province indicating benefits in the cooking room). Fuel consumption for heating (versus cooking) is generally more stable and less intense, compared to cooking stoves. Therefore, the indoor air quality benefits of heating stoves are less susceptible to compromise from stove-handling behavior if the combustion is well separated from the living and sleeping areas and/or smoke is ventilated outdoors (for example, new heated beds in Gansu or underground heating stoves in Shaanxi) were effective in reducing IAP. The results of cooking stove interventions were more mixed because users modified combustion patterns more regularly (including large fluctuations in combustion intensity). To better succeed, cooking stove interventions require greater modification of user behaviors (for example, proper use of flues, wood size and dryness, and frequency of stoking) and/or stoves which are robust to these behaviors.

Introduction of alternative stove-handling behaviors, as part of the health education program, led to increased IAP-related knowledge and changes in specific behavioral indicators based on self-reported data. With regard to indoor air quality, however, no measurable IAP benefits resulted from health education and behavioral interventions alone, despite the extensive nature of the program (Table 6.1).

Table 6.1: Change in Selected Knowledge and Behavior Indicators

	Gansu				*Guizhou*				*Inner Mongolia*		*Shaanxi*			
Indicator	S + B		B		S + B		B		B		S + B		B	
Significant at 5% Level	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
Knowledge														
Women														
Sources of IAP														
Cooking	↑		↓							↑				
Heating	↑			↓					↓					
Smoking		↑		↑										
Health Impact of IAP		↑	↓		↑		↑							
IAP Control Methods														
Improving Stove		↑		↑						↑	↑		↓	
Improving Ventilation		↑	↑									↑		↑
No Smoking Indoor		↑	↑							↑				
Understanding Rate of Dental Fluorosis					↑		↑							
Children														
Source of IAP			↓					↑	↑					↑
Pollutants			↑					↑					↑	
Health Impact			↓				↓		↓				↑	
IAP Control Methods			↓				↑		↑				↑	
Etiology of Dental Fluorosis												↑		
Coal Smoke							↑						↑	
Food Contaminated with Fluorides							↑						↑	
Measures for Dental Fluorosis Prevention							↑						↑	
Behavior														
Women														
Close Stove Door When Using	↑			↑					↑					
Using Shorter Wood	↑			↑								↑		↓
Watering Ash Before Removing		↑		↑	↑			↑	↑					
Opening Windows in Cooking (often)	↑			↓	↑			↑	↑		↑			↓
Children														
Every Day or Often in the Kitchen				↓				↓					↓	
Get Out and Avoid Smoke							↓						↓	

Note: S + B = stove plus behavioral intervention, B = behavioral intervention; Y = yes, N = no.

These findings may reflect that people's behavior with regard to cooking and heating – activities central to daily life – may be little affected by their knowledge and concerns about long-term health outcomes, especially where infrastructure and household economic status limit opportunities for switching fuels and stoves (Jin et al. 2006). The findings may also reveal the need to improve the design of behavioral interventions. Provincewide characteristics may not sufficiently reflect local conditions, including differing fuel-types, cooking and heating combinations, housing structures and household behavioral patterns. Interventions tailored to household needs must consider the diverse characteristics of household energy use and the time and economic constraints faced by low-income rural households.

Study Limitations

With regard to study design, one must distinguish between inherent limitations, based on intrinsic properties of the design, and limitations caused by incomplete or variant field application and data collection practices.

In this study, one design limitation involved the small number of households subject to detailed post-intervention measurements of indoor air pollutants (about 30 for each province). This constraint, necessitated by the need to conserve costs and minimize household disruption, affected the statistical power of the analysis. One feature of the findings, however, was consistency of reductions across pollutants, seasons and locations for some provinces (for example, S + B in Gansu) versus inconsistent and opposite evidence on benefits in other cases (for example, B); the consistency of results is less likely to have been affected by sample size.

A second design limitation concerned selection of the study groups. Factors and practical considerations such as political will, location and population size, which affect program implementation, were used to select the study groups, with intervention and control groups selected at the community versus individual household level. Community randomization also avoided or limited the contamination of control group by health education intervention. Despite efforts to select similar villages and households, there may have been differences in environmental and socioeconomic factors, even between townships in the same county. These differences would mean that the study design is only partially randomized and that there may have been differential secular trends in pollution before and after interventions in different townships, or differential potential response to interventions. An alternative analysis of the same data could use matching techniques, with households matched on sociodemographic and other factors, to reduce the exogenous effects on the results.

Other practical considerations were caused by incomplete or variant field application of the study design and data collection properties, including use of scientific measuring equipment within a compressed period of time and, hence, the need for concentrating tests within selected townships (the baseline phase was further affected by the SARS outbreak which limited travel by the project team). For example, day-to-day fluctuations in temperature would have affected the results by increasing random variation in stove use.[81]

A third limitation of the study design involved the time span between baseline and post-intervention data. It is possible that over time user behavior improves leading to better performance for both interventions; on the other hand, stove

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[81] *Converting pollutant concentrations to per hour stove use, based on the self-reported number of stove use hours each measurement day, did not alter the study results.*

deterioration may lead to a reduction in the observed performance of new stoves. Further, within this one-year period, the health effects could not be adequately assessed; thus, the analysis focused instead on health symptoms, proxy indicators of reduced exposure and lung function tests. Information on changes in selected health indicators was made available to provide background for future studies (Table 6.2). In addition, much of the health indicators among women and older children (eight to 12 years of age) were self-reported, which has a number of shortcomings.

Finally, the study was not designed to evaluate the local environmental effects of the stove and behavioral interventions. In China, rural energy use accounts for 12.7 percent of the total energy consumption, and solid fuels account for 90 percent of the rural household energy use, with important implications for ambient air pollution and climate change. Harvested

Table 6.2: Summary of Changes in Selected Health Indicators in Comparison with Control Group

Indicator	*Gansu*				*Guizhou*				*Inner Mongolia*		*Shaanxi*			
	S + B		B		S + B		B		B		S + B		B	
Significant at 5 % Level	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
Women														
Respiratory	↑		↑			↓	↓		↓		↓			↓
Eye		↓	↑			↑	↓		↓		↓			↓
Headache/Dizziness		↑	↑		↑		↓		↓		↓			↑
Children 8-12														
Eye		↑	↑			↓	↓		↓		↓			↓
Nose		↑	↑		↓		↓		↓		↓			↓
Pharynx		↑	↑		↑		↑		↓		↓		↓	
ARI for Children under Five														
ARI Symptoms		↓	↓		↓		↓			↓	↑		↓	
Cough, Phlegm, Hemoptysis		↑	↓		↓		↓		↓		↑		↑	
Dyspnea		↓				↓		↓	↑		↑			
Nasal Discharge	↓		↓		↓		↓			↑	↑		↑	
Pharynx		↓	↓		↓		↓			↑	↑			↑
Eye		↑		↓		↓		↓		↑				

Note: S + B = stove plus behavioral intervention, B = behavioral intervention, and C = control. Y = yes, N = no; ARI = acute respiratory infection.

sustainably and burned under ideal conditions, biomass as a fuel is largely neutral in terms of GHG emissions (Smith, Uma and Kishore 2000; Bailis, Ezzati and Kammen 2003). In many developing countries, however, biomass stoves are typically inefficient, resulting in incomplete combustion. When the products of incomplete combustion are considered, biomass cooking stoves often have considerably worse GHG effects than such fossil fuels as kerosene and LPG, even if biomass is 100 percent renewably harvested (Edwards et al. 2004).

While the alternative biomass stoves introduced in this study improved combustion and overall efficiency under controlled conditions (less fuel was needed to boil and vaporize a given quantity of water), IAP measurements focused on pollutants harmful to health. Rural households' increased reliance on coal, combined with their sharp increase in energy use (30 percent since 1998), has meant increased sulfate aerosols and other forms of ambient air pollution with wide local, regional and even global implications. The environmental advantages of biomass over coal were not a subject of this study.

Lessons Learned

The following lessons may be drawn from this study:

- Interventions designed to reduce IAP must also fulfill the purposes of energy use, itself affected by climatic, ecological and sociocultural factors. Even the small study subset of China's rural population exhibited much diversity in housing characteristics, stove designs, ventilation systems, fuel use, levels of indoor air pollutants and household behavioral patterns. Interventions must be tailored to meet local needs and conditions. They must also be affordable and sustainable;
- Provincial- and community-level energy infrastructure, both physical and institutional, is an important consideration for IAP intervention programs (for example, transport access to fuel sources free of toxins and availability of skilled workers to design and install improved stoves). The study included extensive training programs for stove workers to ensure successful stove interventions;
- For much of China's population, heating is an important source of IAP exposure, and is likely to respond to stove interventions. The main reason is that heating can be separated from the living space, and does not require constant user adjustment (unlike cooking);
- Behavioral interventions alone appear ineffective in lowering IAP exposure, as changes in stove use, ventilation and other habits affecting IAP levels and exposure are insufficient. Furthermore, knowledge of IAP health risks alone is insufficient to change fuel or stove purchasing decisions, especially if alternative stove technologies are costly, not readily available, or are perceived as such;
- Although the study found that the IAP benefits from health education and behavioral interventions were insignificant, two potential benefits from health education justify their continued use as part of more comprehensive intervention programs. First, health education may have long-term benefits in the form of encouraging the uptake of other interventions – such as cleaner fuels and less expensive alternative stoves which may become available in the future – or affect how these technologies are used. Second, health education may help reduce IAP exposure through specific routes, even if ambient concentrations remain unchanged. For example, the study indicated that children subject to health education interventions in Guizhou and Shaanxi became more aware of the risk of bioaccumulation of fluorine from smoke-dried corn, peppers and other foods. Detailed data on household time activity budgets could help identify behavior which may lead to larger IAP reductions;

- Fuel alternatives for traditional biomass cooking stoves and coal heating stoves need further R&D. Cleaner fuels, including gasified biomass (Larson and Jin 1999), could substantially reduce IAP and related health risks. The Chinese Ministry of Agriculture has established an effective nationwide network to develop rural RE sources, including gasified biomass, solar energy and microhydropower. Gasification of biomass has been the key element of the Ministry's rural Renewable Energy Development Program. Since 2000, it has invested 3.4 billion RMB in the program, which has involved 26,344 villages and 3.74 million rural households. To date, 18 million rural households have methane-generating pits, and the Ministry plans to increase the number of households to 39 million (15.82 percent of the total rural households) by 2010;
- While continued reliance on locally available fuels is important for rural households, reflecting concerns of affordability and infrastructure limitations, advances in clean technologies applied to these fuels are increasingly relevant (Kammen, Bailis and Herzog 2002). Clean energy alternatives for cooking stoves are an important consideration in reducing IAP. Electricity, available in most rural areas, accounts for only a small percentage of energy use (mainly for lighting). Oil and natural gas are also alternatives, but their cost and limited availability in most rural areas, combined with demand for industrial and urban use, mean that biomass and coal will remain the dominant energy sources in rural China for the foreseeable future. In this context, conversion of solid fuels to clean liquid and gaseous fuels for cooking stoves offers the potential for significant reduction in harmful emissions. Public sector support is required for conducting R&D on these new technologies and reaching the economies of scale necessary to make them affordable to low-income households; and
- IAP studies and interventions require interdisciplinary expertise and multisectoral/cooperation, reflecting the complex interrelationships between household energy use, IAP levels, household exposure, health and environmental effects, and other factors. A comprehensive approach to household energy use and IAP exposure is needed. The Chinese Ministries of health, agriculture and environment have become more aware of the health effects of IAP. However, the issue must be further mainstreamed into the policy making process of the ministries concerned, and interventions should be packaged to reduce multiple risk factors.

Policy and Program Recommendations

The options for promoting the sustainable introduction of clean energy technologies are closely tied to developing countries' capacity for energy research, development, demonstration and deployment. Beyond the critical lack of funding is the paucity of training venues, technology and information exchange and technology standards. In addition, microcredit to foster locally designed and implemented commercialization efforts are systematically lacking. Moreover, research is lacking on the relationship between RE projects and the socioeconomic contexts in which they are embedded. All too often, projects are planned, implemented and evaluated based on unexamined assumptions about local conditions and the projects' socioeconomic consequences.

Meeting these challenges entails overcoming market failures, which cannot be resolved by private enterprises alone. Scaling up and improving the sustainability of interventions require better assessment of the supply and demand for alternative energy technologies and evaluation of the policies and programs which can optimally increase intervention coverage with a high degree of community effectiveness.

Need for Public Intervention

A public good is such that consumption of it by one individual does not preclude its use by other individuals. Its two main features are nonrivalrous consumption and nonexcludability. This concept contrasts with that of a private good, whose consumption precludes consumption by others (Mas-Colell, Whinston and Green 1995). While access to clean water and sanitation is widely recognized as a set of environmental health-exposure indicators, and these are commonly cited as measures of indicators of poverty and measures of ill health, the levels of water-related hygiene could also be parallel to indicators of household air quality-related hygiene. These potential indicators could be correspondingly defined as access to clean fuel and access to ventilated combustion technology (World Bank 2002). Therefore, it is necessary to apply lessons from water supply and sanitation experience to community-based approaches to stoves programs. We conclude that parallels between IAP and sanitation interventions are strong and assume that indoor air quality is a local (intrahousehold) public good, with substantial welfare gains. However, one must distinguish between direct and active public interventions (for example, stove distribution) and indirect interventions (for example, tax subsidies to manufacturers or tax cuts to consumers who purchase better quality stoves).

In particular, due to nonrivalrous consumption, it is difficult to price use of the information in a way which reflects marginal cost. Because of nonexcludability, it is difficult to exclude use of the information by households unwilling to pay for it. Information related to IAP health risks, therefore, has characteristics of a public good. Without public sector intervention, too little information would be made available to households. While the study indicated that baseline awareness of IAP-related health risks was high, at least among younger and better educated women, the opportunity costs of these risks, in terms of illness and lost income, may be poorly understood. As a follow-up step, setting and enforcing standards for fuel and heat efficiency are necessary, as are setting guidelines for indoor air quality.

Research and Development Support

The public sector also plays an important role in supporting R&D of household energy use alternatives. Basic and early stages of applied research also have characteristics of a public good, and require public sector support to ensure the socially desired level of investment. This is especially the case concerning energy use for rural households in developing countries. Their governments lack the resources to pursue such R&D, while industrial countries have made the transition to clean fuels and are no longer concerned with IAP (Ezzati et al. 2004). Resolving the IAP problem in developing countries has parallels with the Global Alliance for Vaccines and Immunization (GAVI), which addresses poorer countries' inability to provide child vaccines. A public/private alliance, GAVI accelerates the development of new vaccines and technologies through its support of R&D. The alliance includes vaccine manufacturers and research institutes. For only US$30 per immunized child, many lives are being saved. Without this global effort, some 2-3 million children would die each year from vaccine-preventable diseases. Such institutional approaches are needed to bring technology to the poor (Sachs 2002).

Role of Subsidies

The potential role of RETS and clean fuels in transforming rural residential energy use in developing countries is enormous. However, the transition will only be realized if energy projects and policies are evaluated and implemented based on their overall social, economic, environmental and public health merits. The lock-in effect of established energy services and infrastructure weighs against introduction of new technologies. Subsidies for existing systems or fuels exacerbate the problem.

On the other hand, subsidies which support introduction of new energy technologies may be needed to spur progression along the learning curve and help offset initial production and distribution costs before economies of scale become operational. Furthermore, the tendency of poor households to progressively discount future benefits and heavily weight present costs (hyperbolic discounting) suggests public intervention, particularly if significant externalities (for example, public health costs) are associated with this tendency (Cutler, Glaeser, and Shapiro 2003); otherwise, households and communities at large would tend to underinvest in measures to reduce IAP exposure. In turn, this would discourage the development and introduction of new energy technologies, warranting some form of government intervention to better approximate the socially optimal level of investment.

Support for Skill Development and Training

Beyond technology, the public sector needs to support development of human capital related to household energy use. This applies to education generally, including sensitizing students to the IAP problem, as well as to the more specialized fields of engineering, economics, public health, environmental science and other subjects critical to research on IAP and household energy use alternatives. At a practical level, training is needed to create a pool of skilled technicians capable of properly installing and maintaining stove and ventilation systems and adapting stoves to new fuel alternatives. One would expect the private sector to function effectively in providing such services once the technology and infrastructure hurdles had been surmounted; however, market flaws, such as the free rider problem, might again require government intervention or encouragement.
In developing countries, technicians skilled in household energy use are usually in short supply. Training may be relatively costly for private enterprises, and the returns low, especially if the training is lost to competitors through labor transfers. Provision for systematic training, possibly through some form of public/private sector partnership, is required. The Chinese Ministry of Personnel could be the relevant authority to set qualification standards and help provide training.

