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Pilot Commercialization of Improved Cookstoves in Nicaragua

December 2005

ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME (ESMAP)

PURPOSE

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Table of Contents

List of Tables

List of Figures

Acknowledgments

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1

Introduction

1.1 About 3 billion people in developing countries still rely heavily on traditional biomass fuels. In Central American countries, particularly Guatemala, Honduras, Nicaragua and Haiti, many poor people use wood almost exclusively for cooking and heating. Where the wood burned for energy comes from unsustainable sources, the long-term impact on surrounding forest resources could be devastating. Equally serious is the negative impact on the health of women and other household members caused by indoor air pollution from cookstoves used in enclosed traditional kitchens.

1.2 The advent of modernization and improved access to modern fuels in these countries are not likely to significantly reduce dependence on biomass by majority of the populations in the coming decades. The problem must be met head-on by a combination of measures that promote sustainability of supply (e.g., forest management, renewable plantations) and improve efficiency of use. If biomass production and use could be carried out in a sustainable manner, it has the potential of generating much-needed employment opportunities in rural areas and contributing to energy self-reliance in petroleum-poor countries.

1.3 One problem is that biomass, as a “renewable” energy source, is commonly perceived as a “free good” that will continue to be available to all indefinitely. But urbanization and industrialization has, in many countries, already irreversibly constrained the availability of biomass resources. Peri-urban areas, in particular, have come under increasing pressure to use scarce land for both biomass energy and agricultural products. In many areas, biomass scarcity has already forced people to use low quality residues as cooking fuel. Rising demand for commercially-traded fuelwood in towns and cities, on the other hand, has put pressure on supplies in nearby rural areas. As rural supplies become monetized, traditional “free” sources for poor rural dwellers are drastically diminished

1.4 A survey of several urban areas of Nicaragua in 1998 showed 59% of the population as daily wood users, consuming almost 500,000 tons of wood per year. According to the energy profile report published by the Nicaraguan Energy institute for 1997, fuelwood represented about 47% of the internal gross primary supply of energy, while petroleum represented 24%, electricity 25% and other biomass residues 3%. The fuelwood consumption in Nicaragua is predominantly for household use, since 90% of it is used for home cooking, while the other 10% is for rural and artesanal industries (bakeries, lime and brick production and charcoal).

1.5 The problems facing the fuelwood sector in Nicaragua can be summarized as follows: First, almost all harvest or production is based on non-sustainable forestry, with little or no regulation or enforcement of wood cutting laws, no incentives for conservation and no long-term supply-side planning. Second, almost all fuelwood is consumed by users in low efficiency stoves or kilns, and no demand-side management efforts have been carried out. Although wood is the major energy source and forest product of Nicaragua, and strongly linked to the lives of the poor, there appears to be no government agency charged with the planning and modernization of this sector,

Project objectives and background

1.6 Among ESMAP's major goals are to improve access to efficient and affordable energy by the unserved or underserved populations in developing countries especially those in rural and peri-urban areas, and to promote environmentally sustainable energy practices. The proposed activity was highly consistent with these goals, as it seeks to improve the standard of living and health conditions of poor urban households that still rely on traditional fuels. As much as a third or half of wood consumption per household could be avoided with a shift to higher efficiency stoves, with a consequent reduction in fuel expenditures Since the improved stoves will have chimneys to vent smoke to the outside, there will be immediate relief from inhalation of fumes and, in the long term, a reduced incidence of respiratory illnesses in these households.

1.7 In 1998 an ESMAP-financed study of the household energy sector resulted in several recommendations to improve fuelwood supply and demand management in Nicaragua for environmental and social welfare reasons. A follow-up study was done in 1999 by CATIE-PROLEÑA for the National Energy Commission (CNE). Among its findings was that less than 5% of the fuelwood users in the Pacific region (the most populated region) are aware of improved woodstoves. It also found that the reasons for the very low level of dissemination of improved woodstoves in the Pacific region are its geographical limitation to areas where NGOs operate, the unavailability of commercial models and/or specialized materials for construction, lack of mass promotion, and lack of financial incentives to stoves producers. The flaws of past programs have been many, including inattention to basic household economics, inclusion of inappropriate markets (e.g. where wood was not purchased, scarce or expensive) lack of a commercial focus, inappropriate stoves, high cost, lack of credit mechanisms, inefficient production methods, lack of effective dissemination strategies, lack of public education and inadequate funding. Almost all fuelwood is consumed in low efficiency traditional stoves (about 10-15% thermal efficiency), thus wasting vast amounts of the biomass resource. Most of the traditional stoves have no chimney.

1.8 The present ESMAP technical assistance activity strongly emphasizes the role of the private sector in improved stoves dissemination. Its expected outcomes were:

- Useful knowledge gained by small private stoves producers of more efficient, less polluting stoves designs, and
- Considerably heightened public awareness of the health impacts of traditional open fire stoves used in typical closed kitchens, and hence appreciation of the health benefits of improved stoves.
- Reduction of indoor pollution where feasible through promotion of the use of high efficiency stoves equipped with chimneys that vent emissions outside the house.

1.9 The technical assistance activity would catalyze the commercialization of improved cookstoves in Nicaragua by improving the understanding of consumer preferences, developing an effective dissemination strategy, selecting financially viable high-efficiency models which satisfy consumer preferences, training and supporting private entrepreneurs to manufacture and sell the stoves in a financially sustainable manner, and supporting development of credit networks for stove purchases. The specific objectives were to improve the kitchen and household environment, reduce indoor pollution and lower cooking costs. Further, the project would support the efficient use of fuelwood and, thus, help to protect biomass resources.

1.10 In Nicaragua, two agencies were involved in the realization of this ESMAP activity: the *Comision Nacional de Energia* (CNE), the government agency in-charge of the energy sector; and PROLEÑA, an active NGO specializing in fuelwood issues that has had a long presence in Nicaragua, Honduras and other parts of Central America. PROLEÑA had been active in identifying, testing and promoting a variety improved stove designs originating from various parts of Central America, such as the EcoStove from Honduras, the Chefina Stove from Guatemala and the Turbo Stove from El Salvador. A subcontract was executed with PROLEÑA to manage the day to day implementation tasks. PROLEÑA's capabilities were further strengthened as a result of this work. After the ESMAP project, PROLEÑA intends to seek new sources of funds for future expansion to other geographic areas. This project is replicable in cities of Nicaragua other than the pilot sites. Its potential for replicability is also high in similar heavy fuelwood consuming Central American countries such as Honduras, El Salvador and Guatemala.

1.11 The main components of this ESMAP activity were: the development of improved stoves models suitable for the target group (Ecostoves); conduct of an empirical study about impacts of the use of the improved stoves on indoor air pollution; conduct of a survey evaluating the market demand for improved stoves; design of a dissemination strategy, which involves the selection of participating private manufacturers, technology transfer and conduct of focused marketing activities, and, finally, monitoring and evaluation of sales and project impementation.

2

Stoves and Indoor Air Pollution

2.1 It is well known that emissions from biomass-fueled stoves in homes are a major contributor to respiratory diseases, particularly to women and children who tend to spend more time indoors. Studies in Africa, India and Nepal have shown that concentrations of particles, organic compounds and carbon monoxide in rural village homes burning biomass fuels are 10-100 times higher than in dwellings using non-biomass cooking appliances. Past studies conducted in Kenya, Papua New Guinea, India, China and Nepal found strong correlation between biofuel use for indoor cooking and high prevalence of respiratory infections such as chronic lung disease, bronchitis, emphysema and nasopharyngeal cancer. The major pollutants used as indices in the studies were carbon monoxide, particulates, polycyclic organic matter and formaldehyde, all of which are present in emissions from wood cookstoves. The studies also found evidence of a link between incidence of respiratory illness and other deseases and poor kitchen ventilation, as well as with the amount of time regularly spent in cooking.