Fuel and Stove Standards

National and local area technology (for example, fuel and stove) standards are yet another requirement in addressing the IAP problem. The government of China has begun setting energy efficiency standards for household appliances, and a mandatory labeling system for energy using appliances has been introduced. China's medium- and long-term energy development program (to 2020) includes energy conservation and fuel diversification measures. Stricter standards for energy efficiency of buildings are being enforced in urban areas; to date, these standards do not apply to rural buildings.

Standards are necessary to reduce information asymmetry between producers and consumers. In a developing country context, where competition may be limited and regulatory provisions minimal, absence of standards could result in producers providing misleading information. Requiring producers to meet verifiable standards of fuel efficiency and emissions helps consumers determine value for expenditure. In this way, the government can help reduce information asymmetry and provide a means for market signaling. However, standards for cooking and heating stoves must be carefully designed. The relationship between cooking and heating functions must be reflected in the standards, which should not act as barriers to entry for new stove manufacturers and distributors.

Standards must also reflect diversity of consumer demand, which reflect differing circumstances of household incomes, fuel availability behavioral characteristics and customs, housing structures and other location-specific factors. Whether households adopt and use alternative fuels and stoves will depend on the ease of accessing these alternatives and their cost. It will also depend on household perceptions and valuation of the IAP health risk and benefits to be gained from reducing it. Household demand for technology will further be affected by intrahousehold variation in risk/benefit perception and access to resources.

Facilitation of Private Sector Responses

Since alternative stoves and cleaner fuels are private goods, it could be expected that the marketplace could fairly determine their prices through competition among suppliers and distributors. Consumer choice is exercised simply by deciding whether to buy the alternative stove technologies. Of concern are the impediments or possible barriers to their provision and purchase. Severe poverty in rural areas is perhaps the main barrier, explaining continued reliance on rudimentary stove and ventilation systems despite the pervasiveness of IAP. As the China IAP study demonstrates, in certain cases, the cost of nonsubsidized alternative stoves may equal to a high percentage of net household income, which typically is subsistence level. Rural households have limited or no access to credit; even if they decide that the net benefits of the alternative stoves would be positive, they may simply lack the necessary funds. Microcredit facilities are needed in such circumstances.

Despite poverty and lack of financial means, China's rural population is large, and evidence of consumer-based experimentation with alternative stoves and fuels would be the expected market response, especially given the improvement in rural incomes over the past three decades. Furthermore, given the market's large size – even though dispersed over wide areas – economies of scale should be quickly realizable. Supply-side impediments, however, may include the risk of failure to capture the expected Rate of Return from investment in experimentation (or adaptation of foreign technology), caused by copying by others (Hausmann and Rodrik 2002). Research is needed on why market mechanisms appear unresponsive to the IAP problem. As this study shows, health education alone is insufficient to lower IAP exposure; it is a necessary complement to strengthening the demand for new household energy technologies. Market dysfunctionalities may warrant tax or other incentives which raise investment in household energy technologies to a more socially optimal level.

Welfare, Preventive Health Care and Poverty Reduction

The case for greater public sector action in addressing IAP-related health risks in developing countries has a broader logic. Health is fundamental to enh4ancing the lives of people and the freedom they enjoy. A sick person may cripple a household and greatly limit its range of real opportunities, undermining substantial or positive freedom (Sen 1999). Thus, it is often more effective, in the promotion of substantial freedom, to invest in public programs which provide access to inexpensive heath assistance (preventive health care) than to divide the allocated funds among those who happen to be sick. Furthermore, empirical studies show that health improvements provide a significant boost to economic growth in developing countries (Bloom and Canning 2000). Health, like education, is a fundamental component of human capital. IAP, as a major cause of mortality and morbidity in rural areas of China and other developing countries, should become a more serious priority than has been the case to date.

The goal of poverty reduction underscores this priority. Despite rapid economic growth in China, more than 100 million people continue to suffer from severe poverty. Nearly 30 percent of these severely poor are impoverished due to illness or injury.[82] Furthermore, a high percentage of rural households lives close to the poverty line, is highly susceptible to illness and lacks access to health care services.[83] Again, IAP should be a priority concern.

Suggestions for Future Work in Research and Development

Further research and testing are required in the following areas:

- Better understanding of the seasonal patterns of IAP exposure and how stove and behavioral interventions may affect exposure; coupled with this, a clearer distinction is needed between IAP emissions from heating versus cooking, stoves and purposes;
- Monitoring of stove performance and user behavior over time; particularly needed is testing the degree to which proper stove and ventilation maintenance can contribute to reduced IAP exposure and improved IAP-related health indicators (Sinton et al. 2004);[84]
- Effects of alternative stoves on the amount of fuel used and their local/global environmental effects;
- Review of the supply-and-demand factors critical to achieving high quality technological advances in household energy use, recognizing the affordability limitations of rural households;
- Review of the respective roles of the private and public sectors in addressing the IAP problem, recognizing market imperfections and government weakness in developing countries;
- Review of training, standards and other specific elements needed for effective intervention programs;
- Analysis of the practicality of focusing public interventions on supporting poor rural households, in light of the need to move along the learning curve and gain economies of scale before new technologies reach affordability by the poor;
- Cost-effectiveness analysis of intervention options, including microcredit and commercial, private sector led initiatives (Easterly 2006);[85]
- Cost-benefit analysis of intervention program; welfare benefits and costs of IAP interventions should be evaluated;[86] and
- Analysis of how gender issues and intrahousehold gender disparities influence household technology choices, and how these are affected by education and literacy levels.

In conclusion, IAP should be a priority concern in poor rural areas of China, where a high percentage of households is susceptible to respiratory and other IAP-related health risks and lacks access to adequate health care. This study has documented the effects of household stove and behavioral interventions for reducing IAP concentration levels in rural China, with health indicators as the outcome of interest. It did not document the energy savings or reduction in GHG emissions from these interventions; but potential gains in these areas suggest that benefits from the government's involvement in reducing IAP could extend well beyond health.

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[82] *Government of China, Ministry of Health, Statistics and Information Center, 2004.*

[83] *United Nations Development Programme, China Human Development Report, 2005.*

[84] *Sinton et al. (2004) found that, good stove maintenance were negatively correlated with childhood asthma and adult respiratory diseases.*

[85] *The Shell Foundation is experimenting with a market-based approach to the problem of indoor smoke. Microenterprises are being encouraged to produce and distribute improved stoves, adapting them to consumer wants and relying on cash sales to consumers, including payments in goods.*

[86] *Health benefits could be addressed by determining the level of benefits necessary to just the cost of the interventions, then assessing their degree of reasonableness. Welfare benefits should include energy conservation and associated savings in time and labor for gathering fuel and the improved productivity of the rural labor force and hence potential for higher household incomes. Environmental benefits should also be evaluated. Costs include the international assistance and budgetary funds used to support IAP projects, as well as the private costs incurred (for example, alternative food-drying techniques). The Economic Internal Rate of Return (EIRR) for IAP projects should be greater than the social opportunity cost of capital (approximately 12 percent in real terms). Sensitivity analysis would likely indicate that EIRR estimates for IAP projects are heavily influenced by IAP measurement levels, which are difficult to gain free of econometric "noise."*

Annex 1
Project Implementation Schedule

Project Initiation (December 2002-February 2003):

- Project launch conference; technical workshop, training of trainers and explanation and promotion for project partners;

- Pilot field visits to determine project county and township sites and household groups according to agreed-on selection criteria; pilot surveys with small samples of households;

- Establishment of local lead and working groups for project implementation;

- Pilot sampling of IAP for design of evaluation technique; and

- Assessment of local stove market and design of initial stove improvement and market development interventions.

Baseline Surveys/Initiatives (March 2003-April 2004):

- IAP monitoring (indexes included RPM, CO, SO_2 in indoor air and fluorine and arsenic traces in air, coal, food, drinking water and soil);
- Baseline data on energy use/fuel consumption and stove-types;
- Health questionnaire survey (data collection on general household situation and health status of family members);
- Health examinations (lung function, eyes, nose and throat, fluorosis and arseniasis and urine testing of women and children);
- Pyrological tests of heat efficiency and IAP emissions for alternative household stoves to improve design; and
- Preparation of health education materials aimed at IAP control and stove improvement in accordance with local culture, tradition and economic circumstances.

Implementation of Interventions (May 2004-December 2004):

- Proposed stove improvement devices for various areas; conducted large-scale stove/ventilation intervention; conducted post-intervention inspection;
- Implementation of public health education at project sites using multiple approaches and focused on behavioral changes;
- Pyrological tests, comparing improved and original stoves;
- Stove market development (including knowledge dissemination and technical training of local stove entrepreneurs, measures to lower production costs and increase quality and mobilizing local enterprises to participate in the project); and
- Local capacity-building in controlling IAP through workshops, training of local personnel in IAP monitoring and stove technologies and knowledge dissemination.

Postevaluation and Reporting (January 2005-November 2005):

- IAP monitoring, postmonitoring as the same households in baseline study;
- Evaluation of health education;
- Evaluation of women and children's health status;
- Status of stove market development;
- Status of local capacity-building; and
- Evaluation of project management.

Fieldwork:

IAP Monitoring

IAP baseline studies were conducted in March and December 2003 in Gansu, Guizhou and Shaanxi provinces and in December 2003 in Inner Mongolia. Evaluation studies were conducted in December 2004 and March 2005 in Gansu, Guizhou and Shaanxi provinces and in December 2004 in Inner Mongolia.

Health Education/Behavioral Activities Surveys

Health Education/Behavioral Activities Surveys and general health surveys were carried out in April 2003 (baseline) and April 2005 (evaluation).

Household Energy Interventions

Stove (2004)	
Gansu	May-November
Shaanxi	May-December
Guizhou	June-October
Inner Mongolia	June-October

Health Education (2004 or 2004-05)	
Shaanxi	May-December
Inner Mongolia	June-October
Gansu	May-January
Guizhou	June-February

Annex 2
Project Partner Organizations

Central level

Foreign Loan Office, Ministry of Health (Contract Holder)

The FLO (formerly World Bank Loan Office) was established in 1983 under supervision of the Bureau of Foreign Affairs and Department of Planning and Finance. As part of the institutional reform of 1989, the Office was renamed and its responsibilities were expanded. Since 1992, the Office has been categorized as an enterprise, rather than a government department. Its 39 staff members manage health loan projects. Major responsibilities include coordinating health projects supported by loans from international financial institutions; health loans from bilateral governments and nongovernmental agencies; grants which finance and supplement loan projects; interaction with international fund-raising and project-implementing institutions and organizations in support of health sector development in ethnic minority, marginalized and impoverished areas; management of project supported by foreign capital; project-management services, including finance, procurement, technical assistance and operational research; domestic and overseas training services; and business and enterprise development through project cofinancing or joint ventures.

The Office uses a three-pronged approach in foreign capital utilization. It borrows from World Bank, while seeking grants from various sources to soften World Bank/International Bank for Reconstruction and Development(IBRD) loans.
In addition, the central government increases investment in priority health problems; provincial-, district-, and county-level governments may also allocate counterpart funding.

Institute for Environmental Health and Related Product Safety, Chinese Center for Disease Control and Prevention

The Institute for Environmental Health and Related Product Safety, Chinese Center for Disease Control and Prevention, established in May 2002, is based on the former Institute of Environmental Health and Engineering and Institute of Environmental Health Monitoring, Chinese Academy of Preventive Medicine. The Institute has seven administrative and 12 technical departments, with more than 260 faculty and staff, including more than 60 senior researchers.

The Institute’s research focus includes indoor air quality, drinking water quality, environmental chemical pollutants, environmental microorganisms and health effects of electromagnetic radiation. Major responsibilities are providing scientific evidence of and technical support for formulating laws and hygiene standards on environmental health and product safety and advising government decision makers on environmental health issues. The Institute also monitors environmental health factors (for example, air, water, soil and solid waste) and assesses construction projects from a hygiene perspective. In addition, it conducts premarket, environmental safety evaluations of new techniques and products; collects environmental health information and preventive care statistics; and participates in community-based, environmental health Promotion

Huaxi School of Public Health, Sichuan University

Huaxi School of Public Health is one of China's most respected academic institutions in the public health field. The school consists of 15 departments with 284 staff members (25 professors, 51 associate professors and 98 lecturers). University departments include health statistics, epidemiology, environmental health and health economy. Doctoral and masters programs focus on toxicology, child/adolescent and maternal/child health, public health and public administration. The total number of full-time students exceeds 1,400. The school is a member of the Health Economy Research and Training Network, established by the Ministry of Health, Ministry of Finance and World Bank.

Provincial level

Foreign Loan Office, Provincial Public Health Bureaus

The Foreign Loan Office, Provincial Public Health Bureaus undertakes activities using health-related World Bank loans and foreign government loans and grants. The Office's main responsibilities are to prepare program proposals and final summaries of projects and their implementation, coordinate counterpart fund-raising, compile annual project plans and provincial work plans in accordance with project objectives, prepare supervisory visits, and negotiate with partner organizations to confirm technical schemes and resource allocation for operational implementation.

Provincial Centers and Offices:
  Center for Disease Control and Prevention (Gansu)
  Center for Disease Control and Prevention (Guizhou)
  Office of Project Administration (Inner Mongolia)
  Office of Project Administration (Shaanxi)

County level

Public Health Bureau in Districts, Townships and Counties

At the county level, public health bureaus (part of the county government) are in charge of health-related issues. The number of staff members ranges from 30 to 60. Bureaus include multiple departments (for example, health policy, disease control, legal supervision, finance and foreign loans). Main responsibilities are preparing and implementing health guidelines and regulations, supervising implementation of health development plans, undertaking surveillance of infectious and endemic diseases, establishing certified public standards for medical workers, organizing assistance for emergency situations and implementing health education and technology development.

Center for Disease Control and Prevention in Districts, Townships, and Counties

Local branch offices of the central Center for Disease Control are staffed by 20-60 personnel. Departments include offices of endemic disease and tuberculosis control. Major responsibilities are establishing and implementing health education plans and an expanded county immunization program, managing responses to epidemics and public heath issues (for example, iodine deficiency, fluorosis, Kaschin-Beck disease and intestinal parasite control) and conducting surveillance of environmental health. The centers implement regulations under the Statute for Infectious Disease Control on treatment of sexually transmitted diseases, including HIV/AIDS. Centers are equipped with X-ray machines, vapor phase color spectrometers, atomic absorption spectrophotometers and atom fluorometry and enzyme-linked apparatuses.

Country Bureaus and Centers:

Public Health Bureau and Center for Disease Control (Huixian County, Gansu)

Public Health Bureau and Center for Disease Control (Guiding County, Guizhou)

Public Health Bureau and Center for Disease Control and Health Care Station (Helingeer County, Inner Mongolia)

Public Health Bureau and Center for Disease Control (Hanbin District, Ankang City, Shaanxi)

Township level

Community Hospitals, Townships and Counties

The community hospitals' responsibilities include child immunization, maternal and child health activities, endemic control in precincts and implementation of various tasks determined by the health administration department and township government. Hospitals have 10-20 staff members and both outpatient and inpatient departments (about 10 beds). Medical equipment is usually limited.