2.2 The expected reduction in incidence of these illnesses is a secondary but vital outcome of programs to disseminate higher efficiency cooking stoves. Improved woodstoves, such as the types promoted in this ESMAP project, clearly have the potential to greatly reduce exposure to emissions from cooking with biofuels not only due to more efficient combustion but also the incorporation of chimneys that vent smoke to the outdoors.

Method

2.3 The Center for International Health and Development (CEIHD) at the University of California was commissioned to carry out indoor air pollution (IAP) measurements in kitchens using open fire and EcoStoves. IAP exposure is widely accepted as a valid and reliable indicator of health risk.

2.4 In 2002, CEIHD researchers conducted the study in Ciudadela de San Martin, a recently settled village approximately 2 Km from the town center of Tipitapa, to evaluate the efficacy and effectiveness of two models of the EcoStove in reducing IAP. The village was chosen because of the population’s almost exclusive use of biomass fuel and open fires for household cooking and the large proportion of indoor kitchens. The town is located approximately 15 Km to the north of Managua and has approximately 1000 homes. Typical homes are made of wooden planks for walls and corrugated iron for roofs and have dirt floors. Most of the homes have electricity. Only participants with kitchens with walls on all four sides were recruited for the study, which would make the ventilation rates lower than in typical homes. Households with any kind of gas stove were excluded from the study.

2.5 Specific objectives of the study design included:

- comparing the performance of two competing EcoStove designs for reducing indoor concentrations and personal exposures to particle matter less than 2.5 micrometers in aerodynamic diameter ($PM_{2.5}$).
- simulating, as much as possible, the non-experimental, real-life conditions under which people use improved stoves.
- controlling the influence of confounding factors that may bias the stove comparisons.

2.6 The CEIHD research analyst coordinated field staff training, revisions of field data logs, refinement of the inclusion criteria for the study, and a brief pilot study using a continuous particle monitor. After the initial round of measurements among the 60 study participants, half the participating households received an entirely closed EcoStove while the others received a newer, slightly less expensive model with a semi-open design. The closed EcoStove model had a completely closed 1/8" steel stovetop griddle, on top of a stove body made of a mix of cement and pumice stone cast around a ceramic combustion chamber elbow ("closed EcoStove"). The second, slightly less expensive, newer model, had the same stove body, however with a smaller metal griddle on one side and one open pothole on the other side, allowing both direct contact between the fire and the pots and an opportunity for release of combustion emissions indoors if a pot is not placed over the pothole ("semi-open EcoStove"). Both models had metal tube chimneys and ceramic elbow combustion chambers. IAP-measurements were made of kitchen pollution levels and personal exposures (through monitors attached to the person cooking).

Results

2.7 The results show that use of the EcoStove reduced kitchen pollution and personal exposure levels by about 75%. Both the closed and semi-open EcoStove models achieved large reductions in indoor air pollution and exposure among Nicaraguan women cooking in enclosed kitchens. Adjusting for the effects of study group, duration of cooking, burning trash and average daily temperature, introduction of the closed Eostove was associated with an 86% reduction in $PM_{2.5}$exposure, while the introduction of the semi-open model was associated with an 80% reduction. The magnitude of the exposure reductions for both EcoStove models is expected to have great health benefits for Nicaraguan families.

2.8 Since the health benefits will be multiplied by the amount of time the exposure reductions are maintained, an important next step would be to evaluate whether these reductions in exposure are sustained over time.

3

Determining Market Demand for Improved Stoves

3.1 A market demand study was commissioned for the ESMAP activity with consultants Jose Eddy Torres and Jorge Navas.[1] Their research was done in three cities of the Pacific region-Managua. León and Granada. Two questionnaires were prepared for the two main potential markets of the Ecostove: households and small and medium-sized businesses in the food sector

3.2 The questionnaires for the households gauged consumption patterns and preferences : principal cooking fuels used, amount of food cooked for consumption at home, and the food precooked for consumption outside, e.g. the tortillas cooked at home and the tortillas they brought to work precooked. Households were excluded that were located in districts and have medium or high income, as the majority are already using modern fuels, and also those families that live in extreme poverty because they would not be able to afford the purchase of a new woodstove. The questionnaire for households consisted of 93 questions divided into the following groups:

- Data about the family members
- Character of the household: living conditions, size of the house, public services etc.
- Use of combustible in the household: combustibles used, places where they collect firewood, suppliers of LPG, different types of stoves used, time spent for cooking etc.
- Cooking habits: place of stove, cooking utensils used, favourite combustibles for different kind of food
- Advantages and disadvantages of different fuels and reasons for fuel change
- State of knowledge about improved stoves; desired characteristics of improved stoves, willing to pay etc.

1 For more details please see market survey Estudio de Mercado de Estufas Mejoradas de Leña en el Pacífico Urbano de Nicaragua – 2001 PorJosé Eddy Torres con Jorge Navas Informe de Consultoría al Banco Mundial Marzo, 2002

- Household equipment and level of household expenditure: house equipment in terms of electrical house appliances and vehicles, level of related expenditure etc.
- Health aspects: Kind and extent of emissions, time spent in kitchen, diseases of the person spending most of the time in the kitchen etc.

3.3 The questionnaire for the businesses contained 54 questions divided in the following groups:

- Localization, Identification and history of the business
- Consume of firewood and charcoal
- Estimation of the average volume of production
- Preferences for the combustibles (Similar to household questionnaire)
- Knowledge, preferences and willingness to pay for improved stoves (Similar to household questionnaire)
- Average daily production of food, etc.
- Health aspects (Similar to household questionnaire)

In Managua the consultants obtained data on 93 food businesses and 85 fuelwood or carbon vegetal sellers, in León on 74 food businesses and 44 fuel sellers, and in Granada on 41 businesses.. The most common businesses were charcoal sellers, fuelwood sellers, frijoles y tortillas shops, in this order.

Results

Fuels used for cooking

3.4 In Managua more than half of the households questioned used LPG as the only fuel, 8 % used only fuelwood and nearly 20% used both fuels for cooking in 2001. The trend was clearly towards an increased use of LPG. In León, LPG use increased from 41% to 50% between 1999 to 2001. In Granada only data of 2001 were available but, there also, half of the population was already using LPG as the principal fuel for cooking. Overall, about 35% of all urban households were using two different fuels at the same time. This suggested that those in transition to LPG cooked at least some food with firewood or charcoal and, therefore, they continue to be potential improved stoves buyers.

3.5 The principal reason give for using wood for cooking for about 43% of wood consumers was that wood seemed cheaper to them and nearly 30% have the opinion that the food tasted better than when it was cooked with wood. Further, these households said it was quicker and they could buy the fuel on a daily basis.

Substitution of fuelwood with modern fuels

3.6 A marketing risk for improved stoves is the rapid and continuing shift to LPG and/or kerosene for domestic cooking. Since this appears to be the natural market progression, it would be inappropriate and probably futile to counter this shift. Therefore, the market analysis focused also on the market development of LPG.

3.7 The three main determinants in the transition from traditional to modern energy use are fuel availability, affordability and cultural preferences. In cities, consumption patterns are more likely to be affected by relative fuel prices. In general, there exist several barriers for the transition from biomass to LPG:

- The high costs of stoves replacement, the convenience of being able to buy wood on a daily basis and in small amounts, in contrast with LPG which requires a larger disbursement from the family budget when it is time to refill the cylinder.
- Volatility of LPG prices and increasing international oil prices.
- Problems with import and delivery of LPG
- Cultural factors

3.8 The most important reason given for substitution of wood with LPG by nearly 60% of respondents was that wood is “dirtier” than LPG. This was followed by concerns regarding the effects of wood use on health. Less frequently, the reason given was that LPG is a modern fuel and thus protects the environment.

3.9 Nearly 84% of the people who still used wood said they would like to switch to another fuel within the next 12 months. Of these, 85% would like to switch to LPG, about 11% were undecided and only a small group would like to switch to electricity, kerosene or charcoal. The most important reason given by more than 50% of the households was that cooking with LPG was quicker.

3.10 However, given the large percentage of users who wanted to switch, the question is why they had not switched yet. In all three cities the main barrier was found to be the needed investment in LPG stove equipment. Thus, lack of financial resources werethe main reason for the continued use of fuelwood, in particular the lack of resources for acquiring the LPG stove (48%) and/or the gas cylinder (26%).

3.11 LPG users were in general satisfied with their gas stoves, but in Nicaragua people also expressed fear of the risk of explosions. Additionally, people thought cooking with gas was expensive, and that availability is sometimes limited due to distributional problems.

3.12 The use of LPG for cooking has grown significantly in Nicaragua and such growth is likely to continue.. However, for the foreseeable future a substantial portion of the population will continue to use fuelwood. The CNE´s EMOLEP project estimated that by the year 2010, at least 20% of the urban households of the Pacific region will satill be using fuelwood. Improved woodstoves could be promoted as an alternative to LPG stoves. They save fuelwood, the indoor air quality is improved and cooking is quicker compared to the use of wood in traditional open-fire stoves. Additionally, operating costs will be lower compared to LPG. The market demand survey concluded that there exists a sufficient willingness and capacity to pay for improved stoves in peri-urban and urban households, especially in Managua and León. Therefore, PROLEÑA focused its subsequent activities on these two cities.

Types of traditional stoves used for cooking

3.13 The survey found that fuelwood users use mainly the traditional three stones stove, followed by the U-stoves, built with clay or cement. Only 1,1% of the users in Managua and 1,6% in León use improved stoves with chimneys. No improved stove user was found in Granada stoves do not exist yet. Urban users of LPG prefer big cookers with three or four burners (mostly with an oven). 1.3% of the households use cookers with one burner without oven and 54.5% use the most advanced technology (four burners with oven). The preference for big cookers is an important characteristic which will most probably also support the marketing of improved woodstoves. Other fuels, mainly charcoal, kerosene and electricity were only used by 13% of the households, principally as a secondary fuel. Households and businesses use mainly a metal stove (in Managua 81.7% and in Granada 77.7%). In León, charcoal when used is mainly burned in three stone stoves and also in clay or cement stoves. There is very limited use of kerosene (3.6% of the households) and electricity stoves (2.3%).

4

Development of Improved Stoves Models

4.1 Based on the information obtained from the market survey, PROLEÑA developed several stove models that meet the required characteristics. The models were designed with the following criteria:

4.2 With regard to operation:

- Low or zero emissions inside the house
- Affordable price
- Thermal efficiency of 20% as a minimum
- Has to fulfill all the functions of a traditional stove
- Reduce risks of burns
- Durable and reliable
- Improvement of status and quality of life

4.3 With regard to production:

- Simple technology and easy to manufacture with locally available labour
- Construction materials are easily obtained at local markets
- Adequate profit for the manufacturer

4.4 With regard to commercialization:

- Existence of several manufacturers to create competition
- High quality of production guaranteed
- Profit margin for sellers comparable to sales of other products

4.5 Three types of stoves were considered for development under the ESMSAP project:

- <u>Clay Stoves</u>**.** This type of stove based on the LORENA, CHULA and CETA models has already been under test by PROLEÑA Because the clay parts are handmade it is very expensive to achieve high quality. The advantage is that there is a national capability to produce clay products. However, there is no experience in producing large quantities of clay stoves. Foreign expertise would be needed to commercially produce a portable and low weight stove of this type.

- Ecostove. PROLEÑA had at this time already developed an improved metal stove it called the EcoStove. The stove design is amenable to mass production. All materials needed are locally available and several private manufacturers are already producing some of the key components. While the Ecostove meets the required criteria mentioned earlier. The cost is too high for poor households. For the ESMAP activity, PROLEÑA developed a smaller, least costly version of the EcoStove.
- Concrete cooker design.The idea for this model was to take advantage of concrete laundry structures for domestic use that was already being mass produced in Nicaragua The launderer would be modification the addition of a cooking plate with two burners similar to a CETA stove The main disadvantage is the relative fragility and high weight of the of the concrete support structure.

4.6 After the evaluation of these three types of stoves, PROLEÑA decided to produce a model that uses the combustion technology of the EcoStove and the technique of concrete cooker production of private manufacturers. The resulting stoves are made of pumice and cement, with a metal plate for conducting the heat to the pots or pans, and a chimney to direct the smoke and soot outdoors. Two different models were developed using the same construction base. One model has a complete metal plate while the other model has a partial metal plate and is semi-open, as already described in the chapter about the IAP-measurement.[2]

4.7 The production costs of these stoves vary between 21 and about 23 US$ for the stove with the partial plate and 28 to 32 US$ for the stove with the full plate. Included are the costs for material, tools, labour and other services (electricity, water etc.) and the user manual. Transportation costs are not included. The difference in costs of the two models is mainly because of the different plates.

4.8 The plan was for PROLEÑA to produce and deliver the chimneys and metal plates to the participating private companies that would then build the other parts of the stove. For the pilot program, it was thought that the involvement of PROLEÑA in production would maintain a high quality of the key metal parts. Local private companies do not yet have experience in this field.

4.9 Performance of the two Ecostove models was field tested:

- Indoor air pollution reduction: Both Ecostove models significantly reduced exposure of women to air pollution in enclosed kitchens.[3]

[2] For construction test and laboratory tests please see PROLEÑA: Informe final del proyecto: Comercializacion piloto de cocinas mejoradas – Pilot commercialization of improved cookstoves in Nicaragua, Mayo 2004

[3] For more information please see the Annex 1 about the IAP measurement.

- Firewood consumption: Tests showed firewood savings of 37% to 45% compared to the widely used open fire or “three stone” stoves.
- User acceptance: 100% of the households liked the design of the stove, many households reported that the time spent for cooking was reduced and that cooking became more hygienic.
- Cooking costs: 79% of the users thought that fuelwood consumption had been reduced, leading to financial savings for the families.

5

Commercial Dissemination Strategy

5.1 Based on the results of the field tests, PROLEÑA decided to use the two Ecostove models for the pilot marketing part. The selling prices of the stoves were initially set at 35 US$ for the partial metal plate type and 45 US$ for the complete plate type. The selling prices assured adequate margins for the participating manufacturers and stoves retailers.

5.2 PROLEÑA and ESMAP developed a dissemination strategy based on consumer preferences, willingness to pay and related factors. The strategy also addressed the need for consumer credit, producer credit, quality standards and quality control, stove standardization, sales locations, public information, existing and appropriate marketing methods and sales volume requirements for profitability. The following activities were implemented:

- Idenitification of interested and capable participating manufacturers
- Signing of a contract with the PM to convert part of their production to improved stoves
- Supervision of production of improved stoves
- Continuous monitoring of the quality of stoves produced
- Development of a marketing plan
- Conduct of specific marketing activities (ads in newspapers, TV-commercials and talk-shows, radio etc.)