Community Hospitals:

Yinxing, Jialing and Mayan (Huixian County, Gansu)
Xinpu, Xinba and Dexin (Guiding County, Guizhou)
Xindianzi and Dahongcheng (Helingeer County, Inner Mongolia)
Hongshan and Shizhuan (Hanbin district, Ankang City, Shaanxi)

Annex 3.1
Provincial Statistical Overview

Statistic	*Gansu*	*Guizhou*	*Inner Mongolia*	*Shaanxi*
Economic Performance				
GDP (billions of yuan), 2003[1]	130.5	135.6	215	239.9
GDP Growth Rate (%), 1996-2000[1]	9.2	10.1*	10.0	9.3*
GDP per capita (yuan), 2003[1]	5,022	3,603	8,975	6,480
Urban[1]	11,651	8,573	14,658	13,233
Rural[1]	2,928	2,042	4,740	3,258
Per capita, Net Rural-household Income (yuan), 2003[1]	1,673.0	1,564.7	2,267.6	1,675.7
Consumption				
Per capita Expenditure, Urban (yuan)[2]	5,299	4,949	5,419	5,667
Per capita Expenditure, Rural (yuan)[2]	1,337	1,185	1,771	1,455
Food (% of total)[2]	43.8	57.0	41.3	39.4
Medicare (% of total)[2]	7.2	4.0	7.0	7.4
Housing: Average Number of Rooms by Household, 2000[3]	3.89	2.21	1.9	3.02
Energy				
Total Energy Production (10,000 tons of sce)[1]	2,854.5	5,829.5	8,428.6	5,848.5
Coal (% of total)[1]	83.0	96.0	97.2	71.6
Total Energy Consumption (sce)[1]	3,068.4	3,725.7	5,190.1	3,447.9
Coal (% of total)[1]	92	63	93.47	68.9
Demographic Trends				
Total Population (millions), 2003[1]	26.03	38.7	23.8	36.9

Statistic	*Gansu*	*Guizhou*	*Inner Mongolia*	*Shaanxi*
Annual Population Growth Rate (%),1990-2000[1]	1.3	0.8	1.0	.9
Rural Population (% of total), 2000[4]	76.0	76.1	57.3	67.7
Population Under Age 15 (% of total), 2000[3]	26.9	30.2	21.2	24.9
Human Development Index 2003[2]	0.675	0.639	0.738	0.729
Health Services				
Health Agencies (no.)[1]	1,1201	6,499	6,859	11,831
Hospitals (no.)[1]	382	390	450	813
Beds (no.) per 1,000 People, 2003[5]	2.2	1.5	2.6	2.6
Practicing Physicians (no.) per 1,000 People, 2003[5]	1.4	1.0	2.1	1.7
Basic Medical Insurance Coverage (% of population)[2]	5.6	3.5	10.6	8.2
Hospitalized Delivery Rates (%), 2002[2]	59	31	83	80
Health Indicators				
Urban Life Expectancy at Birth (years), 2000[2]	75.5	73.9	74.1	75.9
Male[2]	74.0	71.4	71.9	74.7
Female[2]	77.2	76.7	76.5	77.2
Rural Life Expectancy at Birth (years), 2000[2]	67.2	64.7	68.8	69.3
Male[2]	66.5	63.5	67.5	68.1
Female[2]	67.8	66.2	70.4	70.6
Infant Mortality Rate (%), 2000[3]	50.9	67.9	31.0	31.7
County Infant Mortality Rate (%), 2000[3]	60.1	78.9	38.7	35.9
Male[3]	50.6	68.5	34.9	29.9
Female[3]	71.3	90.6	43.0	43.7
Under-five Mortality Rate (%), 2000[3]	9.7	15.6	6.0	6.1
County Under-five Mortality Rate (%), 2000[3]	11.1	17.8	7.3	6.7
Male[3]	9.4	15.5	6.7	5.7
Female[3]	13.0	20.5	8.02	7.9
Literacy and Enrollment				
Adult Illiteracy Rate (% age 15 and above), 2000[3]	19.7	19.8	11.6	9.8

Statistic	*Gansu*	*Guizhou*	*Inner Mongolia*	*Shaanxi*
County Adult Illiteracy Rate (% age 15 and above), 2000[3]	24.2	23.8	15.5	12.5
Male[3]	15.2	12.1	9.7	7.5
Female[3]	33.6	36.6	22.0	17.7
Primary School Attendance Rate (%)[2]	97.3	97	99	98.9
Junior High School Attendance Rate (%)[2]	91.6	87.8	90.1	94.2
Public Sector Finances				
Local per capita Income (yuan)[2]	342	328	590	488
Local per capita Expenditure (yuan)[2]	1,171	876	1,902	1,152
Public Expenditure on Education (% of total)[2]	17	19	20	15

[*] 2003 data.

Sources:

[1] *Provincial Statistical Yearbook 2003.*
[2] *UNDP, China Human Development Report 2005.*
[3] *Population Census 2000 (Province).*
[4] *China Population Statistical Yearbook 2001.*
[5] *China Health Statistical Yearbook 2003.*

Annex 3.2
County Statistical Overview

County (province)	*Huixian (Gansu)*	*Guiding (Guizhou)*	*Helingeer (Inner Mongolia)*	*Ankang (Shaanxi)*
Economic Performance				
GDP (10,000 yuan), 2003[1]	32,757	149,055	293,203	1,036,000
GDP per capita (yuan), 2003[1]	1,492	5,193	15,505	3,963
Net Rural Household income (yuan)[1]	1,697	1,568	2,672	
Housing				
Average Number of Rooms, By Household[2]	3.6	2.0	2.6	2.8
Demographic Trends				
Total Number of Households[1]	54,500	45,674*	51,688	750,126*
Total Population (millions), 2003[1]	0.219	0.258	0.189	2.613
Rural Population (% of total), 2003[2]	0.89	0.84	0.88	0.83
Population Under Age 15 (%), 2000[2]	24.3	29.3	20.8	26.8
Total Fertility Rate, 2000-05[2]	1.5	1.8	1.6	1.6
Health Services				
Sickbeds (no.) per 1,000 people[1]			1.2	1.9
Medical Technical Personnel (no.) per 1,000 people			0.1	2.8
Health Indicators				
County Infant Mortality Rate (%), 2000[2]	24.9	60.9	102.3	20.2[3]
Male	27.3	53.7	52.5	
Female	22.4	68.9	163.6	
County Under-five Mortality Rate (%), 2000[2]	5.6	13.9	19.6	24.6[3]

County (province)	*Huixian (Gansu)*	*Guiding (Guizhou)*	*Helingeer (Inner Mongolia)*	*Ankang (Shaanxi)*
Male	6.5	12.8	9.9	
Female	4.7	15.0	31.3	
Literacy and Enrollment				
Adult Illiteracy Rate (ages 15 and above), 2003[2]	15.7	13.3	21.2	19.0
Female[2]	21.1	21.3	30.7	25.1
Male[2]	11.0	6.1	12.8	13.6
Public-sector Finances				
Local per capita Revenue (yuan)[1]			697	155
Local per capita Expenditure (yuan)[1]		627	1,715	563

[*] *Census data, 2000.*

Sources:

[1] *Statistical Yearbook 2003 (County).*

[2] *Population Census 2000 (Province).*

[3] *Ankang City Women and Children's Development Status Report (www.akstats.gov.cn/news/ShowArticle.asp?ArticleID=459).*

Annex 3.3
Demographic and Socioeconomic Characteristics of Study Households and Respondents

Characteristic	*Gansu* *(n = 463)*	*Guizhou* *(n = 476)*	*Inner Mongolia* *(n = 323)*	*Shaanxi* *(n = 479)*
Gender of Respondent				
Male	4.3	30.9	35.9	35.9
Female	95.7	69.1	64.1	64.1
Age of Respondent				
Below 40	89.2	64.1	78.6	67.2
40-59	9.7	30.9	21.1	28.8
60 or Above	1.1	5.0	0.3	4.0
Education Level of Respondent				
Illiterate	19.0	34.5	25.7	36.3
Elementary	52.7	45.8	39.6	38.6
Junior High	25.7	17.4	26.9	21.7
Senior High	2.6	2.3	5.9	1.9
Junior College and Over	0.0	0.0	1.9	1.5
Number of Household Members				
Fewer than Four	13.0	19.2	84.8	17.7
Four to Seven	86.2	76.8	13.9	80.8
Eight or More	0.8	4.0	1.2	1.5
Family Annual Income in the Previous Year (yuan)[1]				
Less than 1,000	47.4	14.3	12.4	39.6
1,000-1,999	18.1	6.5	6.8	9.4

Characteristic	*Gansu* *(n = 463)*	*Guizhou* *(n = 476)*	*Inner Mongolia* *(n = 323)*	*Shaanxi* *(n = 479)*
2,000-2,999	19.1	28.3	13.6	26.3
3,000-3,999	8.5	18.4	10.2	9.6
4,000 or More	6.8	32.6	57.0	15.1
Family Annual Storage Income in the Previous Year (yuan)[2]				
Less than 1,000	45.6	68.1	10.8	40.7
1,000-1,999	26.2	10.4	17.6	19.6
2,000-2,999	18.3	10.0	18.0	22.4
3,000-3,999	5.5	3.8	18.6	9.9
4,000 or More	4.3	7.7	35.0	7.5
Rank Order Correlation of Family Income and Storage	0.310	0.472	0.301	0.260

[1] Exchange rate (2003-04) of 8-8.5 yuan = US$1.

[2] Respondents' estimated value of foods and other agricultural products families produced and consumed at home or stored in the previous year.

Note: Numbers in Table represent % households or respondents; n = number of observations.

Source: Jin et al. (2006).

Annex 3.4
Technical Design for Measuring IAP Concentrations

Respirable particles were measured according to the protocol of the National Institute for Occupational Safety and Health (NIOSH protocol 0600), which was designed to capture particles with a median aerodynamic diameter of 4 mm (PM_4). Samples were collected using a 10 mm nylon cyclone equipped with a 37mm diameter poly-vinyl-chloride (PVC) filter (pore size 5μm supplied by SKC Inc., U.S.) at a flow rate of 2.5 l/min. Air was drawn through the cyclone preselectors using battery-operated constant flow pumps (Model PCXR8 supplied by SKC Inc., U.S.). All pumps were calibrated before and after each sampling day, using a field mini-meter, itself calibrated by a soap bubble meter in a laboratory. Pumps were also calibrated in a laboratory after each field exercise, using the same mini-meter. In order to maintain battery power throughout the sampling period, pumps were programed to cover the 24-hour interval through intermittent sampling (one minute out of every four to six minutes). One field blank was taken on each sampling day.

Gravimetric analyses were conducted at the laboratory of the National Institute for Environmental Health and Related Products Safety, China CDC, using an analytic microbalance (1/100,000, Sartorius 2004 MP, Germany) calibrated against standards provided by the Bureau of National Technological Control.

All filters (field blanks and samples) were conditioned for 24 hours before weighing. Sampling for Respirable Particle Matter (PM_{10}) were continually determined using the LD-3C dust sampler (China). Respirable dust concentrations were calculated by dividing the blank-corrected increase in filter mass by the total air volume sampled (mg/m^3).

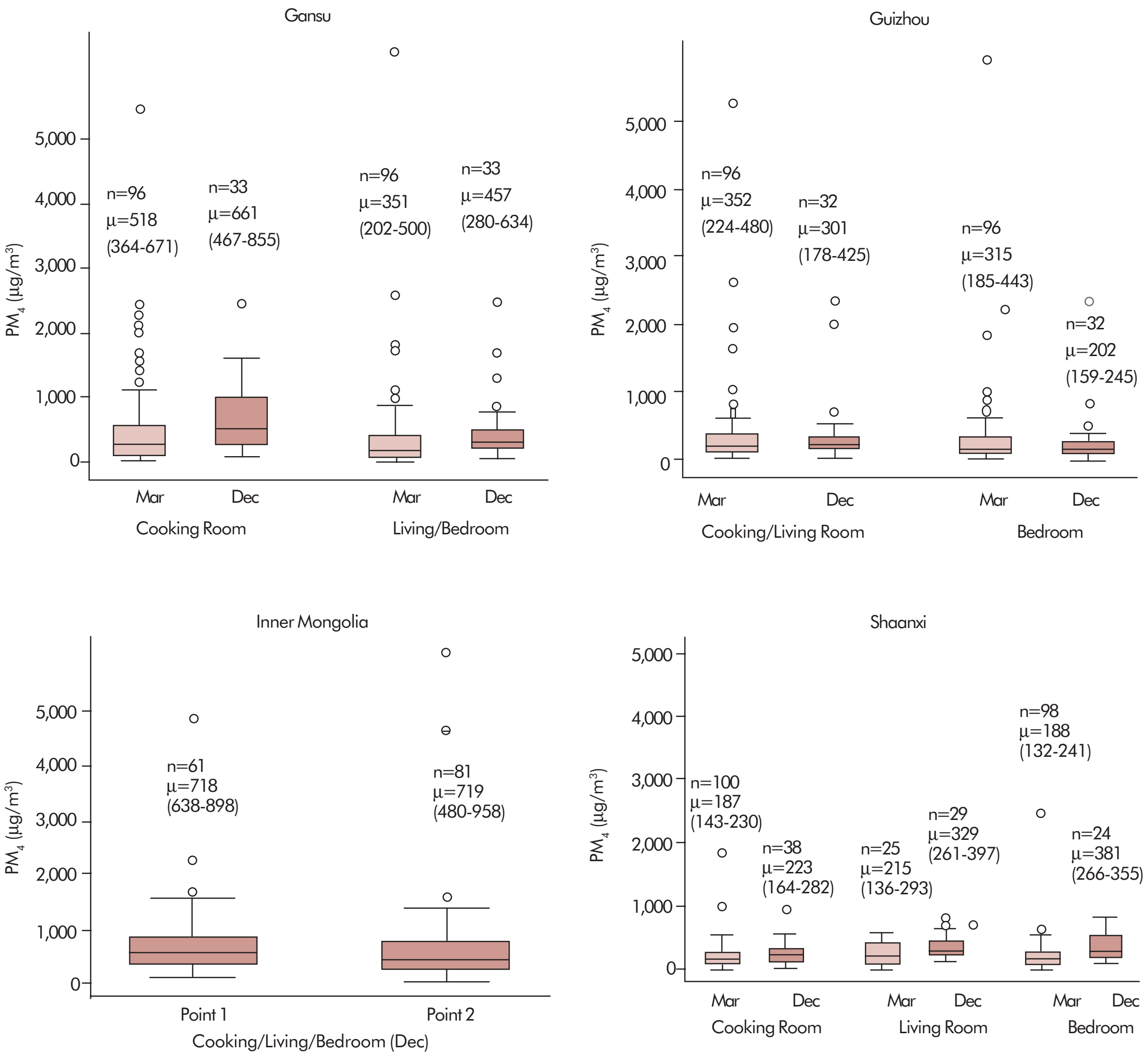
CO and SO_2 were measured using long-term diffusion tubes (manufactured by GASTEC, U.S.), with detection ranges of 10-200 or 50-1000 ppm for CO and 2-100 ppm for SO_2. The average concentrations were calculated on a time-weighted basis and expressed as mg/m^3. Due to cost considerations, SO_2 levels were measured only in the two coal-burning provinces of Guizhou and Shaanxi. Samples of fluoride and As were collected using a relative filter-flow rate of 2.0 l/min., operated with programmable constant flow pumps (PCXR8 supplied by SWKC Inc., U.S.). They were tested according to NIOSH protocols 7300 and 7902, respectively.

PM_{10}, $S0_2$ and CO concentrations were evaluated according to the Standard for Indoor Air Quality of China (GB/T 18883-2002). PM_4 concentrations were evaluated according to the Japanese Indoor Standard Enforced in Office Buildings ($< 3.5\,\mu$m, 0.15mg/m^3).

Annex 3.5
IAP Baseline Data

Figure A3.5.1: Baseline RPM Data

Average 24-hour concentration of RPM (PM_4) at difference points and measurement periods (March and December 2003) in the four project provinces.

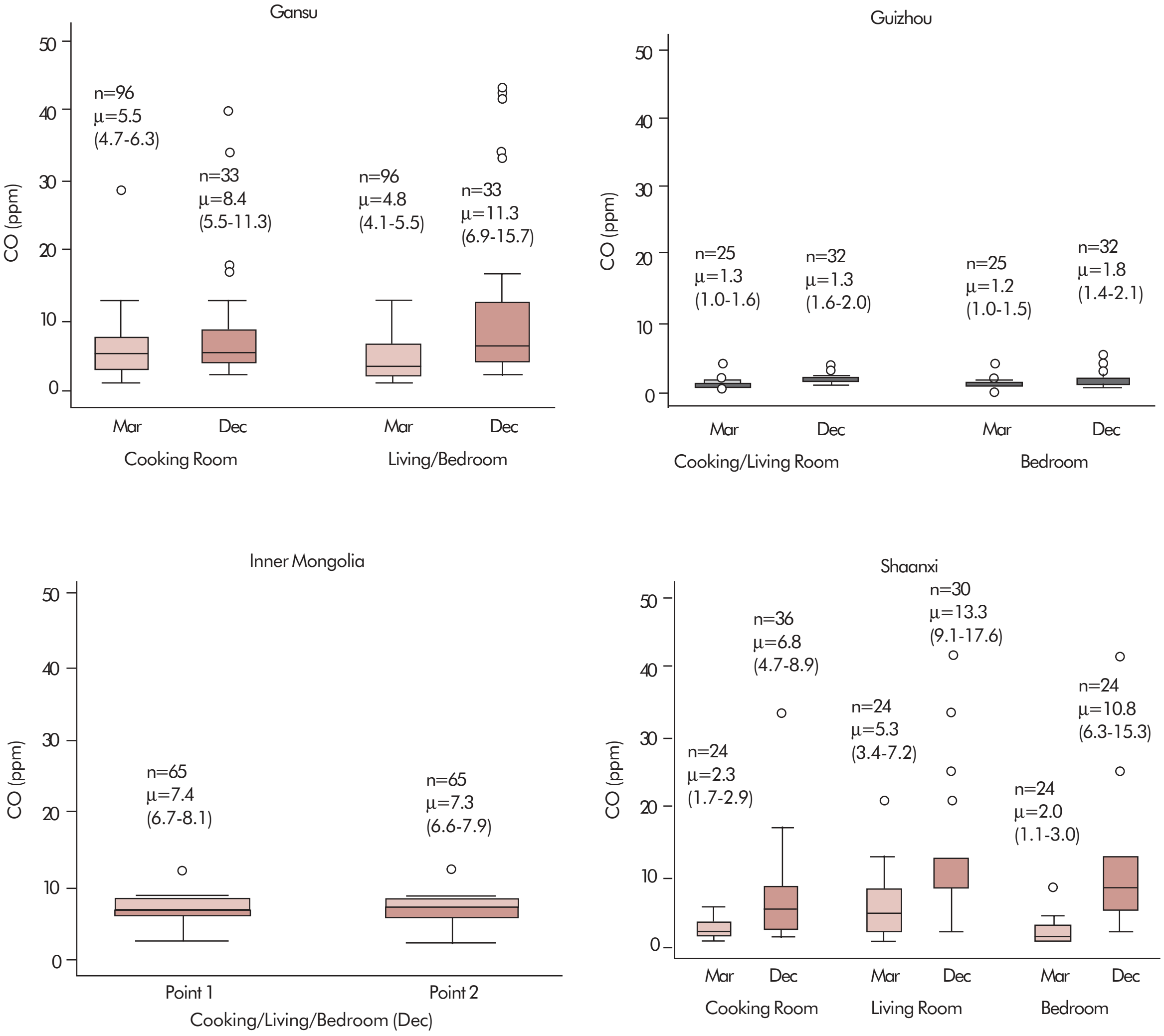


Note: n = number of observations; μ = mean (numbers in parentheses give the 95 percent Confidence Interval [CI] for the mean).