Selection of Private Manufacturers and Technology transfer

5.3 In July 2002 PROLEÑA invited 37 companies from Managua and León to explain to them the objectives of the pilot project. PROLEÑA then selected four (4) companies—2 in Managua and 2 in Leon—that:

- already have experience in producing cement stoves and are willing to include the improved stove in their production and sales.
- have the technical and financial capacity to produce and sell the improved stove, but have no past experience in this field.

- are in suitable geographic locations

5.4 A contract for participation in the ESMAP pilot project was signed between PROLEÑA and the 4 manufacturers in February 2003. Under the agreement, PROLEÑA provided technical assistance on improved stoves manufacturing, preparation of business plans and marketing methods. PROLEÑA cost-shared the factory conversions and continued to make the key metallic and ceramic parts, and provided these to the manufacturers at preferential terms. PROLEÑA closely supervised the manufacturing process in each factory. All stoves produced received a quality control label. Initially, ten Ecostoves were produced (five half plate models and five complete plate models).

Information and Marketing activities

5.5 An extensive public education and promotion campaign was then launched. PROLEÑA used mass media such as radio, TV and newspapers, distributed brochures and posters, posted signs at highways and organized workshops. The improved stove was promoted as "*Mi Fogón*" (My Stove). The advertising campaign was named: "*HOGAR SIN HUMO*" (household without smoke).

5.6 Public recognition of Mi Fogon was quickly enhanced through TV commercials, especially with two-minute spots for 6 months in the famous Saturday program called "El clan de la picardía".. In this program users talked about their own experience with the "Mi Fogon". Further, a 20 minute documentary film about the production of the improved stoves was shown in September 2003. Mi Fogon was also presented in a quiz show called: "Cuchareando con el Clan."` This activity lasted for a period of two and a half months. Radio spots were also intensively used since September 2003. Altogether, 1,051 radio spots were broadcast until spring 2004. Finally, PROLEÑA published articles and ads in the three main newspapers in Nicaragua La Prensa, El Nuevo Diario and El Mercurio.

5.7 Highly visible 5 ft x 8 ft signs were put up on main roads in Managua and León). About 5,000 pamphlets were printed and provided to the private manufacturers for distribution to the public.

Workshops

5.8 PROLEÑA held four demonstration workshops-- two in Managua and two in León-- between September and November 2003 mainly for NGO's, institutions and corporations. Finally, an international workshop was held on March 18 2004 in Managua to disseminate the findings of theESMAP project. The day-long workshop was attended by about 60 invited participants from government agencies, donor representatives, private stoves producers, NGOs and academe from the region and elsewhere. Speakers from Honduras and Brazil described the experience in their countries. The international perspective was described in a presentation by Dr. Keith Openshaw, Biomass Specialist, formerly of the World Bank and the International Resources Group (IRG), which compared successful and unsuccessful programs and stove designs in Thailand, Botswana, Ethiopia, India, China and other countries in the past. CEIHD presented final results of indoor air pollution measurements carried out in Nicaragua under the ESMAP project to compare improved stoves models developed by PROLEÑA. Keynote speaker for the workshop was Mr. Raul Solorzano, President of the National Energy Commission (CNE). He emphasized the commitment of the government in Nicaragua to support the ongoing initiative. CNE's energy strategy takes full account of the role of traditional fuels. CNE has several ongoing initiatives to more accurately measure fuelwoods supply quantities, and promote demand management measures in both households and wood-using rural industries.

6

Demand Constraints

6.1 The participating private manufacturers started marketing the improved stoves in July 2003. PROLEÑA monitored the sales on a weekly basis. At the initially set market price of 35 and 45 US$ for the two models, respectively, there were hardly any sales. Although many people expressed interest in buying the stove (an average of 10 inquiries were received per day by each participating manufacturer), it was clear that the price was too high for potential buyers, being equivalent to about one month salary for many households

6.2 In response, various changes in the promotional and pricing strategies had to be made. To jump-start the market, prices were temporarily lowered. The hope was that, as the new stoves are used more and their benefits in fuel savings and indoor pollution reduction become widely recognized, users would be willing to pay a higher price. First, PROLEÑA decided to subsidize the stove by 10% starting September. However, this had little effect on the sales. In October the original selling price was reduced by 45% and special offer payment arrangements were offered, such as 50% payment at sale and 50% two months later. These measures resulted in sales of about one stove/week per manufacturer, a modest but acceptable sales volume.

6.3 However, the strategy was clearly unsustainable. Subsidy funds came from PROLEÑA's marketing budget and were enough for only about 150 stoves. The longer term solutions were to reduce production costs significantly and intensify marketing efforts to target groups. These measures are already being implemented.

6.4 The short-term strategy did succeed in increasing popularity of the stoves and sales. In May 2004 the selling price was raised to 28 US$ and 36 US$. Even with this price increase, 220 stoves were sold. Altogether, until end of May some 369 stoves were sold.[4]

4 Please see PROLEÑA report for details. PROLEÑA: Informe final del proyecto: Comercializacion piloto de cocinas mejoradas – Pilot commercialization of improved cookstoves in Nicaragua, Mayo 2004

7

Some Lessons Learned

7.1 It was evident that a major barrier to the commercial dissemination of improved stoves is the fact that many households in Nicaragua do not purchase stoves, and simply use self-made traditional three-stones types. The most important barrier, however, was the high initial costs of the improved stove. While fuelwood savings could be substantial, ordinary households could not fully grasp the financial benefits, as fuelwood is purchased in small quantities or even collected at no cash cost..

7.2 PROLEÑA´s improved woodstove as it is today is a relatively costly technology, not affordable by the majority of the fuelwood users without credit. The availability of credit is likely to be the essential ingredient for success of the dissemination strategy. Microfinancing agencies for the poor at rural and urban areas already exist in many regions of Nicaragua. However, the amount needed to buy a stove is too small for the credits usually obtained at these institutions in Nicaragua. Because of the high administration costs, there is little incentive for these institutions to participate in improved stoves marketing. Some creative way of bundling the individual credit needs of stoves purchasers must be found to address this problem.

7.3 PROLEÑA also concluded that the marketing efforts carried out were not intense and focused enough to develop the market.. Social acceptance of a new technology always takes time. Further, the participation of more private manufacturers in future should be sought to increase regional coverage.

7.4 PROLEÑA made efforts to consider gender isasues in all stages of the pilot project. The objective was for women should have access to and control of the resources and profits of the project. In general, women took part in the marketing process. They worked as administrative officers and were heavily involved in the procurement of the materials. There was no opportunity, however, for women to participate in the production process. Focused seminars were held by PROLEÑA to encourage dialogue between men and women on how best to improve and market the stoves. The seminars were held in Ciudadela Tipitapa, Managua and León and 87% of the participants were women.

7.5 Overall, despite these problems, improved stoves initiatives still appear to be a relatively low cost way to avoid serious public health issues cause by indoor air pollution, and to reduce environmental degradation in areas where fuelwood use impacts forests. Such initiatives should continue to be supported.

References

Apunte de transferencia de calor. DINOT – UNI Alejandro Palmi 1994

Estudio de Mercado de Estufas Mejoradas de Leña en el Pacífico Urbano de Nicaragua – 2001 consultaría ESMAP / BM. Marzo 2002

Estufas en imágenes: una documentación sobre las estufas mejoradas y tradicionales de África, Asia y América Latina. Beatriz Westhoff y Dorsi Germann. Dirección General del Desarrollo de la División. Ministry of Information Technology, Government of India. Dr.A.D.Karve

Evaluation of the efficacy and effectiveness of the ecostove for reducing indoor air pollution exposures among Nicaraguan women. John McCracken and Dana sharron. Center for Entrepreneurship in International Health and Development. 2003.