Source: Jin et al. (2005). Reprinted with permission from the American Chemical Society.

Figure A3.5.2: Baseline CO Data

Average 24-hour concentration of CO at different measurement points and measurement periods (March and December 2003) in the four project provinces.

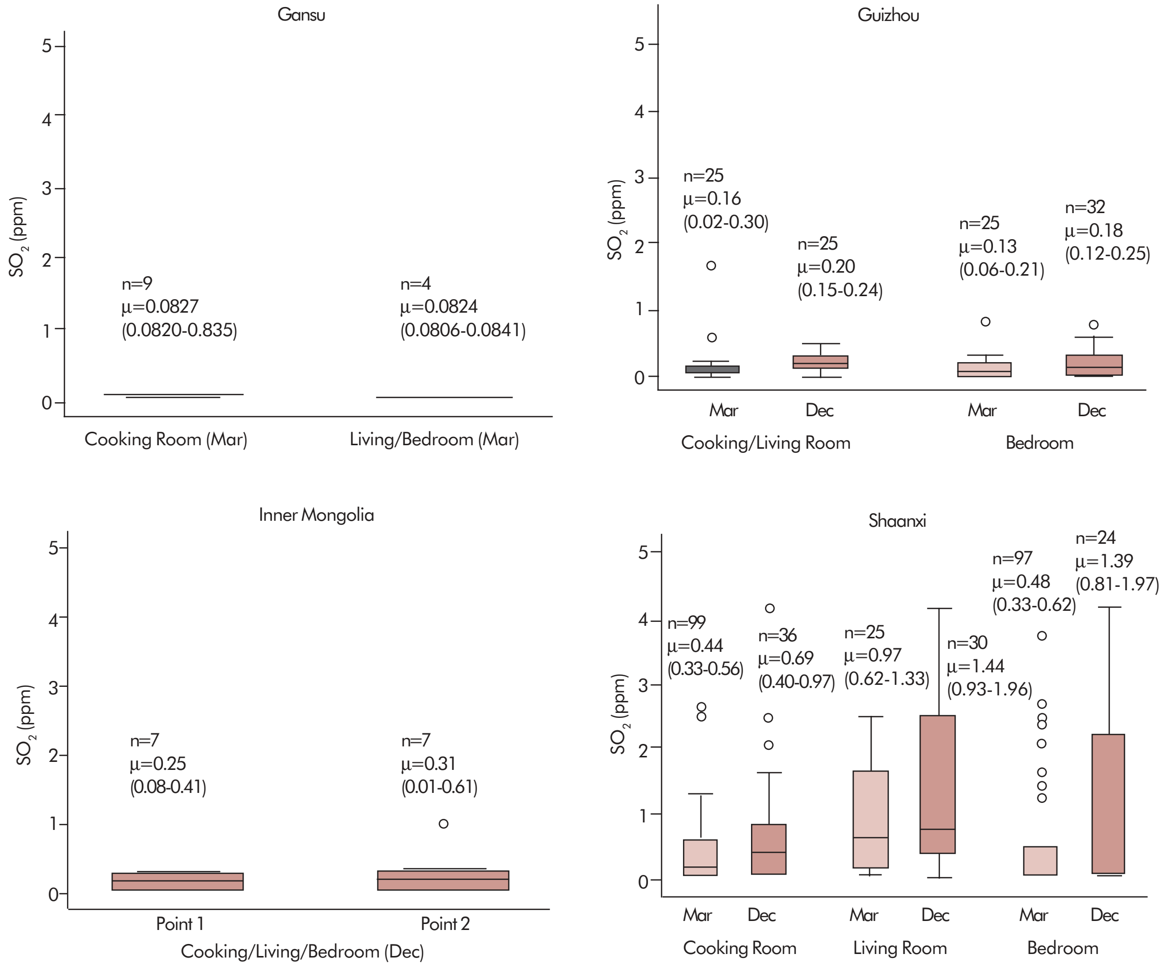


Note: *n* = *number of observations;* μ = *mean (numbers in parentheses give the 95 percent CI for the mean).*

Source: Jin et al. (2005). Reprinted with permission from the American Chemical Society.

Figure A3.5.3: Baseline SO_2 Data

Average 24-hour concentration of SO_2 at different measurement points and measurement periods (March and December 2003) in the four project provinces.



Note: If the concentration of CO and SO_2 were outside the detection range of the testing tubes, the following assumptions were made: (i) those measurements only slightly higher than the measurement range were set to the maximum value; (ii) those measurements substantially higher than the measurement range were set to 150 percent of the maximum value; (iii) those measurements lower than the measurement range were set to the minimum value. The overall results and conclusions of the analysis were not sensitive to these assumptions.

n = number of observations; μ = mean (numbers in parentheses give the 95 percent CI for the mean).

Source: Jin et al. (2005). Reprinted with permission from the American Chemical Society.

Annex 3.6
Baseline Questionnaires

Household Questionnaire

ID: □□□□□□□□

Household Address:
Group: ________ Village: __________Town: __________ City/County: __________

	Householder	*Women 1*	*Women 2*	*Women 3*	*Child 1*	*Child 2*	*Child 3*
Name							
Sex		F	F	F			
Age							

Name of surveyor: _______________ Date (day/month/year): __________

Name of responder: _______________ Sex:_______ Age: _______ (years old)

Education degree: 1. illiterate 2. elementary school 3. primary school 4. senior high school/vocational high school/technical secondary school/junior college and higher

Information and agreement:

To inform the responder, the following items ask for his/her agreement and signature:

1. The objective of this survey is to discover the relationship between IAP and your and your family's health. Samples may be required, including water, food, urine, etc.
2. We undertake to hold confidential all information from this survey.
3. You may collaborate with us on your free will, Thank you.

Signature:

(By responder or guardian)

Section A: Household Characteristics

A1. How many persons are in your family? (They must be the family members who live together)

____

A2. Where do you get the water that you use for drinking?

1. Tap water
2. From well in village
3. From well in the yard
4. From river, lake, cistern, pool
5. Natural spring
6. Water stored in vault
7. Other (specify):____________

A3. Your do you get drinking water? From:
1. water tap 2. vat 3.pool 4. other (specify): ____________

A4. Your cash part of annual income of your family last year: ____________ RMB yuan

A5. Please estimate as precisely as you can the value of food and other agricultural products which your family produced and consumed or stored last year. ____________ RMB yuan

A6. Do you raise the following animals or plants?

A6a. poultry (chicken, duck, goose, etc.)	1. Yes 2. No
A6b. livestock (pig, horse, cattle, sheep, etc.)	1. Yes 2. No
A6c. cat, dog, or bird	1. Yes 2. No
A6d. flowers and plants	1. Yes 2. No

A7. The main source of light for your family:
1 = electricity 2 = kerosene 3 = biogas 4 = candle 5 = other (specify):__________

Section B: House and Kitchen Characteristics

B1. How large is your indoor area? __________________m^2

B2. When was your house built? ______________ (for example, 1999)

B3. Main material composing of your house:
1 = earth, wood, grass
2 = earth, wood, tile
3 = brick, wood, tile
4 = brick, concrete
5 = metal, concrete
6 = other (specify): __________

B4. Is there a gap between the wall and roof?
1. Yes 2. No (if no, go to B5)

B4a. Record the typical size of the gap in centimeters. ☐☐ cm

B5. How often do you open windows in winter while heating?

1. once or more every day
2. once every 2-3 days
3. once every 4-5 days
4. once a week
5. once every 2-3 weeks
6. once a month
7. never in winter
8. other (specify): ___________

B6. Where do you usually do cooking?

1. in specialized kitchen
2. in bedroom
3. in living room
4. other (specify):______________

B7. Characteristics of cooking place

B7a. Indoor kitchen with separation wall to ceiling .... 1. Yes 2. No
B7b. Indoor kitchen with partial separation wall .... 1. Yes 2. No
B7c. Indoor kitchen without separation wall .... 1. Yes 2. No
B7d. Separated indoor kitchen outside the house .... 1. Yes 2. No
B7e. Open air kitchen outside the house .... 1. Yes 2. No

B8. Is there a fan for ventilation (vented to outside) in the kitchen?

1. Yes 2. No

B9. Are there windows in the kitchen which open to the outside air?

1. Yes 2. No

Section C: Fuel Use

C1. What types of fuels does your household mainly use for cooking and heating?

Cooking		*Heating*	
C1a1 winter:	_____________	C1a2 winter:	_____________
C1b1 spring:	_____________	C1b2 spring:	_____________
C1c1 summer:	_____________	C1c2 summer:	_____________
C1d1 autumn:	_____________	C1d2 autumn:	_____________

1 = wood (logs), 2 = wood (twigs/branches), 3 = crop residue, 4 = dung,
5 = coal/coke/bone coal, 6 = charcoal, 7 = kerosene, 8 = Liquefied Petroleum Gas (LPG),
9 = biogas, 10 = other (specify):___________

C2. If you use coal stove, how much coal do you use monthly?

C2a. Not during heating days: ______Jin (0.5kg)
C2b. During heating days: ______Jin

C3. If you use traditional biomass stove, how much do you use per month?
C3a. Not during heating days: ______Jin
C3b.During heating days: ______Jin
C4. Has your household changed the main fuel in the past 10 years? 1) Yes 2) No

C5. Briefly describe changes: time, extent and reasons for change.

C6. For you, what's the price of fuel you are using? 1) Expensive 2) Moderate 3) Cheap

C7. Do you know other fuel? 1) Yes (note:__) 2) No

C8. Are you willing to use other fuel? 1) Yes 2) No

C9. A new type of fuel can reduce indoor smoke, but it's more expensive than what you are using. Are you willing to change? 1) Yes 2) No 3) Don't care 4) Don't know

C10. How much are you willing to pay if you change to using a new type of fuel?
1) No more than 110 percent compared to current price
2) 110-120 percent compared to current price
3) 120-150 percent compared to current price
4) 150-200 percent compared to current price

Section D: Stove Characteristics

D1. The type of stove(s) you own and its main purpose (each type is just for one main purpose)

	Mainly for Cooking		*Mainly for Heating*	
	Number	Location*	Number	Location*
Unimproved Biomass Stove				
Improved Biomass Stove				
Traditional Coal Stove				
Improved LPG Stove				
Biogas				
Firedamp				
Fire Pan				
Open fire with no Hearth				
Other (specify):_________				

**Location: 1 = specialized kitchen, 2 = bedroom, 3 = living room, 4 = other(specify):_________*

D2. Does your household have the following:
D2a. Heated bed ("kang," a bed-heating configuration) 1) Yes 2) No
D2b. Ground stove 1) Yes 2) No

D3. Does the heated bed have a chimney extending outside? 1) Yes 2) No 3) Other (note)

D4. Do you know about other stoves? 1) Yes (note) 2) No

D5. Are you satisfied with the stove you are using? 1) Yes (go to D3) 2) No 3) Indifferent
D6. Are you willing to improve the stove you are using if possible? 1) Yes 2) No 3) Indifferent 4) Don't know

D7. If you want to improve the stove, how much are you willing to pay for it?
1) Less than ☐100 2) ☐ 100-199 3) ☐ 200-299

Interviewer: If household has one or more biomass stoves, fill out the following questions:

D8. What purpose is the stove used for?

D8a. Cooking meals	1 Yes 2 No
D8b. Heating/boiling water	1 Yes 2 No
D8c. Heating on rainy days	1 Yes 2 No
D8d. Heating in winter	1 Yes 2 No
D8e. During shortage of other fuels	1 Yes 2 No
D8f. Cooking animal feed	1 Yes 2 No
D8g. Other (specify): __________	

D9. Does the stove have an air-blower (fan)?
1. No 2. air-blowing box (traditional) 3. manual fan 4. electric fan

D10. Does this stove have a chimney? 1. Yes 2. No
D10a. If so, does the chimney go outside your house 1. Yes 2. No

D11. How often is the chimney cleaned? _______month

D12. Distance from top of chimney to the eaves in centimeters? ______cm
D12a. Does the chimney go past the eaves? 1. Yes 2. No

D13. Height of chimney in centimeters (from ground to top of chimney) ______cm

D14. Does the stove have a hood? 1. Yes 2. No

D15. Does the stove have a door that is for adding fuel and that can be closed? 1. Yes 2. No

D16. Does the stove have a grate? 1. Yes 2. No

D17. If used for heating, is this stove connected to a "kang" (heated bed)? 1. Yes 2. No
D17a. In the past year, has any family member suffered burns from the kang? 1. Yes 2. No
D17b. Name of the injured person and frequency of scalding (burns):
Name: ________ frequency: _________
Name: ________ frequency: _________
Name: ________ frequency: _________

D18. When was the stove installed?_______(for example, 1999)

D19. How did you acquire this stove?

D19a. Decided to purchase on own 1. Yes 2. No
D19b. Relative or friend recommended 1. Yes 2. No
D19c. Government required purchase or install 1. Yes 2. No
D19d. Government provided a subsidy 1. Yes 2. No
D19e. Already existed in the house when moved in 1. Yes 2. No
D19f. Other (specify): ________________

D20. How much did it cost, including materials and labor for installation?______Yuan

D21. Did other persons pay for the stove? 1. Yes 2. No (go to D19)

D22. Who paid for the stove?
1. Government 2. Nongovernmental Organization 3. Enterprise 4.Other (specify):_____

D23. How much did the other person pay for the stove? ________yuan

D24. How long ago was stove last repaired or refurbished? _____year

Interviewer: If household has one or more coal stoves, fill out the following questions:

D25. Interviewer: Describe the Type of Stove:
D25a. Portable stove 1. Yes 2. No
D25b. Fixed stove 1. Yes 2. No
D25c. Other (specify):__________

D26. For what purposes is the stove used?
D26a. Cooking meals 1. Yes 2. No
D26b. Boiling water 1. Yes 2. No
D26c. Heating on rainy days 1. Yes 2. No
D26d. Heating in winter 1. Yes 2. No
D26e. During shortage of other fuels 1. Yes 2. No
D26f. Cooking animal feed 1. Yes 2. No
D26g. Other (specify): __________

D27. Does the stove have a chimney? 1. Yes 2. No
D27a. If yes, does the chimney go outside the house? 1. Yes 2. No

D28. If the stove has a chimney, how often is the chimney cleaned? _____ times per month

D29. Height of the stove in centimeters (from top of chimney to eaves): _____ cm

D30. Height of chimney in meters (from the floor ground): _____ m

D31. Does the stove have a hood? 1. Yes 2. No

D32. Does the stove have a fire door? 1. Yes 2. No

D33. Do you close the fire door while cooking? 1. Yes 2. No

D34. Does the stove have a grate? 1. Yes 2. No

D35. If used for heating, does the stove have a water heating system or other apparatus for heating water? 1. Yes 2. No

D36. When was the stove installed?______(for example, 1999)

D37. How did you acquire this stove?