Proyecto EMOLEP Comisión Nacional de Energía. . Diagnostico del sector leñero Comercial del Pacifico de Nicaragua. CATIE – PROLEÑA 1999.

Annex

Background Paper: Evaluation of the Efficacy and Effectiveness of the EcoStove for Reducing Indoor Air Pollution Exposures Among Nicaraguan Women*

Several recent studies have concluded that indoor air pollution (IAP) is a risk factor for acute respiratory infections, chronic obstructive lung disease, tuberculosis, lung cancer, low birth weight and cataracts. Much of the developing world relies on solid biomass fuels for cooking. The use of these fuels in simple, unvented cookstoves is the principle cause of elevated IAP levels. Improved biomass cooking stoves have the potential to reduce concentrations of pollutants in kitchens and thereby reduce harmful exposures. However, evaluation of such interventions has been very limited relative to the magnitude of this public health problem. Only a handful of studies have measured the reductions in exposures to harmful air pollutants achieved by improved cookstoves.

Since health risks often drive policy decisions, it is increasingly common that non-governmental organizations, funders and international agencies involved in the development of improved biomass stoves are interested in evaluation of the health benefits of their programs. This information can be used to make a compelling case for support from funding agencies and may also be useful in motivating families to invest in an improved biomass stove. However, making causal inferences about the health benefits of a specific stove design requires large study populations and expensive and complex data collection systems, even for the evaluation of a single health outcome. For example, an intervention study designed to detect whether acute lower respiratory infections (ALRI) are reduced among Guatemalan children due to improved stoves will require weekly visits to 500 children over a period of 12 to 18 months. Most of the health effects of IAP are less common diseases, some developing over several years, and would require much longer periods of observation than childhood ALRI. Stove programs do not typically have the resources to invest in long-term health studies, nor would this likely be a desirable use of resources, given the pressing need to promote and disseminate improved stoves.

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* This Annex was prepared by John McCracken and Dana Charron, Centre for Enterpreneurship in International Health and Development.

Since population exposure to IAP is a valuable proxy for several health outcomes, a more practical approach to assessing health benefits of an improved stove project is to measure exposures to IAP among people in households with traditional and improved biomass stoves. The combined results of several epidemiological studies on the effects of solid fuel biomass smoke support the use of IAP exposure as an indicator of health risk. In addition, IAP exposures can be accurately measured using small sample sizes, such as 25 – 50 participants per study group. An evaluation of health benefits based on measured exposure reductions provides more useful information than a study attempting to establish causal links between environmental improvements and changes in disease incidence. For example, although the weight of evidence of roughly a dozen studies suggest ALRI incidence is 2.5 times higher among children exposed to IAP from solid biomass fuel combustion, the results of each individual study vary widely and were sometimes inconclusive. Thus, for stove program evaluation, assessing changes in human exposure to biomass smoke may not only be more practical and cost-effective than conducting a health-outcome study, it will also prove to be more accurate and comprehensive.

The characterization of health effects from indoor air pollution in developing countries is based on several studies among households that use solid fuel. Findings from the more numerous health studies of tobacco smoke and ambient air pollution are incorporated for supporting evidence. Four main categories of health effects are thought to result from indoor combustion of solid fuels in developing countries:

- Infectious respiratory diseases: acute respiratory infections in children and tuberculosis;
- Chronic respiratory diseases: chronic bronchitis, chronic obstructive pulmonary disease and lung cancer;
- Adverse pregnancy effects: stillbirth, low birth weight; and
- Other suspected health effects for which less evidence exists: blindness, asthma and heart disease.

The weight of evidence for these health effects has been discussed in detail in the literature (Smith 2000, Bruce 2000). The studies outlined have provided evidence of links between indoor air pollution and various diseases. The most common health effect estimates compare the difference between improved stoves or fuels and the traditional open fire. However, the exposure contrast in each study is different. Also, the reduction in exposure offered by a particular stove design may be less or more than the exposure contrasts in these studies. An understanding of the dose-response relationship between biomass smoke and each health outcome is required to extrapolate along the continuum of exposure levels associated with each fuel-stove combination. Therefore, the most useful kind of study relates specifically defined health outcomes to measured air pollution exposures, rather than a binary exposure variable. Although dose-response relationships between biomass smoke and the diseases it is thought to cause have not been established, it is reasonable to assume that the magnitude of health benefits will be related to the extent to which exposures are reduced.

Ezzati and Kammen conducted detailed exposure assessment and monitored acute respiratory infections (ARI) and acute lower respiratory infections (ALRI) symptoms every one to two weeks for two years in Kenya (Ezzati, 2001). Their analysis controlled for several confounding factors, such as sex, age, village type, number of people residing in the house, and smoking. They used these data to estimate a dose-response relationship between biomass smoke and ARI and ALRI using ordinary-least-squares regression. They estimated that children under five years of age with average PM_{10} exposures between 200 - 500 $\mu g/m^3$ would have ARI symptoms during an additional 6% of the time, compared to those with exposures lower than 200 $\mu g/m^3$ (p-value = 0.002). The fraction of time that a child had ARI was 5% in the lower exposure group, compared to 11% of the time in the next higher exposure group. The effect of a similar exposure increase among the 5 – 49 years age group resulted in an additional 2.7% of the time with ARI (p-value = 0.003). These same comparisons of fraction of time with illness were performed for ALRI, a more serious category of disease that includes pneumonia, but the effect estimates were insignificant. They also calculated odds ratios using logistic regression and found that the odds of having ARI was 2.42 (95%CI: 1.52-3.83) higher among the children under four years and 3.01 (95% CI: 1.59-5.70) times higher among people aged 5 – 49 years. Although the odds of ALRI were not significantly elevated among either age group in the 200 - 500 $\mu g/m^3$ exposure category, the odds were significantly elevated at exposure levels above 500 $\mu g/m^3$ and there was a trend of increasing risk with each higher exposure category.

While these types of exposure-response estimates provide a quantitative basis for estimating the health benefits of improved cooking stoves using information on exposure reductions, further evidence is required before such analyses can be performed with confidence for childhood pneumonia. In addition, exposure-response relationships have not even been explored for most of the suspected health outcomes of IAP in developing countries. When such models are developed, estimates of the total burden of disease averted by an improved stove intervention, which is most relevant to policy decisions, would also require information on prevalence and incidence of the specific diseases in the population. Burden of disease analyses would be useful for estimating the public health benefits of improved stoves, such as the EcoStove in Nicaragua.

Study Objectives

In January 2002, a CEIHD research analyst met with Proleña staff in Managua, Nicaragua, to plan a study that would assess and compare the indoor air pollution concentrations and human exposures associated with open fires and two competing models of the EcoStove, within the context of an ongoing World Bank/ESMAP/PROLEÑA project “Nicaragua – Pilot Commercialization of Improved Woodstoves”. The planning, field staff recruitment, and study site selection took place over the next three days. The CEIHD research analyst coordinated field staff training, revisions of field data logs, refinement of the inclusion criteria for the study, and a brief pilot study using a continuous particle monitor over the following seven days. The CEIHD research analyst returned to the United States for the remainder of the study. The field staff, one Nicaraguan environmental scientist with a masters degree, one

Guatemalan field work supervisor with experience conducting indoor air pollution research, and one local assistant, completed the study over the next five months.

Specific objectives discussed by CEIHD and Proleña during study preparation and incorporated into the study design include:

- To compare the performance of two competing EcoStove designs for reducing indoor concentrations and personal exposures to $PM_{2.5}$.
- To emulate, as much as possible, the non-experimental, real-life conditions under which people purchase improved stoves.
- To control for the influence of confounding factors that may bias the stove comparisons.

One EcoStove model has a completely closed 1/8" steel stovetop griddle, on top of a stove body made of a mix of cement and pumice stone cast around a ceramic combustion chamber elbow. This will be referred to as the closed EcoStove. The second, slightly less expensive, newer model, has the same stove body, however with a smaller metal griddle on one side and one open pothole on the other side, allowing both direct contact between the fire and the pots and an opportunity for release of combustion emissions indoors if a pot is not placed over the pothole. This will be referred to as the semi-open EcoStove. Both EcoStove models have metal tube chimneys and ceramic elbow combustion chambers. Proleña hypothesized that switching to the semi-open model would involve a tradeoff between increased energy efficiency and increased indoor air pollution.

Methods

Study Site and Population

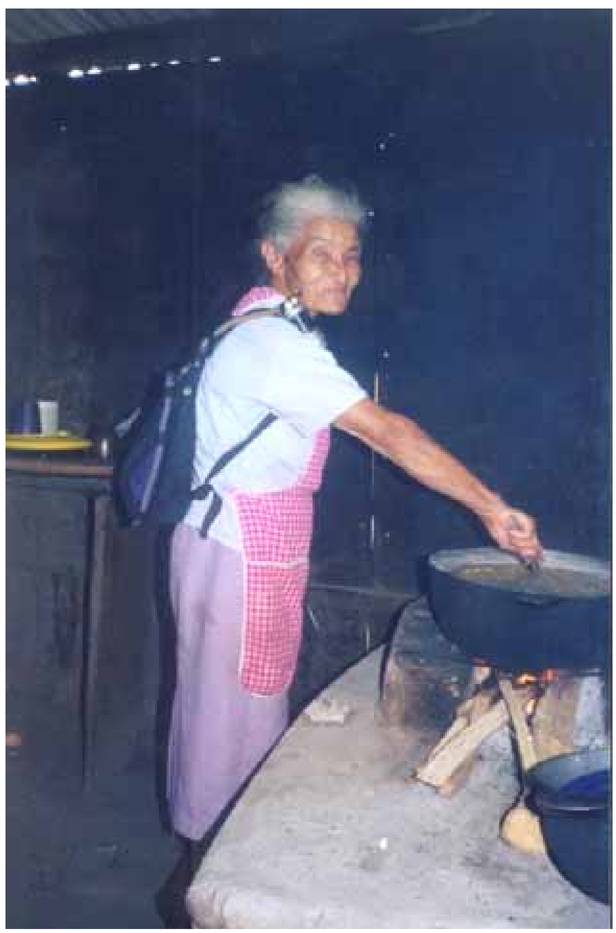
The search for an appropriate study site included visiting two communities in the capital city and three semi-rural communities within a 2-hour drive from Managua. In addition, the CEIHD research analyst met with representatives of the NGOs Handicap International and Plan International, and the governmental agency National Energy Commission (CNE). These groups which were active in the region and perform work relevant to improved stoves, were informed of our study objectives and provided helpful tips on identifying our target and study populations. The CEIHD research analyst observed during visits to potential study sites that many household kitchens are only partially enclosed, often having one or two open sides and only two or three sides with walls. Since the air pollution levels in these kitchens may be more similar in magnitude to background outdoor air pollution levels, it would be more difficult to detect any true differences in air pollution exposures by stove type. The research analyst subjectively compared the potential study communities by the proportion of open kitchens.

The stove comparison study took place in Ciudadela de San Martín, a recently settled village approximately 2 Km from the town center of Tipitapa. The population was chosen for the almost exclusive use of biomass fuel and open fires for household cooking and the large proportion of indoor kitchens, as shown in the photo below. The town is located approximately 15 Km to the north of Managua and approximately at latitude: 12°

08’ 36” N, longitude: 86° 09’ 49” W, and elevation: 56 m above sea level) and has approximately 1000 homes. Typical homes are made of wooden planks for walls and corrugated iron for roofs and have dirt floors. Most of the homes have electricity.

Only participants with kitchens with walls on all four sides were recruited for the study, which would make the ventilation rates lower than in typical homes. Since the indoor emissions from cooking stoves would be more concentrated in these kitchens, this participant selection provided greater assurance that we would be able to detect any influence of stove type. However, this selection criterion made the air pollution levels less representative. The CEIHD fieldwork coordinator, Victorina López, selected the homes to create thirty pairs matched according to location (street block) and kitchen type. The kitchen types included: 1) inside a one-room dwelling including sleeping areas, 2) part of the main house, but with a partition separating the kitchen from other rooms, and 3) separate structures apart from living areas and bedrooms. Households with any kind of gas stove were excluded from the study.

Figure A.1: Study Participant in Ciudadela de San Martin, Tipitapa, Nicaragua: Wearing $PM_{2.5}$ Exposure Monitoring Equipment and Cooking Over Traditional Open Fire



The field staff explained the concept of the EcoStove and the objectives of the study during participant recruitment. They also told the people about the burdens of carrying IAP equipment and having it operate in their homes during 24-hours for each of the two rounds of sampling. The field staff also informed the householders that they would receive a free stove as compensation for participation in the study, that participation was voluntary, and that they could leave the study at any moment without any consequences.

Study Design

CEIHD evaluated the influence of stove type on kitchen air pollution levels and women's exposures to particle matter less than 2.5 micrometers in aerodynamic diameter ($PM_{2.5}$) through a randomized stove intervention trial. $PM_{2.5}$, rather than the often measured courser particles (PM_{10}) or carbon monoxide, was chosen as the pollutant to be measured since it has most consistently been associated with respiratory and cardiovascular health effects. While CO is included in many studies of biomass smoke, this is more due to the availability of simple and inexpensive measurement methods, rather than evidence of health impacts found at the levels in developing country households. Prior to the first round of measurements, the field staff performed the randomization among the households pair-by-pair with the toss of a coin. One household from each matched pair was assigned to each of the competing EcoStove models: one with a closed stovetop and the other with a semi-open stovetop. Before the stoves were introduced, women's 24-hour average exposures to $PM_{2.5}$ were measured among the 60 participants cooking over open fires. Kitchen 24-hour average $PM_{2.5}$ concentrations were measured in a roughly half of the homes.

After the first round of measurements, the field workers and Proleña staff coordinated the introduction of the EcoStoves according to the random assignments. The stoves were installed by Proleña in the same way they usually are. The principle cooks in the study households, who were all women, participated in a training session organized by Proleña. The objective of the training was to mimic the normal circumstance under which Proleña instructs women about the recommended ways of using and maintaining the stoves. The training included a discussion of appropriate pots to be used with the EcoStoves. People using open fires often cook with curved-bottom pots, while flat-bottom pots are essential to allow complete contact with the metal stovetop of the EcoStoves, which is necessary for increased energy efficiency. Several families were provided flat-bottom pots to encourage adoption of the EcoStoves.

The same air pollution measurements as in the pre-intervention round were repeated several weeks after the intervention. The average duration between introduction of the EcoStove and the post-intervention IAP measures was 34 days (St. Dev. = 12 days), with a minimum of 11 days and maximum of 69 days. These durations should have allowed enough time for the families to get comfortable with use of the new stoves.

Since an objective of this study was to emulate non-experimental, real-life conditions, there were no demands placed on the families to use only the improved stove. The extent to which the EcoStoves are adopted is a key component of the test of their ability to reduce IAP exposures.