D37a. Decided to purchase on own	1. Yes 2. No
D37b. Relative or friend recommended	1. Yes 2. No
D37c. Government required purchase	1. Yes 2. No
D37d. Government gave or subsidized	1. Yes 2. No
D37e. Already existed in house when moved in	1. Yes 2. No

D37f. Other (specify): _________________

D38. How much did it cost, including materials and labor for installation?____ yuan

D39. Did others pay any of the cost? 1. Yes 2. No

D40. By whom?
1. Government 2. Nongovernmental Organization 3. Enterprise 4.Other (specify): ______

D41. How much _____ yuan

D42. How much does the kind of coal you use most cost?
_____ yuan / 50kg or _____ yuan/piece

D43. When was stove last repaired or maintained? ________ year (for example, 1999)

Biogas Stoves

Interviewer: If household has a biogas stove, fill out the following questions:

D44. For what purposes is the stove used?

D44a. For cooking meals	1. Yes 2. No
D44b. For boiling water	1. Yes 2. No
D44c. During shortage of other fuels	1. Yes 2. No
D44d. Cooking animal feed	1. Yes 2. No

D44e. Other (specify):_______________

D45. Is this the stove mainly used for cooking? 1. Yes 2. No

D46. Where do you acquire the biogas?
1. Household biogas digester
2. Village biogas digester
3. Other (specify): __________

D47. When was the stove installed? _____(for example, 1999)

D48. How did you acquire this stove?

D48a. Decided to purchase on own	1. Yes 2. No
D48b. Relative or friend recommended	1. Yes 2. No
D48c. Government required purchase	1. Yes 2. No

D48d. Government gave or subsidized 1. Yes 2. No
D48e. Already existed in house when moved in 1. Yes 2. No
D48f. Other (specify): ________________

D49. How much did it cost, including materials and labor for installation? _______ yuan

D50. Did others pay any of the cost for? 1. Yes 2. No

D51. By whom?
1. Government 2.Nongovernmental Organization 3. Enterprise 4.Other (specify): _________

D52. How much? _______ yuan

Section E: Food Processing and Cooking

E1. What is the main food you consume daily?
E1a. Corn 1) Yes 2) No
E1b. Wheat 1) Yes 2) No
E1c. Rice 1) Yes 2) No
E1d. Oat 1) Yes 2) No
E1e. Potato 1) Yes 2) No
E1f. Other (note: ______) 1) Yes 2) No

E2. What are the main means for drying food?
E2a. Corn 1) Dry in the sun 2) Dry in the shade 3) Roast 4) Other (note:_)
E2b. Wheat 1) Dry in the sun 2) Dry in the shade 3) Roast 4) Other (note:_)
E2c. Rice 1) Dry in the sun 2) Dry in the shade 3) Roast 4) Other (note:_)
E2d. Oat 1) Dry in the sun 2) Dry in the shade 3) Roast 4) Other (note:_)
E2e. Capsicum 1) Dry in the sun 2) Dry in the shade 3) Roast 4) Other (note:_)
E2f. Other (note:_)

E3. What are the main means for storing food?
1) Storage in poke 2) Pile up without cover
3) Pile up and covered with plastic pellicle 4) Storage in container without cover
5) Storage in covered container 6) Other (note:__)

E4. Do you wash capsicum before eating it?
1) Always 2) Sometimes 3) Never (go to E7)

E5. How do you wash it?
1) Soaking 2) Scouring 3) Rinsing 4) Other (note:_)

E6. What water do you use to wash?
1) River or dyke water 2) Well water 3) Tap water

E7. Do you wash corn before grinding or eating it?
1) Always 2) Sometimes 3) Never (go to E10)

E8. How do you wash it?
1) Soaking 2) Scouring 3) Rinsing 4) Other (note:_)

E9. Which water do you use to wash?
1) River or dyke water 2) Well water 3) Tap water

E10. Which water do you use to cook with?
1) River or dyke water 2) Well water 3) Tap water

E11. Do you cook?
1) Always 2) Sometimes 3) Never

E12. How often do you feel choking or burning eyes when your family is cooking?
1) Always 2) Sometimes 3) Never 4) Don't know (go to E14)

E13. What is the reason?
1) Fuel smoke 2) Grease mist 3) Other (note:_)

E14. Do you usually burn the grease until mist appears while cooking?
1) Yes 2) No

E15. Do you open the door and windows to ventilate when your family is cooking?
1) Always 2) Sometimes 3) Never

E16. Do you think smoking can do harm to you and your family's health?
1) Yes 2) No 3) Don't care 4) Don't know

E17. Do you know which means can reduce smoke?
E17a. Improved stove
1) Yes 2) No
E17b. Improved chimney:
1) Yes 2) No
E17c. Improve the skills of making a fire 1) Yes 2) No
E17d. Improved ventilation 1) Yes 2) No
E17e. No smoking in the house 1) Yes 2) No
E17f. Spending less time cooking 1) Yes 2) No
E17g. Other (note:_) 1) Yes 2) No

E18. Do you know which components of smoke can do harm to health? *(choose all that apply)*
1) Dust 2) CO 3) SO_2 4) F
5) As 6) Other (note:_) 7) Don't know

E19. Smoke is denser when cooking. How do you deal with it?
1) Open the windows to ventilate 2) Leave the kitchen provisionally
3) Don't care 4) Don't know

E20. Do you ever want to reduce the time spent in kitchen?
1) Yes 2) Don't care 3) No

E21. During the past year, has your family wanted to construct new house?
1) Yes 2) No 3) Don't know

Section F: Health Awareness (Cognition)

F1. How often do you feel choking or burning of eyes when you are cooking?
1) Always 2) Sometimes 3) Never 4) Don't care

F2. Do you know whether the ventilation is good or bad in your home?
1) Good 2) Bad 3) Don't care

F3. Do you think you need to improve the ventilation in your home?
1) Yes 2) No 3) Don't care

F4. Are you willing to improve ventilation in your family?
1) Yes 2) No 3) Don't care

F5. Do you know what is the cause of indoor air pollution?

F5a. Cooking	1) Yes	2) No
F5b. Heating	1) Yes	2) No
F5c. Smoking	1) Yes	2) No
F5d. Bad ventilation	1) Yes	2) No
F5e. Other (note:__)	1) Yes	2) No

F6. Are there smokers in your family?
1) Yes (how many:__) 2) No (go to F8)

F7. How often do they smoke in your house?
1) Always 2) Sometimes 3) Never

F8. Do you think smoking can do harm to health?
1) Yes 2) No 3) Don't know

F9. When somebody smokes near you, do you think whether it will do harm to your health or not?
1) Yes 2) No 3) Don't know

F10. Have you ever heard of dental fluorosis (apply in Guizhou and Shaanxi)?
1) Yes 2) No (go to F12)

F11. Do you know what causes dental fluorosis?
1) Water 2) Coal 3) Food 4) Smoking 5) Other (note:__)

F12. Do you want to acquire more information on the relationship between health and smoke?
1) Yes 2) No 3) Don't care 4) Don't know

F13. Which means of information do you like?
1) TV, broadcast 2) Slogan written on the wall
3) Field consultation to doctor 4) Field symposium with expert
5) Other (note:______)

The survey is over, thanks!
Surveyor check: signature__________________ Date ___________

Annex 3.6.1
Health Survey Questionnaire: Adult Health Survey Individual Questionnaire

(To Be Completed by Household Members over 18 Years Old)

ID: ☐☐☐☐☐☐☐☐

Household Address:

Group: ___________	Village: ___________	Town: ______________	City/County: ___________
Name of householder:	_________________	Name of responder:	_____________________
Name of surveyor:	_________________	Date (day/month/year):	_____________________

Section A: General Information

I would like to ask you some general questions about yourself. Like the other questions I've asked, your responses are voluntary; if you don't want to answer any question, tell me and we'll go on to the next question.

A1. In which month and year were you born? (in lunar calendar)

A2. How old were you at your last birthday?
A3. Your ethnic background:
1. Han 2. Hui 3. Mongolia 4. Weiwuer 5. Man 6. Miao
7. Zhuang 8. Buyi 9. Yi 10. Dai 11. Yao 12. Other (specify:_______) 13. I don't know

A4. What is the highest grade or year of schooling you've completed?
1 = No schooling 2 = Primary school 3 = Middle school 4 = High school/technical secondary school/vocational high school 5 = Junior college or above

A5. How long have you lived in this place? _______years

A6. Do you smoke? 1. Yes 2. No

A7. Did you used to smoke? 1. Yes 2. No
(If both A6 and A7 answered "no," then go to A11)

A8. How old were you when you first started smoking? Enter age ☐☐

A9. What kind of cigarette/tobacco do you smoke?
1. Nonfiltered cigarette 2. Filtered cigarette 3. Tobacco pipe/tobacco
4. Other (specify_______________)

A10. How many cigarettes/cigars/pipes or how much tobacco do you typically consume in one day?

A10a. Nonfiltered cigarette: _________
A10b. Filtered cigarette: _________
A10c. Tobacco pipe/tobacco: _________Liang (50 gram)

A11. Is there anyone else in your household smoking? 1. Yes 2. No
A11a. If yes, how much tobacco do they consume per day?
A11a1. Nonfiltered cigarette: _________
A11a2. Filtered cigarette: _________
A11a3. Tobacco pipe/tobacco: _________ Liang (50 gram)
A11b. Does he/she smoke at home? 1.= Often 2 = Sometimes 3 = Never

A12. Do you cook at home? 1 = Yes 2 = No
A12a. When did you start cooking? _________ years of age

A13. How long does your family cook every day? ___________ minutes

A14. How long do you take in cooking every day? __________ minutes

A15. Your job/career: 1 = Aquatics breeding/animal culturing/planting, 2 = Village cadre/teacher/village doctor, 3 = Carpenter/handcrafter, 4 = Individual operator, 5 = Cook, 6 = Employee of enterprise in village/town, 7 = Student, 8 = Housewife, 9 = Other (specify):______

A16. How long have you been engaged in this work? ____________ years

A17. In the past 12 months, how long have you worked outside your town?______months

A18. Here are some questions about the place and time of your daily activities (converted into minutes by investigator):

Locus	*Duration*
A18a. In kitchen, by the stove	
A18b. In kitchen, not by the stove	
A18c. At home, but not in kitchen	
A18d. Indoor, but not at home	
A18e. Outdoor	

Section B: Dietary Habits

Attention! The following questions refer to your own appetite, not your whole family.

B1. On an average, how much vegetables do you eat every day? _________Jin (500gram)

B2. On an average, how much meat do you eat every day? _________Liang (50 gram)

B3. Have you eaten the following foods for a long time? (If you have, please fill in the blanks with your amount and frequency; if you don't, fill in with "0.")
B3a. Smoky dried chili ________ Jin ________ Liang (every month)
B3b. Smoky dried corn ________Jin ________ Liang (every month)
B3c. Baked ________ Jin ________ Liang (every month)
B3d. Fumed bean curd ________ Jin ________ Liang (every month)
B3e. Other (specify________) ________ Jin ________ Liang (every month

Section C: General Health Condition and Disease Burden

C1. In general, do you feel your health is: 1 = Excellent 2 = Fair 3 = Poor

C2. Compared with most people of the same age around you, would you feel your health is:
1 = Better than others 2 = The same as others 3 = Worse than others

C3. In general, can you deal with the following activities?
C3a. Planting 1 = Yes (without difficulty) 2 = Yes (with difficulty) 3 = No
C3b. Cooking, washing 1 = Yes (without difficulty) 2 = Yes (with difficulty) 3 = No
C3c. Climbing steps 1 = Yes (without difficulty) 2 = Yes (with difficulty) 3 = No
C3d. Walking around by yourself 1 = Yes (without difficulty) 2 = Yes (with difficulty) 3 = No
C3e. Eating, drinking and dressing by yourself 1 = Yes (without difficulty) 2 = Yes (with difficulty) 3 = No

C4. In the past one year, were you diagnosed with the following diseases? (you can select more than one option)
a. Eye diseases b. Respiratory diseases (including flu) c. Digestive diseases
d. Gynecological diseases e. Arsenic poisoning f. Fluorosis/fluorosis of bone
g. Cardiovascular diseases h. Accident/injury i. Others (specify:_________)

C5. In the past one year, how much money did you spend on seeing a doctor? _________Yuan

Section D: Diseases and Symptoms

D1. Do you often cough when you have a cold? 1. Yes 2. No
D2. Do you often cough even if you don't have a cold? 1. Yes 2. No
D3. If both D1 and D2 are answered "Yes,"
D3a. How many months does cough last each year? 1. < 1 month 2. 1-2 months
3. $\geq$3 months
D3b. How many years has the condition above lasted? ___________years

D4. Is cough always with phlegm when you have a cold? 1. Yes 2. No

D5. Do you often cough with phlegm even if you don't have a cold? 1. Yes 2. No

D6. If both G4 and G5 are answered "Yes,"
D6a. How many months does cough with phlegm last each year? 1. < 1 month 2. 1-2 months 3. ≥ 3 months
D6b. How many years has the condition above lasted? __________years

D7. Do you have the syndrome of breathing heavily?
D7a. When you have a cold: 1. Yes 2. No
D7b. When you don't have a cold 1. Yes 2. No
D7c. In most of the daytime/at night 1. Yes 2. No

D8. D8a. Do you have difficulty in breathing when you walk fast or climb on a slope? 1. Yes 2. No
D8b. Do you walk more slowly than persons as old as you for difficulty in breathing? 1. Yes 2. No
D8c. Do you have to stop to catch your breath when you walk at moderate speed? 1. Yes 2. No
D8d. Do you have to stop and catch your breath when you have walked 100m or for a few minutes? 1. Yes 2. No
D8e. Do you feel that you are unable to go outside for difficulty in breathing or do you feel difficulty in breathing even while taking off/on your cloths? 1. Yes 2. No

D9. In the past three months, have you had:
D9a. Headache lasting more than 4 hours 1. Yes 2. No
D9b. More than five times of headache in a week 1. Yes 2. No
D9c. Dizziness, where you felt like you were spinning 1. Yes 2. No
D9d. Nausea with vomiting 1. Yes 2. No
D9e. Nausea lasting more than eight hours 1. Yes 2. No
D9f. Nasal discharge 1. Yes 2. No
D9g. Nasal obstruction 1. Yes 2. No
D9h. Continuously sneezing 1. Yes 2. No
D9i. Cough 1. Yes 2. No
D9j. Cough with phlegm 1. Yes 2. No
D9j1. What was the color of phlegm?
1 = white 2 = yellow 3 = yellow/green 4 = green 5 = brown
D9k. Fever 1. Yes 2. No
D9l. Irritation of both eyes lasting more than four hours 1. Yes 2. No
D9m. Irritation of both eyes more than five times in a week 1. Yes 2. No
D9n. Itching (not irritation) of both eyes 1. Yes 2. No
D9o. Hyperaemia of eyes 1. Yes 2. No
D9p. Watery often 1. Yes 2. No
D9q. Discharge of one or both eyes making your eyelids stick together in the morning 1. Yes 2. No
D9r. History of allergies affecting one or both eyes 1. Yes 2. No
D9s. Other symptoms (specify): ________________

D10. Have you ever been diagnosed with any of the following diseases?

	Were you diagnosed with the following diseases by doctor?			*Were you diagnosed with the following diseases in the past 12 months?*	
Diseases	Yes	No	Years	Yes	No
Rhinitis					
Flu					
Bronchitis					
Pneumonia (bronchial pneumonia)					
Tuberculosis					
Asthma					
Emphysema					
Chronic Bronchitis					
Hypertension					
Heart Disease					
Mite-related Allergy					
Allergy induced by food, medicine, pollen, chemicals or others					
Skeletal Fluorosis					
Dental Fluorosis					

D11. During the last 12 months, did illness cause you to miss work or school? 1. Yes 2. No (Go to Section C)

D12. During the last 12 months, how many days or months have you missed of the following due to illnesses?