Measurements

Particle matter less than 2.5 micrometers in aerodynamic diameter ($PM_{2.5}$) was measured using SKC Personal Environmental Monitors (PEMs), which are designed to provide a 2.5 μm cut-size by impaction at a flow rate of 4 liters per minute (LPM). Teflon filters with 2 μm pore size were placed on top of support pads inside the $PM_{2.5}$ PEMs. These samplers were connected to personal pumps (BGI-400, BGI Inc. and SKC PCXR-4, SKC Inc.) set at a flow rate of 4 LPM. The field staff measured flows at the beginning and end of each 24-hour monitoring period with Matheson rotameters, which the CEIHD research analyst calibrated at Harvard School of Public Health and compared with a manual bubble tube, a primary standard, at the field site. To ensure that the calculated volumes of air that passed through the filters were accurate, the field workers checked each PEM for leaks after assembly. The leak test consists of measuring the difference in flow through a tube attached to the pump compared to the flow through the inlet of a PEM attached to the same tube. A large decrease in flow (more than 5 rotameter divisions) indicates a significant pressure drop, which would probably be due to a leak, since the pumps are flow controlled.

The sampling equipment, weighing approximately 3 pounds, was carried inside backpacks by the women and hung in the kitchens. The PEMs were cleaned with distilled water and/or alcohol on a daily basis and the impactor plates were wiped clean and oiled between samples to prevent particle bounce. The field worker or fieldwork supervisor visited the homes during the 24-hour periods monitoring to verify that the women were wearing the monitors and that they were functioning properly. The standard location of the equipment in all kitchens was 1.25 meters off the floor and 1 meter from the outer perimeter of the stove and at least 1.5 meters from all doors and windows.

The Teflon filters were weighed using a Mettler MT5 microbalance at Harvard School of Public Health before and after sampling for determination of $PM_{2.5}$ mass.

CEIHD included several observations and questionnaire items on time activity patterns and housing characteristics in the IAP exposure assessment (EA) survey. These measures were included in order to be able to control for their influence on IAP exposures when comparing the stove types. These items were also evaluated as predictors of kitchen concentrations and personal exposures for the potential calibration of a simple questionnaire that would allow easier access to information on changes in exposure. The usefulness of each item for the calibrated questionnaire will be indicated by the amount of variability in air pollution concentrations and exposures explained.

Meteorological data were collected by the weather station at the Managua airport. These were daily average data and included: temperature, humidity, atmospheric pressure, wind direction, wind speed, and precipitation. Fieldwork for this study took place mostly during the dry season, from January to May 2002.

Analysis

Air pollution levels and exposures associated with the two EcoStoves can be compared directly between the two study groups or by comparing the changes in exposure associated with the introduction of each EcoStove. Although the two types of improved stove were randomly assigned, the small sample size allows a large role for chance in producing differences between the two groups. Direct comparisons of measurements between the two groups are susceptible to confounding by any factors that by chance are associated with the assigned improved stove type and independently with pollution levels and/or exposures. However, by comparing the changes in air pollution from before to after the stove intervention between the two groups, the analysis is less susceptible to the influence of any factors that differ between homes. Also, by taking into account the baseline IAP levels, given that the IAP levels pre- and post-intervention are correlated among homes, the unexplained variability is reduced and the probability of detecting any true differences between the closed and semi-open EcoStoves is increased.

Since the research team monitored in the same kitchens before and after installation of the improved stoves, the comparison of the EcoStoves to the traditional open fire cannot be confounded by any factors that are constant within homes over the duration of the study. Although the comparisons between open fires and EcoStoves may be influenced by time-varying characteristics, we considered that the effects of these characteristics on air pollution levels should be minimal over the duration of this study relative to the expected influence of the improved stoves. In addition, any time-varying factors that we measured in the study can be controlled for in the multivariable analyses.

A remaining concern, however, may be differences in the extent to which the two study groups adopt and properly use the improved stoves, which may be related to differences in the participants or differences in the stoves. Since we collected data on the amount of continued open fire use after the improved stove intervention, we will be able to subtract the effect of open fire use in order to estimate what the IAP levels and exposures would be if people completely substituted the EcoStove for the open fire. In models including a variable for duration of open fire use post-intervention, the effect estimate for each EcoStove becomes a measure the efficacy of the stoves (i.e. how well the stoves reduce IAP if they are fully adopted). In models that do not include a variable for duration of open fire use post-intervention, the effect estimate for each EcoStove is a measure of the effectiveness of the stoves (i.e. the actual benefit of being assigned the stoves, regardless of the extent to which they are adopted). While effectiveness is most pertinent to policy decisions, a comparison of efficacy and effectiveness can help determine whether the limitations of a stove design are more related to technical performance or the extent to which they meet the needs of the cooks.

Results

The two randomized intervention groups are very similar on all of the household variables and time-activity data collected (see Table A.1). This indicates that a good balance was achieved and that the randomization was successful. In addition, the weather conditions on the days that the $PM_{2.5}$ samples were collected were similar between the two groups. Given these results, we assume that the distribution of all other unmeasured variables that may influence kitchen concentrations and exposures were similar between the two groups.

Table A.1: Univariate Comparisons of Baseline Data by Randomized Group before Intervention

Continuous Variables	Group 1 (n=30)		Group 2 (n=30)		
	Average	St. Dev.	Average	St. Dev.	p-value
Kitchen Volume (m^3)	16.38	7.80	19.65	11.04	0.2339*
Time Fire Lit (hr)	9.9	3.9	10.7	3.7	0.4349
Time Cooking (hr)	6.9	2.5	6.0	2.2	0.1843
Time Active Smoking (hr)	0.1	0.2	0.2	0.7	0.6983*
Time Passive Smoking (hr)	0.9	2.1	0.8	1.2	0.1311*
Burning Garbage (hr)	0.2	0.4	0.3	0.6	0.2037*
Neighbor Burning Garbage (hr)	1.1	2.3	0.3	0.6	0.2096*
Reports Moderate Smoke Levels (hr)	5.4	3.1	4.7	3.3	0.3643
Reports High Smoke Levels (hr)	3.1	2.9	3.7	2.7	0.4281
Avg. Daily Temperature (C)	27.4	0.8	27.2	0.8	0.2734
Avg. Daily Wind Speed (mph)	4.2	0.6	4.3	0.6	0.8037
Avg. Daily % Relative Humidity	63.0	3.8	62.9	3.8	0.9197
Categorical Variables	**N**	**%**	**N**	**%**	**Chi-Square p-value**
Kitchen Type					
One Room House	7	23	8	27	0.7656
Separate Room	10	33	9	30	0.7814
Separate Building	13	43	13	43	1.0000
Kitchen with Outside Door	21	70	23	77	0.5593

* Indicates that Kruskal-Wallis non-parametric test was performed due to violation of normality assumption.