D12a. Work/agriculture ________days
D12b. Work indoor (employed) ________days
D12c. Homework ________days
D12d. Going to school or learning ________days

Section E: Hypertension

E1. Interviewer Checks Section D:
Does Respondent have History of Hypertension?
1 =Yes (Continue) 2 =No (Go to Section F)

E2. Do you have hypertension now? 1. Yes 2. No 3. I don't know

E3. How many years have you had hypertension? Enter years: ☐☐

E4. Do you currently take medication for your hypertension? 1 =Yes 2 =No

E5. How many different types of medication do you take? ENTER #: ☐☐☐

E6. Have you ever been told that you have had any of the following conditions which have been affected by your hypertension?
E6a. Myocardial infarction 1 =Yes 2 =No
E6b. Stroke 1 =Yes 2 =No
E6c. Nephropathy 1 =Yes 2 =No

E7. Have you lost weight or changed your diet for the treatment and control of hypertension?
1. Yes 2. No

E8. In the past 12 months, how many times did you seek medical care for your hypertension?
E8a. As an inpatient (in a hospital) Enter #: ☐☐☐
E8b. As an outpatient (in a hospital) Enter #: ☐☐☐

E9. Have you ever had your cholesterol checked? 1 = Yes 2 = No 3 = Don't know

E10. In the past one year, how much money did you spend seeing a doctor for your hypertension?
☐☐☐☐ Yuan/RMB

Section F: Tuberculosis

F1. Interviewer Checks Section D: Does respondent have history of tuberculosis?
1 = Yes (Continue) 2 = No (Go to Section G)

F2. When were you first diagnosed with tuberculosis?_______years old _______ don't know

F3. In the past one year, has anyone else in your house been diagnosed with tuberculosis?
1 = Yes 2 = No

F4. Has any of your household members been tested for tuberculosis in the past one year? 1 = Yes 2 = No

F5. Do you currently take medication for this problem? 1 = Yes 2 = No (go to F8)

F6. How many medications do you take? Enter #: ☐☐☐

F7. For how many months have you been taking the medications? ENTER # of months: ☐☐☐

F8. Do you still have the cough now? 1 = Yes 2 = No

F9. How many weeks did you have your cough? ENTER # of weeks: ☐☐☐

F10. In the past 12 months, how many times have you sought medical care for this problem?
F10a. As an inpatient (in a hospital) Enter #: ☐☐☐
F10b. As an outpatient (in a hospital) Enter #: ☐☐☐

F11. In the past one year, how much money did you spend seeing a doctor for your tuberculosis?
☐☐☐Yuan/RMB

Section G: Asthma

G1. Interviewer checks Section G: Does respondent have a history of asthma?
1 =Yes (Continue) 2 =No (Go to Section H)

G2. How long have you been diagnosed with asthma? ☐☐ Years

G3. How many different types of oral medicines do you take now? Enter #: ☐☐☐

G4. How many different types of inhaled medicines do you take now? Enter #: ☐☐☐

G5. How many times of asthma attack have you had in the past year? Enter #: ☐☐☐

G6. In the past 12 months, how many times have you sought medical care for this problem?
G6a. As an inpatient (in a hospital) Enter #: ☐☐☐
G6b. As an outpatient (in a hospital) Enter #: ☐☐☐
G7. Have you ever had a test of your breathing? 1 = Yes 2 = No 3 = Don't know

G8. How much money did you spend on seeing a doctor in the past year? ☐☐☐☐Yuan/RMB

Section H: Emphysema and Other Obstructive Pulmonary Diseases

H1. Interviewer Checks Section D:
Does Respondent Have a History of Emphysema, Chronic Bronchitis,
or COPD Disease?
1 = Yes (Continue) 2 = No (Go to Section I)

H2. Which of the following have you been diagnosed with?
H2a. Emphysema 1 = Yes 2 = No
H2b. Chronic bronchitis 1 = Yes 2 = No
H2c. Chronic obstructive pulmonary disease 1 = Yes 2 = No
H2d. Other lung disease (specify):__________ 1 = Yes 2 = No

H3. Which of the following have you been diagnosed with in the past year?
H3a. Emphysema 1 = Yes 2 = No
H3b. Chronic bronchitis 1 = Yes 2 = No
H3c. Chronic obstructive pulmonary disease 1 = Yes 2 = No
H3d. Other lung disease (specify):__________ 1 = Yes 2 = No

H4. How many oral medicines do you take now? Enter #:☐☐☐

H5. How many inhaled medicines do you take now? Enter #:☐☐☐

H6. In the past 12 months, how many times have you sought medical care for this problem?
H6a. As an inpatient (in a hospital) Enter #:☐☐☐
H6b. As an outpatient (in a hospital) Enter #:☐☐☐

H7. Have you ever had a test of your breathing? 1 = Yes 2 = No 3 = Don't know

H8. In the past year, how much money did you spend on seeing a doctor for this disease?
☐☐☐☐Yuan/RMB

Section I: Pregnancy and Delivery

I1. Is Respondent a Woman Who Reports Being Pregnant in the Past Five Years?
1 = Yes (Continue) 2 =No (Go to Section J)

I2. How many times have you been pregnant in the last five years? Enter #: ☐☐

I3. How many times have you given birth? Enter #: ☐☐

I would like to ask you some questions about your most recent delivery. (By delivery we mean the last time you gave birth to a child).

I4. Did you weigh this most recent baby at birth? 1 = Yes 2 = No 3 = Dead (go to I7)

I5. What was the birth weight of this most recent baby? Enter # of Grams____________

I6. How old is that child now? Enter either years or months and circle code. If less than one month enter "00" in months.

I7. Where did the delivery take place? 1 = Home 2 = Hospital 3 = Clinic
4 = Other (specify):______

I8. How much money did you spend for the delivery of the most recent baby? _________Yuan

I9. How old were you when the baby was born? Enter Age: ☐☐

I10. Were there any complications around the time of delivery? a. Bleeding b. Infection c. Asphyxia d. High blood pressure e. Other (specify):_________

I11. Did you have prenatal care for this pregnancy? 1 = Yes 2 = No (Go to I14)

I12. How many prenatal care visits did you take for this pregnancy? Enter #: ☐☐

I13. At how many months of pregnancy did you obtain the first prenatal care? Month #:

I14. Did you have an ultrasound examination during this pregnancy? 1 = Yes 2 = No

I15. How many times did you have an ultrasound examination for this pregnancy?
Enter # of Times: ☐☐

I16. How many weeks was the pregnancy before you delivered this last baby? Enter # of Weeks: ☐☐

I17. Was this most recent baby breastfed? 1 = Yes 2 = No

I18. Did you have hypertension during this most recent pregnancy? 1 = Yes 2 = No 3 = Don't know

I19. Did you smoke during this most recent pregnancy? 1 = Yes 2 = No

I20. Did you drink alcohol during this most recent pregnancy? 1 = Yes 2 = No

I21. Were you diagnosed with tuberculosis during this most recent pregnancy? 1 = Yes 2 = No

Section J: Health Measures

J1.	Eyes		
	J1a. Hyperaemia of conjunctiva	1. Yes	2. No
	J1b. Lachrymation	1. Yes	2. No
	J1c. Secretion	1. Yes	2. No
J2.	Nose		
	J2a. Nasal obstruction	1. Yes	2. No
	J2b. Nasal discharge	1. Yes	2. No
J3.	Arsenic Poisoning		
	J3 Dermatosis	1. Yes	2. No

Classification:

Keratosis at palm and sole 1 = Normal 2 =☐ Degree 3 =☐ 4 = III
Pigmentation: 1 = Normal 2 =☐ Degree 3 =☐ 4 = III
Depigmentation: 1 = Normal 2 =☐ Degree 3 =☐ 4 = III
Bowen's Disease or Skin Carcinoma 1 = Yes 2 = No
Clinic classification: 1 = Normal 2 = Dubious 3 = Low-grade 4 = Mid-grade 5 = High-grade
6 = Bowen's Disease or Skin Carcinoma

Annex 4.1

Pre- and Post-intervention IAP Concentrations and Changes by Province

Gansu												
	Control				*Behavioral Intervention*				*Stove and Behavioral Intervention*			
	Dec-Jan	Dec-Jan	Mar-Apr	Mar-Apr	Dec-Jan	Dec-Jan	Mar-Apr	Mar-Apr	Dec-Jan	Dec-Jan	Mar-Apr	Mar-Apr
	2003	2004	2003	2005	2003	2004	2003	2005	2003	2004	2003	2005
T1(°C)	2.8	0.8	23.2	18.8	-0.9	2.6	15.5	14.5	8.9	1.2	17.1	21.8
T2(°C)	8.2	11.5	17.8	16.8	7.4	12.4	13.0	14.1	13.0	13.4	14.4	16.3
Cooking Room RPM ($\mu g/m^3$)												
n	12	28	32	10	12	28	32	10	9	28	32	12
	780	400	457	186	391	307	397	203	862	184	700	199
Level	(444, 1,116)	(252, 547)	(231, 683)	(122, 250)	(233, 548)	(259, 356)	(219, 574)	(49, 356)	(290, 1,435)	(150, 218)	(326, 1,073)	(137, 262)
△1	-380 (-49%) (p1 = 0.04)		-271 (-59%) (p1 = 0.02)		-84 (-21%) (p1 = 0.29)		-194 (-49%) (p1 = 0.09)		-678 (-79%) (p1 = 0.03)		-501 (-72%) (p1 = 0.01)	
△2					296 (p2 = 0.07)		77 (p2 = 0.77)		-298 (p2 = 0.15)		-230 (p2 = 0.54)	
△3									-594 (p3 = 0.00)		-307 (p3 = 0.39)	
CO (ppm)												
n	12	30	32	12	12	30	32	10	9	30	32	12
Level	9.9 (3.6, 16.1)	7.7 (6.6, 8.9)	6.4 (4.6, 8.2)	5.7 (1.8, 9.7)	3.8 (3.0, 4.5)	6.4 (4.8, 8.1)	3.5 (2.9, 4.1)	3.3 (1.8, 4.7)	12.5 (5.5, 19.4)	4.3 (3.4, 5.2)	6.5 (5.4, 7.6)	4.6 (3.3, 5.9)
△1	-2.2 (-22%) (p1 = 0.47)		-0.7 (-11%) (p1 = 0.74)		2.6 (68%) (p1 = 0.01)		-0.2 (-6%) (p1 = 0.76)		-8.2 (-66%) (p1 = 0.03)		-1.9 (-29%) (p1 = 0.02)	

	Gansu											
	Control				*Behavioral Intervention*				*Stove and Behavioral Intervention*			
△2					4.8 (p2 = 0.05)		0.5 (p2 = 0.82)		-6.0 (p2 = 0.03)		-1.2 (p2 = 0.53)	
△3									-10.8 (p3 = 0.00)		-1.7 (p3 = 0.14)	
	Living/Bedroom RPM ($\mu g/m^3$)											
n	12	28	32	10	12	27*	32	10	9	28	32	12
Level	354 (184, 524)	146 (132, 160)	185 (110, 259)	134 (87, 180)	338 (138, 539)	165 (147, 182)	577 (153, 1,002)	158 (83, 234)	752 (142, 1,363)	177 (128, 227)	292 (156, 428)	171 (150, 193)
△1	-208 (-59%) (p1 = 0.02)		-51 (-28%) (p1 = 0.23)		-173 (-51%) (p1 = 0.09)		-419 (-73%) (p1 = 0.06)		-575 (-76%) (p1 = 0.06)		-121 (-41%) (p1 = 0.08)	
△2					35 (p2 = 0.65)		-368 (p2 = 0.34)		-367 (p2 = 0.02)		-70 (p2 = 0.60)	
△3									-402 (p3 = 0.01)		298 (p3 = 0.43)	
	CO (ppm)											
n	12	30	32	12	12	30	32	10	9	30	32	12
Level	5.4 (3.9, 7.0)	8.6 (7.2, 9.9)	3.3 (2.5, 4.1)	2.9 (2.2, 3.6)	5.3 (3.4, 7.3)	5.6 (4.7, 6.6)	4.6 (3.6, 5.7)	2.9 (2.2, 3.5)	27.1 (15.7, 38.5)	8.2 (6.8, 9.6)	6.5 (5.1, 8.0)	7.8 (1.4, 14.1)
△1	3.2 (59%) (p1 = 0.00)		-0.4 (-12%) (p1 = 0.47)		0.3 (6%) (p1 = 0.75)		-1.7 (-37%) (p1 = 0.01)		-18.9 (-70%) (p1 = 0.01)		1.3 (20%) (p1 = 0.69)	
△2					-2.9 (p2 = 0.06)		-1.3 (p2 = 0.23)		-22.1 (p2 = 0.00)		1.7 (p2 = 0.47)	
△3									-19.2 (p3 = 0.00)		3.0 (p3 = 0.21)	

* *Of the 28 household days of measurement, data for one day was dropped because the duration of measurement was < 960 min. (16 hrs).*

Note: T1 and T2 = temperatures measured outside and inside households with pollution measurement, averaged over all measurement days; n = number of household days of measurement; level = mean concentration (95 percent CI); △1 = change between post- and pre-intervention measurements in the same group; △ 2 = difference in change between each of the two intervention groups and C group; △ 3 = difference in change between S + B and B groups (all changes are relative to the same month [reduction is shown as negative and increase as positive]).

Gaizhou

	Control				*Behavioral Intervention*				*Stove and Behavioral Intervention*			
	Dec-Jan	Dec-Jan	Mar-Apr	Mar-Apr	Dec-Jan	Dec-Jan	Mar-Apr	Mar-Apr	Dec-Jan	Dec-Jan	Mar-Apr	Mar-Apr
	2003	2004	2003	2005	2003	2004	2003	2005	2003	2004	2003	2005
T1(°C)	3.6	0.0	NA	20.6	4.7	1.3	NA	25.8	10.0	1.0	NA	19.2
T2(°C)	9.6	6.3	20.4	21.8	9.3	12.8	18.0	22.2	13.0	6.5	19.0	17.3
Cooking/Living Room RPM ($\mu g/m^3$)												
n	8	30	33	11	12	30	31	12	12	29	32	12
Level	276 (141, 410)	258 (163, 353)	621^a (260, 982)	135 (66, 204)	176 (122, 230)	192 (144, 240)	218 (175, 260)	133 (44, 223)	444 (117, 771)	199 (141, 257)	206 (152, 260)	204 (136, 271)
△1	-18 (-7%) (p1 = 0.81)		-486^a (-78%) (p1 = 0.01)		16 (9%) (p1 = 0.64)		-85 (-39%) (p1 = 0.08)		-245 (-55%) (p1 = 0.13)		2 (-1%) -(p1 = 0.97)	
△2					34 (p2 = 0.73)		401^a (p2 = 0.20)		-227 (p2 = 0.12)		484^a (p2 = 0.12)	
△3									-261 (p3 = 0.02)		83 (p3 = 0.20)	
CO (ppm)												
n	8	32	9	11	12	32	8	12	12	30	8	12
Level	1.64 (1.33, 1.95)	2.35 (1.57, 3.13)	1.25 (1.05, 1.45)	0.98 (0.56, 1.40)	1.64 (1.37, 1.92)	1.55 (1.17, 1.93)	1.24 (0.91, 1.58)	2.20 (0.09, 4.32)	2.00 (1.51, 2.50)	2.25 (1.64, 2.86)	1.46 (0.51, 2.41)	1.98 (1.26, 2.70)
△1	0.71 (43%) (p1 = 0.09)		-0.27 (-22%) (p1 = 0.20)		-0.09 (-5%) (p1 = 0.67)		0.96 (77%) (p1 = 0.34)		0.25 (13%) (p1 = 0.52)		0.52 (36%) (p1 = 0.33)	
△2					-0.80 (p2 = 0.31)		1.23 (p2 = 0.31)		-0.46 (p2 = 0.61)		0.79 (p2 = 0.16)	
△3									0.34 (p3 = 0.56)		-0.44 (p3 = 0.73)	

	Gaizhou											
	Control				*Behavioral Intervention*				*Stove and Behavioral Intervention*			
	SO_2 (ppm)											
n	8 0.23	32 0.77	9 0.07	11 0.17	12 0.14	32 0.20	8 0.09	12 0.30	12 0.23	30 0.29	8 0.34	12 0.32
Level	(0.14, 0.32)	(0.34, 1.20)	(0.03, 0.12)	(0.09, 0.26)	(0.08, 0.20)	(0.15, 0.26)	(0.01, 0.16)	(0.01, 0.58)	(0.13, 0.33)	(0.18, 0.40)	(0.00, 0.81)	(0.15, 0.49)
△1	0.54 (235%) (p1 = 0.02)		0.10 (143%) (p1 = 0.04)		0.06 (43%) (p1 = 0.12)		0.21 (233%) (p1 = 0.14)		0.06 (26%) (p1 = 0.39)		-0.02 (-6%) (p1 = 0.94)	
△2					-0.48 (p2 = 0.22)		0.11 (p2 = 0.53)		-0.48 (p2 = 0.24)		-0.12 (p2 = 0.54)	
△3									0.00 (p3 = 0.99)		-0.23 (p3 = 0.37)	
	Bedroom RPM ($\mu g/m^3$)											
n	8	28	33	10	12	29	31	12	12	26	32	12
Level	204 (122, 287)	250 (104, 397)	552^b (185, 919)	69 (47, 90)	115 (78, 152)	152 (118, 186)	188 (149, 227)	96 (41, 150)	288 (214, 362)	192 (131, 253)	192 (142, 243)	224 (101, 348)
△1	46 (23%) (p1 = 0.56)		-483^b (-88%) (p1 = 0.01)		37 (32%) (p1 = 0.13)		-92 (-49%) (p1 = 0.01)		-96 (-33%) (p1 = 0.04)		32 (17%) (p1 = 0.61)	
△2					-9 (p2 = 0.94)		391^b (p2 = 0.23)		-142 (p2 = 0.30)		515^b (p2 = 0.11)	
△3									-133 (p3 = 0.02)		124 (p3 = 0.05)	

Gaizhou												
	Control				*Behavioral Intervention*				*Stove and Behavioral Intervention*			
	CO (ppm)											
n	8 1.38	32 1.92	9 1.10	11 0.77	12 1.63	32 1.51	8 1.24	12 1.05	12 2.20	30 1.73	8 1.40	12 1.56
Level	(1.06, 1.70)	(1.39, 2.45)	(0.83, 1.37)	(0.52, 1.02)	(1.36, 1.90)	(1.26, 1.76)	(0.99, 1.48)	(0.22, 1.89)	(1.33, 3.08)	(1.29, 2.16)	(0.42, 2.38)	(0.85, 2.26)
△1	0.54 (39%) (p1 = 0.07)		-0.33 (-30%) (p1 = 0.06)		-0.12 (-7%) (p1 = 0.51)		-0.19 (-15%) (p1 = 0.65)		-0.47 (-21%) (p1 = 0.30)		0.16 (11%) (p1 = 0.77)	
△2					-0.66 (p2 = 0.23)		0.14 (p2 = 0.77)		-1.01 (p2 = 0.13)		0.49 (p2 = 0.38)	
△3									-0.35 (p3 = 0.44)		0.35 (p3 = 0.64)	
	SO_2 (ppm)											
n	8	32	9	11	12	32	7	12	12	30	8	12
Level	0.18 (0.08, 0.29)	0.47 (0.23, 0.70)	0.11 (0.07, 0.15)	0.14 (0.08, 0.21)	0.08 (0.00, 0.15)	0.20 (0.15, 0.25)	0.10 (0.00, 0.23)	0.17 (0.03, 0.31)	0.29 (0.15, 0.44)	0.26 (0.14, 0.37)	0.19 (0.00, 0.43)	0.31 (0.07, 0.55)
△1	0.29 (62%) (p1 = 0.03)		0.03 (27%) (p1 = 0.36)		0.12 (150%) (p1 = 0.01)		0.07 (70%) (p1 = 0.38)		-0.03 (-10%) (p1 = 0.68)		0.12 (63%) (p1 = 0.44)	
△2					-0.17 (p2 = 0.46)		0.04 (p2 = 0.68)		-0.32 (p2 = 0.19)		0.09 (p2 = 0.61)	
△3									-0.15 (p3 = 0.15)		0.05 (p3 = 0.82)	

[a] *If the single largest data point (5,900 μg/m³) is dropped, the average concentrations in the preintervention measurements are reduced to 475 μg/m³. All differences also change by 146 μg/m³, showing more relative benefits in the intervention groups.*

[b] *If the single largest data point (5,292 μg/m³) is dropped, the average concentrations in the preintervention measurements are reduced to 385 μg/m³. All differences also change by 167 μg/m³, showing more relative benefits in the intervention groups.*

Note: T1 and T2 = temperatures measured outside and inside households with pollution measurement, averaged over all measurement days;
n = number of household days of measurement; level = mean concentration (95 percent CI); △1 = change between post- and pre-intervention measurements in the same group; △ 2 = difference in change between each of the two intervention groups and C group; △ 3 = difference in change between S + B and B groups (all changes are relative to the same month [reduction is shown as negative and increase as positive]).

	Inner Mongolia											
	Control				*Behavioral Intervention*				*Stove and Behavioral Intervention*			
	Dec-Jan	Dec-Jan	Mar-Apr	Mar-Apr	Dec-Jan	Dec-Jan	Mar-Apr	Mar-Apr	Dec-Jan	Dec-Jan	Mar-Apr	Mar-Apr
	2003	2004	2003	2005	2003	2004	2003	2005	2003	2004	2003	2005
T1(°C)	4.0	-11.3			2.0	-4.9						
T2(°C)	14.7	11.4			14.7	13.1						
Cooking/Living/Bedroom Point 1 RPM (μg/m³)												
n	28	20[a]			33	15[b]						
Level	549 (446,651)	343 (220,466)			862 (541, 1,184)	251 (76,426)						
△1	-206 (-38%) (p1 = 0.01)				-611 (-71%) (p1 = 0.00)							
△2					-405 (p2 = 0.11)							
CO (ppm)												
n	30	25			35	17						
Level	7.12 (6.09,8.15)	5.87 (4.67, 7.07)			7.62 (6.59, 8.66)	5.32 (4.01, 6.62)						
△1	-1.25) (-18% (p1 = 0.11)				-2.30 (-30%) (p1 = 0.01)							

Inner Mongolia					
	Control		Behavioral Intervention		Stove and Behavioral Intervention
△2			-1.05 (p2 = 0.36)		
			Cooking/Living/Bedroom Point 2 **RPM ($\mu g/m^3$)**		
n	28 551	22[c] 174	33 861	14[d] 174	
Level	(440, 661)	(130, 218)	(425,1,298)	(88, 260)	
△1	-377 (-68%) (p1 = 0.00)		-687 (-80%) (p1 = 0.00)		
△2			-310 (P2 = 0.33)		
			CO (ppm)		
n	30 6.53	25 5.50	35 7.92	16 5.46	
Level	(5.67, 7.40)	(4.50,6.51)	(6.98, 8.85)	(4.13, 6.79)	
△1	-1.03 (-16%) (p1 = 0.12)		-2.46 (-31%) (p1 = 0.00)		
△2			-1.43 (P2 = 0.17)		

[a] *Of the 23 household days of measurement, 3 measurements were dropped because their duration was < 960 min. (16 hrs.).*

[b] *Of the 16 household days of measurement, 1 measurement was dropped because its duration was < 960 min. (16 hrs.).*

[c] *Of the 23 household days of measurement, 1 measurement was dropped because its duration was < 960 min. (16 hrs.).*

[d] *Of the 16 household days of measurement, 2 measurements were dropped because their duration was < 960 min. (16 hrs.).*

Note: T1 and T2 = temperatures measured outside and inside households with pollution measurement, averaged over all measurement days; n = number of household days of measurement; level = mean concentration (95 percent CI); △1 = change between post- and pre-intervention measurements in the same group; △ 2 = difference in change between each of the two intervention groups and C group; △ 3 = difference in change between S + B and B groups (all changes are relative to the same month [reduction is shown as negative and increase as positive]).

Shaanxi												
	Control				*Behavioral Intervention*				*Stove and Behavioral Intervention*			
	Dec-Jan	Dec-Jan	Mar-Apr	Mar-Apr	Dec-Jan	Dec-Jan	Mar-Apr	Mar-Apr	Dec-Jan	Dec-Jan	Mar-Apr	Mar-Apr
	2003	2004	2003	2005	2003	2004	2003	2005	2003	2004	2003	2005
T1(°C)	3.0	-1.4		22.2	4.7	3.8		23.4	5.0	-0.2		16.9
T2(°C)	4.3	3.8	15.9	20.5	5.7	7.0	15.3	21.0	3.7	4.0	18.6	16.7
Cooking Room RPM ($\mu g/m^3$)												
n	12 269	32 170	33 169	11 102	12 214	29 128	34 190	11 178	12 185	29 132	33 200	11 119
Level	(115, 424)	(84, 257)	(132, 206)	(55, 149)	(129, 299)	(100, 156)	(83, 298)	(113, 242)	(105, 265)	(74, 190)	(128, 273)	(62, 177)
△1	-99 (-37%) (p1 = 0.24)		-67 (-40%) (p1 = 0.02)		-86 (-40%) (p1 = 0.06)		-12 (-6%) (p1 = 0.83)		-53 (-29%) (p1 = 0.26)		-81 (-41%) (p1 = 0.07)	
△2					13 (p2 = 0.88)		55 (p2 = 0.59)		46 (p2 = 0.63)		-14) (p2 = 0.85	
△3									33 (p3 = 0.58)		-69 (p3 = 0.55)	
CO (ppm)												
n	12 5.2	8 7.3	8 2.5	12 5.0	12 6.1	8 5.7	8 2.4	12 10.2	12 9.3	6 8.8	8 2.0	11 2.9
Level	(3.3, 7.0)	(5.0, 9.7)	(1.2, 3.8)	(2.4, 7.5)	(2.7, 9.4)	(3.7, 7.7)	(0.9, 3.8)	(4.0, 16.4)	(3.8, 14.8)	(2.2, 15.3)	(1.0, 3.0)	(1.3, 4.5)
△1	2.1 (40%) (p1 = 0.12)		2.5 (100%) (p1 = 0.08)		-0.4 (-7%) (p1 = 0.83)		7.8 (325%) (p1 = 0.02)		-0.5 (-5%) (p1 = 0.89)		0.9 (45%) (p1 = 0.28)	
△2					-2.5 (p2 = 0.30)		5.3 (p2 = 0.17)		-2.6 (p2 = 0.50)		-1.6 (p2 = 0.40)	
△3									-0.1 (p3 = 0.98)		-6.9 (p3 = 0.07)	

Shaanxi												
	Control				*Behavioral Intervention*				*Stove and Behavioral Intervention*			
	SO$_2$ (ppm)											
n	12	33	33	12	12	32	33	12	12	30	33	11
	1.08	0.74	0.63	0.93	0.29	0.93	0.43	0.93	0.69	0.55	0.27	0.39
Level	(0.31, 1.86)	(0.42, 1.06)	(0.40, 0.86)	(0.12, 1.74)	(0.10, 0.48)	(0.43, 1.43)	(0.21, 0.65)	(0.49, 1.38)	(0.31, 1.07)	(0.26, 0.85)	(0.16, 0.38)	(0.18, 0.60)
△1	-0.34 (-31%) (p1 = 0.39)		0.30 (48%) (p1 = 0.45)		0.64 (221%) (p1 = 0.02)		0.50 (116%) (p1 = 0.04)		-0.14 (-20%) (p1 = 0.54)		0.12 (44%) (p1 = 0.30)	
△2					0.98 (p2 = 0.07)		0.20 (p2 = 0.58)		0.20 (p2 = 0.63)		-0.18 (p2 = 0.56)	
△3									-0.78 (p3 = 0.11)		-0.38 (p3 = 0.12)	
	Living Room RPM ($\mu g/m^3$)											
n	12	8	8	6	9	7	8	5	8	8	9	6
	372	113	182	103	386	100	121	57	200	200	327	96
Level	(258, 485)	(59, 166)	(11, 353)	(17, 189)	(228, 544)	(54, 146)	(23, 219)	(9,105)	(148, 252)	(89, 311)	(183, 471)	(0,193)
△1	-259 (-70%) (p1 = 0.00)		-79 (-43%) (p1 = 0.34)		-286 (-74%) (p1 = 0.00)		-64 (-53%) (p1 = 0.19)		0 (0%) (p1 = 1.00)		-231 (-71%) (p1 = 0.01)	
△2					-27 (p2 = 0.79)		15 (p2 = 0.88)		259 (p2 = 0.01)		-152 (p2 = 0.23)	
△3									286 (p3 = 0.01)		-167 (p3 = 0.12)	

Shaanxi												
	Control				*Behavioral Intervention*				*Stove and Behavioral Intervention*			
						CO (ppm)						
n	12 8.2	8 21.1	8 4.3	6 1.3	10 21.2	8 31.0	8 2.9	6 1.2	8 11.3	8 30.7	8 8.6	6 3.4
Level	(7.8, 8.5)	(14.6, 27.5)	(1.6, 7.0)	(0.1, 2.5)	(9.7, 32.7)	(15.6, 46.4)	(1.9, 3.9)	(0.3, 2.0)	(4.7, 17.9)	(20.0, 41.4)	(3.8, 13.4)	(0.0, 8.3)
△1	12.9 (157%) (p1 = 0.00)		-3.0 (-70%) (p1 = 0.04)		9.8 (46%) (p1 = 0.25)		-1.7 (-59%) (p1 = 0.01)		19.4 (172%) (p1 = 0.00)		-5.2 (-60%) (p1 = 0.09)	
△2					-3.1 (p2 = 0.70)		1.3 (p2 = 0.41)		6.5 (p2 = 0.23)		-2.2 (p2 = 0.50)	
△3									9.6 (p3 = 0.34)		-3.5 (p3 = 0.25)	
						SO_2 (ppm)						
n	12 2.10	8 2.66	8 0.71	6 0.14	10 1.45	8 1.69	8 0.31	6 0.10	8 0.44	9 2.34	9 1.80	6 0.19
Level	(1.12, 3.09)	(1.46, 3.85)	(0.14, 1.28)	(0.00, 0.28)	(0.55, 2.36)	(0.79, 2.59)	(0.11, 0.51)	(0.05, 0.16)	(0.17, 0.70)	(1.21, 3.48)	(1.25, 2.34)	(0.04, 0.33)
△1	0.56 (27%) (p1 = 0.42)		-0.57 (-80%) (p1 = 0.05)		0.24 (17%) (p1 = 0.67)		-0.21 (-68%) (p1 < 0.05)		1.90 (432%) (p1 = 0.00)		-1.61 (-89%) (p1 = 0.00)	
△2					-0.32 (p2 = 0.73)		0.36 (p2 = 0.24)		1.34 (p2 = 0.14)		-1.04 (p2 = 0.02)	
△3									1.66 (p3 = 0.04)		-1.40 (p3 = 0.00)	
						Bedroom RPM ($\mu g/m^3$)						
n	6 267	29 121	33 150	11 95	8 250	28 98	33 184	12 90	10 506	30 74	32 227	11 70
Level	(160, 373)	(94, 148)	(102, 198)	(56, 135)	(81, 419)	(73, 123)	(133, 235)	(53, 126)	(346, 666)	(48, 100)	(71, 384)	(33, 107)
△1	-146 (-55%) (p1 = 0.02)		-55 (-37%) (p1 = 0.07)		-152 (-61%) (p1 = 0.07)		-94 (-51%) (p1 = 0.00)		-432 (-85%) (p1 = 0.00)		-157 (-69%) (p1 = 0.05)	

Shaanxi												
	Control				Behavioral Intervention				Stove and Behavioral Intervention			
△2					-6 (p2 = 0.91)		-39 (p2 = 0.51)		-286 (p2 = 0.00)		-102 (p2 = 0.46)	
△3									-280 (p3 = 0.00)		-63 (p3 = 0.64)	
CO (ppm)												
n	6 5.5	8 5.1	8 2.5	12 0.7	8 9.5	8 4.6	8 1.5	12 2.0	10 15.0	8 16.7	8 2.2	11 0.8
Level	(3.0, 8.0)	(0.0, 11.8)	(0.3, 4.6)	(0.4, 1.0)	(0.0, 20.6)	(1.4, 7.8)	(0.4, 2.6)	(0.5, 3.4)	(7.4, 22.6)	(5.6, 27.7)	(0.0, 4.4)	(0.5, 1.0)
△1	-0.4 (-7%) (p1 = 0.90)		-1.8 (-72%) (p1 = 0.09)		-4.9 (-52%) (p1 = 0.34)		0.5 (33%) (p1 = 0.56)		1.7 (11%) (p1 = 0.78)		-1.4 (-64%) (p1 = 0.18)	
△2					-4.5 (p2 = 0.47)		2.3 (p2 = 0.06)		2.1 (p2 = 0.77)		0.4 (p2 = 0.72)	
△3									6.6 (p3 = 0.39)		-1.9 (p3 = 0.13)	
SO_2 (ppm)												
n	6 0.81	33 0.62	33 0.35	12 0.15	8 1.06	32 0.63	32 0.29	12 0.34	10 2.00)	31 0.31	32 0.80	11 0.14
Level	(0.00, 1.66)	(0.20, 1.04)	(0.15, 0.55)	(0.01, 0.29)	(0.00, 2.51)	(0.25, 1.01)	(0.08, 0.49)	(0.00, 0.72)	(1.19, 2.82	(0.18, 0.44)	(0.47, 1.13)	(0.07, 0.21)
△1	-0.19 (-23%) (p1 = 0.64)		-0.20 (-57%) (p1 = 0.09)		-0.43 (-41%) (p1 = 0.52)		0.05 (17%) (p1 = 0.79)		-1.69 (-85%) (p1 = 0.00)		-0.66 (-83%) (p1 = 0.00)	
△2					-0.24 (p2 = 0.74)		0.25 (p2 = 0.33)		-1.50 (p2 = 0.01)		-0.46 (p2 = 0.15)	
△3									-1.26 (p3 = 0.02)		-0.71 (p3 = 0.04)	

Note: T1 and T2 = temperatures measured outside and inside households with pollution measurement, averaged over all measurement days; n = number of household days of measurement; level = mean concentration (95 percent CI); △ 1 = change between post- and pre-intervention measurements in the same group; △ 2 = difference in change between each of the two intervention groups and C group; △ 3 = difference in change between S + B and B groups (all changes are relative to the same month [reduction is shown as negative and increase as positive]).

Annex 4.2
Provincial Tables for IAP-related Knowledge and Behavioral Changes

Table A4.2.1: Survey Results for Women's IAP-related Knowledge

	Gansu			*Guizhou*			*Inner Mongolia*		*Shaanxi*		
	n = 152	n = 156	n = 155	n = 154	n = 154	n = 168	n = 164	n = 159	n = 161	n = 159	n = 159
Factor	S + B	B	C	S + B	B	C	B	C	S + B	B	C
Sources of IAP											
Cooking (baseline)	30.3	36.5	43.2				82.3	73.0			
△1	66.9*	41.5*	53.8*				8.4*	1.3			
△2	13.1*	-12.3*					7.1				
△3	25.4*										
Heating	13.8	19.9	16.8				68.3	46.5			
△1	64.3*	41.4*	48.0*				-2.9	-0.8			
△2	16.3*	-6.6					-2.1*				
△3	22.9*										
Smoking	10.5	17.9	19.4								
△1	31.4*	29.5*	26.1*								

	Gansu			*Guizhou*			*Inner Mongolia*		*Shaanxi*		
△2	5.3	3.4									
△3	1.9										
Health Impact of IAP	75	79.5	69	52.0	48.1	60.7					
△1	24.6*	12.3*	28.4*	44.3*	6.4*	0.7					
△2	12.3	-16.1*		43.6*	5.7*						
△3	28.4*			37.9							
IAP Control Methods											
Improving Stove	28.3	26.3	32.9				73.8	49.7	61.4	74.1	79.2
△1	65.5*	65.2*	58.0*				2.2	-3.2	28.9*	-9.3*	-5.1
△2	7.5	7.2					5.4		34.0*	-4.2*	
△3	0.3								29.8*		
Improving Ventilation	31.6	30.1	38.7						37.9	34.8	43.4
△1	5.6	20.0*	-2.5						7.3	17.2*	0.5
△2	8.1	22.5*							6.8	16.7	
△3	-14.4*								-9.9		
No Smoking Indoors	3.9	3.2	6.5				42.7	45.9			
△1	7.4*	10.8*	1.0				21.2*	10.6*			
△2	6.4	9.8 *					10.6				

	Gansu	*Guizhou*	*Inner Mongolia*	*Shaanxi*
△3	-3.4			
Understanding Rate of Dental Fluorosis	4.6	19.1	6.0	
△1	89.1*	71.3*	19.1*	
△2	70*	52.2*		
△3	17.8*			

* *Difference is statistically significant at 5 percent level.*

Note: *△1 = percentage changes pre- and post-intervention in the same study group; △ 2 = S + B and B groups compared with C group for changes; △ 3 = S + B group compared with B group for changes.*

Table A4.2.2: Survey Results for Children's IAP-related Knowledge

	Gansu		*Guizhou*		*Inner Mongolia*		*Shaanxi*	
Factor	B n = 367	C n = 186	B n = 288	C n = 158	B n = 130	C n = 189	B n = 417	C n = 151
Source of IAP	12.7	12.7	7.8	7.8	68.3	43.8	6.2	6.2
△1	61.1*	74.9*	87.0*	78.3*	29.4*	11.2*	78.0*	73.9*
△2	-13.8*		8.7		18.2*		4.1	
Pollutants	26.7	27.4	53.8	16.2			49.4	49.4
△1	33.5*	4.9	43.4	31.9			36.2*	4.2
△2	28.6*		11.5*				32.0*	
Health Impact	45.2	23.7	74	20.7	87.5	44.3	43.9	43.9
△1	28.6*	55.9*	17.7*	55.9*	12.5*	50.9*	53.2*	44.8*
△2	-27.3*		-38.2*		-38.4*		8.4*	
IAP Control Methods	41.1	34.4	66.5	14.9	67.2	51.9	50.1	50.1
△1	35.2*	50.6*	29.3*	60.9*	25.9*	5.2	45.1*	37.3*
△2	-15.4*		31.1*		20.7*		7.8*	
Etiology of Dental Fluorosis								
Coal Smoke			11.7	11.7			3.1	3.1
△1			68.2*	4.1			69.3*	33.3*
△2			64.1*				36.0*	

Gansu	*Guizhou*			*Inner Mongolia*	*Shaanxi*				
Factor	B n = 367	C n = 186	B n = 288	C n = 158	B n = 130	C n = 189	B n = 417	C n = 151	
Food Contaminated with Fluorides				27.0	27.0			33.7	33.7
△1			58.4*	-5.5	7.1*		48.8*	13.3*	
△2			63.9*				35.5*		
Measures for Dental Fluorosis Prevention				56.6	11.9			23.3	23.3
△1			42.7*	33.7*			53.2*	-10.7*	
△2			9.0*				63.9*		

* *Difference is statistically significant at 5 percent level.*

Note: △ *1 = percentage changes pre- and post-intervention in the same study group;* △ *2 = behavioral intervention (health education) (B) group compared with control (C) group for changes.*

Table A4.2.3: Survey Results for Women's IAP-related Behavioral Changes

	Gansu			*Guizhou*			*Inner Mongolia*		*Shaanxi*		
Factor	S+B n = 470	B n = 473	C n = 505	S+B n = 377	B n = 456	C n = 458	B n = 454	C n = 490	S+B n = 414	B n = 458	C n = 437
Cover Stove Mouth After Adding Fuel				86.7	71.5	87.6			66	38.8	54.2
△1				10.9*	24.3*	1.5			10.2*	1	5.2
△2				9.4*	22.8*				5	-4.2	
△3				-13.4*					9.2		
Close Stove Door When Using	39.4	30.9	25.7				22	58.8			
△1	37.4*	5.5	3.8				64.8*	24.7*			
△2	33.6*	1.7					40.1*				
△3	31.9*										
Use Shorter Wood	85.7	91.1	90.7						93.2	91.3	93.9
△1	7.3*	2.3	0.4						5.9*	0.5	2.8
△2	6.9*	1.9							3.1	-2.3	
△3	5								5.4		

	Gansu			*Guizhou*			*Inner Mongolia*		*Shaanxi*		
Water Ash Before Removing	53.4	43.1	37.2	25.5	9.4	16.8	3.7	1.2			
△1	8.5*	3.2	-0.2	10.8*	4.9*	1.3	74.5*	1.9*			
△2	8.7	3.4		9.5*	3.6		72.6*				
△3	5.3			5.9							
Open Windows While Cooking				n = 154	n = 154	n = 168			n = 157	n = 156	n = 58
Often	82.2	89.1	89.9	75.7	69.2	75.6	12.8	33.8	54.8	71.2	72.8
△1	12	-10.3	-2.7	16.8*	15.2*	-9.2	73.9	36.1	32.2	-2.4	3.4
△2	14.7*	-7.6		26.0*	24.4		37.8*		28.8*	-5.8	
△3	22.3*			1.6*					34.6*		
Rarely	7.2	1.9	4.4	5.8	15.9	13.3	84.9	66.2	37.6	21.8	24.7
△1	-2	13.9	6.2	1.5*	-1.0*	13.8	-71.8	-37.3	-27.1	7.6	-1.4
△2	-8.2	7.7		-12.3*	-14.8		-34.5		-25.7	9	
△3	-15.9			2.5					-34.7		
Never	10.5	9	5.7	18.5	14.9	11.1	2.3	0	7.6	7.1	2.5
△1	-9.9	-3.5	-3.5	-18.3*	-14.2*	-4.6	-2.1	0.2	-5.1	-5.3	-2
△2	-6.4	0		-13.7*	-9.6		-2.3		-3.1	-3.3	
△3	-6.4			4.1*					0.2		

* *Difference is statistically significant at 5 percent level.*

Note: △ 1 = percentage changes pre- and post-intervention in the same study group; △ 2 = S + B and B groups compared with control group for changes; △ 3 = S + B group compared with B group for changes.

Table A4.2.4: Survey Results for Children's IAP-related Behavioral Changes

	Gansu		*Guizhou*		*Shaanxi*	
	B	C	B	C	B	C
Factor	n = 367	n = 186	n = 288	n = 158	n = 417	n = 151
Every Day or Often in the Kitchen	35.6	42.2	36.3	33.3	36.5	20.9
△1	0.6	7.8	-2.1	-0.4	-20.8	-4.9
△2	-7.2		-1.7		-15.9*	
Rarely	49.7	51.7	50	56	60.9	71.4
△1	9.6	-7.2	1.8	-5.7	21.2	0.8
△2	16.4		7.5		20.4	
Never	14.7	6.1	13.7	10.7	2.6	3.3
△1	-10.2	-0.6	0.3	6.1	-0.3	-0.5
△2	-9.6		-5.8		0.2	
Get Out and Avoid Smoke			84.4	64.6	71.5	88.3
△1			8.0*	22.1*	22.5*	9.6*
△2			-14.1*		12.9*	

** Difference is statistically significant at 5 percent level.*

Note: There were no survey results for Inner Mongolia; △ 1 = percentage changes pre- and post-intervention in the same study group; △ 2 = B group compared with C group for changes.

Annex 4.3
Health Survey and Examination Results for Selected IAP-related Health Symptoms, by Province

Selected Health Symptom		*Gansu*			*Guizhou*			*Inner Mongolia*		*Shaanxi*	
	S + B	*B*	*C*	*S + B*	*B*	*C*	*B*	*C*	*S + B*	*B*	*C*
Women Respiratory	n= 593	n = 620	n = 653	n = 548	n = 550	n = 562	n = 545	n = 572	n = 578	n = 494	n = 499
	11.1	5	27.3	10.8	14.5	22.7	13	7.7	25.1	11.9	12.2
△1	-2.1	14.6*	-9.7*	12.5*	-1.9	15.8*	-5.5*	12.8*	-1	8.1*	9.8*
△2	7.6*	24.3*		-3.3	-17.7*		-18.3*		-10.8*	-1.7	
△3	-16.7*			14.4*					-9.1*		
Eye	14	7.6	23.3	9.5	13.5	21.2	7.5	3.2	21.1	13	9.2
△1	-3.4	18.7*	-2.2	14.9*	-3.1	14.4*	-2.7	8.5*	2.5	18.1*	23.8*
△2	-1.2	20.9*		0.5	-17.5*		-11.2*		-21.3*	-5.7	
△3	-22.1*			18.0*					-15.7*		
Headache/ Dizziness	28.2	15.3	34.5	15.4	32.2	44.3	17.8	6.6	42.4	28.3	34.9
△1	1	12.7*	-5.4*	15.6*	-8.0*	5.9	-14.2*	-1.5	-30.3*	10.0*	8.6*
△2	6.4	18.1*		9.7*	-13.9*		-12.7*		-38.9*	1.4	
△3	-11.7*			23.6*					-40.3*		

Selected Health		*Gansu*			*Guizhou*		*Inner Mongolia*			*Shaanxi*	
Symptom	*S + B*	*B*	*C*	*S + B*	*B*	*C*	*B*	*C*	*S + B*	*B*	*C*
Children 8-12	n = 730	n = 741	n = 770	n = 711	n = 739	n = 813	n = 623	n = 645	n = 855	n = 748	n = 773
Eye	4.5	1.5	4.2	1.3	3.8	5.7	2.3	2.8	11.4	3.6	2.3
△1	0.9	3.7*	-0.7	4.6*	-2.5*	5.3*	-0.4	4.2*	-5.5	10.1	14.1
△2	1.6	4.4*		-0.7	-7.8*		-4.6*		-19.6*	-4	
△3	-2.8			7.1*					-15.6*		
Nose	14.3	6.5	22	11.1	23.2	18.8	14.6	11.5	40.9	32.2	28.5
△1	2.6	12.5*	-0.2	6.0*	-12.6*	14.7*	-6.1*	10.8*	-20.9*	-4.4	0.8
△2	2.8	12.7*		-8.7*	-27.3*		-16.9*		-21.7*	-5.2	
△3	-9.9*			18.6*					-16.5*		
Pharynx	6	2.6	10.5	3.5	4.7	10.6	5.3	4.7	14.7	6.7	3.1
△1	2.8	8.6*	0.6	2.2	1.2	0.6	-2.5*	-1.3	-5.7*	1.1	7.8*
△2	2.2	8.0*		1.6*	0.6*		-1.2*		-13.5*	-6.7*	
△3	-5.8*			1					-6.8*		
Acute Respiratory Infection(children < 5) Symptoms	n = 600 42.3	n = 569 51.5	n = 885 53.8	n = 785 24.3	n = 792 43.7	n = 670 39.3	n = 1,084 30.2	n = 883 21	n = 1,022 23.1	n = 1,104 15.4	n = 1,109 14.9
△1	0.9	-41.2*	3.4	-14.1*	-14.8*	31.1*	-3.6*	-2.4	29.0*	15.3*	-3.9*

Selected Health Symptom	*Gansu*			*Guizhou*			*Inner Mongolia*		*Shaanxi*		
	S + B	*B*	*C*	*S + B*	*B*	*C*	*B*	*C*	*S + B*	*B*	*C*
△2	-2.5	-44.6*		-45.2*	-45.9*		-1.2		32.9*	19.2*	
△3	42.1*			0.7					13.7*		
Cough, Phlegm, Hemoptysis	32	16.2	26.4	8	11.4	22.6	20	8.5	14.4	7.7	8.2
△1	1.8	-10.4*	-2	-3.5*	0	15.8*	-7.2*	0.1	6.1*	6.7*	-2.7*
△2	3.8	-8.4*		-19.3*	-15.8*		-7.3*		8.8*	9.4*	
△3	12.2*			-3.5					-0.6		
Dyspnea	5.2	1.9	1.1	0.8	0.8	0.9	0.1	0.9	0.3	0.1	0
△1	-1.5	-0.6	-0.4	-0.4	-0.3	0.8	0.5*	-0.5	18.2*	-0.1	0.1
△2	-1.1	-0.2		-1.2	-1.1		1.0*		18.1*	-0.2	
△3	-0.9			-0.1					18.3*		
Nasal Mucus	32.2	23.9	39.1	19.9	39.5	28.1	18.7	14.3	19.1	14.7	13
△1	-1.9	-18.9*	11.5*	-11.5*	-4.9*	20*	2.4	-0.2	19.2*	13.3*	-3.4*
△2	-13.4*	-30.4*		-31.5*	-24.9*		2.6		22.6*	16.7*	
△3	17.0*			-6.6					5.9*		
Pharynx	36.7	41.1	31	4.8	7.8	5.7	3.1	2.2	4	0.8	1
△1	-0.4	-34.2*	0.5	-3.7*	-3.7*	10.4*	3.7*	1.2	11.3*	4.4*	6.3*

Selected Health	*Gansu*			*Guizhou*			*Inner Mongolia*			*Shaanxi*	
Symptom	*S + B*	*B*	*C*	*S + B*	*B*	*C*	*B*	*C*	*S + B*	*B*	*C*
△2	-0.9	-34.7*		-14.1*	-14.1*		2.5		5.0*	1.9	
△3	33.8*			0*					3.1*		
Eye	0.3	1.2	0.6	0	0	0.3	0	0	0.6	0	0
△1	1.8*	-1.2*	-0.2	0	0	0.8	0.2	0	-0.3	0	0
△2	2	-1		-0.8	-0.8		0.2		-0.3	0	
△3	3			0					-0.3		

* *Difference is statistically significant at 5 percent level.*

Note: n = number of observations; △ 1 = percentage changes pre- and post-intervention in the same study group; △ 2 = S + B and B groups compared with C group for changes; △ 3 = S + B group compared with B group for changes.

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The Energy Sector Management Assistance Program (ESMAP) is a global technical assistance partnership administered by the World Bank and sponsored by bi-lateral official donors, since 1983. ESMAP's mission is to promote the role of energy in poverty reduction and economic growth in an environmentally responsible manner. Its work applies to low-income, emerging, and transition economies and contributes to the achievement of internationally agreed development goals. ESMAP interventions are knowledge products including free technical assistance, specific studies, advisory services, pilot projects, knowledge generation and dissemination, trainings, workshops and seminars, conferences and round-tables, and publications.

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