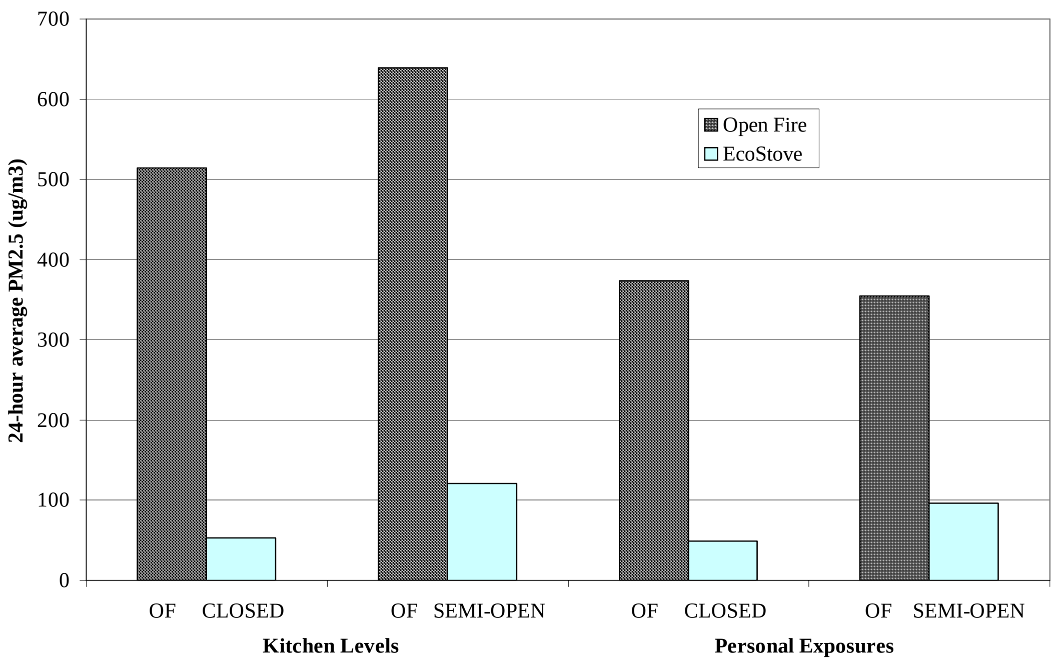
Although there are no statistical differences at the traditional p = 0.05 level, these statistical tests are not sensitive enough to detect small differences between groups that can confound the relation between stove type and IAP. Using a p-value significance level of less than 0.25 to indicate differences between study groups that have more potential to bias the IAP concentration and exposure comparisons between stove groups, kitchen volume, reported time spent cooking, reported time spent burning garbage, reported time neighbor burnt garbage, and time exposed to passive tobacco smoke met this criterion. However, in order for these factors to bias the results, they would also have to be independent predictors of exposure and/or kitchen concentration. In the multivariable analyses, these potential confounding biases will be removed by statistical adjustment, assuming that the variables have been measured accurately.

As shown in Table A.2 (see also Figure A.2 below), personal $PM_{2.5}$ exposures and kitchen concentrations were high during the pre-intervention round of sampling. Although the concentrations were 25 % higher (p-value = 0.3706) and the women's exposures were 9% higher (p-value = 0.7476) among Group 2 compared with Group 1, these differences are consistent with random variability. The standard deviations were similarly high in both groups.

Crude (Unadjusted) Results

According to the random assignments made prior to the first round of measurements, Group 1 received the closed EcoStove, while Group 2 received the semi-open EcoStove. The personal and kitchen $PM_{2.5}$ levels were roughly an order of magnitude lower in both groups during the post-intervention round (Figure A.2).

Figure A.2: IAP Levels with the Closed and Semi-Open EcoStoves compared to the Open Fire (OF)



The average kitchen concentrations decreased from 514 to 53 $\mu g/m^3$ with introduction of the closed stovetop EcoStove in Group1, while the average levels decreased from 639 to 121 $\mu g/m^3$ with introduction of the semi-open EcoStove in Group 2. The average women's exposure to $PM_{2.5}$ decreased from 374 to 49 $\mu g/m^3$ with introduction of the closed EcoStove in Group1, while the average exposure decreased from 355 to 96 $\mu g/m^3$ with introduction of the semi-open EcoStove in Group 2. The reductions in kitchen concentrations and women's exposures in both groups were highly significant, regardless of statistical modeling approach. Due to one equipment failure and one dropout (refusal), only 28 of the 30 personal exposure measurements for women cooking over semi-open EcoStoves were collected. Since the kitchen measurements were taken among a convenience sample of households during each round, the randomization was somewhat sacrificed and not all of the same homes were sampled pre- and post-intervention.

Table A.2: $PM_{2.5}$ Kitchen Concentrations and Personal Exposures Before and After Improved Stove Intervention

	Kitchen Concentrations			**Personal Exposures**		
	N	**Avg.**	**St. Dev.**	**N**	**Avg.**	**St. Dev.**
Pre-Intervention						
Group 1: Open fire	19	514	388	30	374	456
Group 2: Open Fire	17	639	426	30	355	313
Linear Regression*	p-value = 0.6839			p-value = 0.7311		
Post-Intervention						
Group 1: Closed EcoStove	20	53	30	28	49	30
Group 2: Semi-Open EcoStove	14	121	90	30	95	126
Linear Regression*	p-value = 0.0055			p-value = 0.0244		

* Linear regression models test whether log-transformed kitchen concentrations and personal exposures are different between study groups.

It appears from the crude (unadjusted) comparison of the two competing EcoStove models that both kitchen concentrations (p-value = 0.0055) and women's exposures (p-value = 0.0244) are significantly lower among the households randomly assigned to the closed EcoStove. However, these crude (unadjusted) comparisons do not take into account other variables that may confound or modify the relationship between EcoStove model and the air pollution measures, such as kitchen volume, time spent cooking, trash burning, and passive smoking. These comparisons also do not take into account the kitchen levels and exposures at baseline, which would control for other differences among homes prior to introduction of the stoves.

Univariate Analyses of Predictors of Kitchen Levels and Personal $PM_{2.5}$ Exposures

The CEIHD research analysts then began to evaluate the univariate (unadjusted) relationships between women's exposure to $PM_{2.5}$ and household characteristics, time-activity patterns, and weather data. The first priority was to understand the potential influences of the variables that were less balanced between the two groups at baseline, which were kitchen volume, reported time spent cooking, reported time spent burning trash, reported time neighbor burned trash, and reported time exposed to passive tobacco smoke. The CEIHD research analyst ran least squares linear regression models for each of these variables with personal exposures and then kitchen concentrations as the outcomes.

The plots of residuals versus predicted values from these regression models indicated violations of the homogeneous variance and normality assumptions for linear regression.† The CEIHD researcher log-transformed the concentration and exposure data to make the residuals more normal and the variance more constant across the predictors. This strategy was successful. It is important to note that this transformation of the independent variable alters the interpretation of the parameter estimates from the regression models. With a log-transformed outcome, the model is multiplicative, rather than additive, and the parameter estimates for each predictor are interpretable as percent changes, rather than changes in absolute value of the concentrations and exposures. Fortunately, this agrees with the physical models for many of the effects being evaluated. For example, the steady state model for calculation of concentrations (C, $\mu g/m^3$) from emissions (E, μg/hour), volume (V, m^3), and air exchange rate (S^{-1}, hr) is C = E * S / V. This multiplicative model relates to three predictor variables included in the regressions models, namely kitchen volume, kitchen ventilation indicators (air exchange rate), and stove type (emissions).

With this transformation of the dependent variable, the interpretation of the β estimates as percent changes in exposures or kitchen levels requires the following formula:

$$\%\ \text{Change in Exposure} = (e^{\beta} - 1) * 100.$$

Housing Characteristics

According to the equation above for calculating concentrations based on emissions, there should be an inverse relationship between kitchen volume and concentrations. Although each 1 m^3 increase in kitchen volume was associated with a 1.9% decrease in kitchen concentrations, this was not statistically significant (ß = p-value = 0.3391). Although each 1 m^3 increase in kitchen volume was associated with a 0.3% decrease in women's exposures to $PM_{2.5}$, this effect was also non-significant (p = 0.7954).

Stove Use

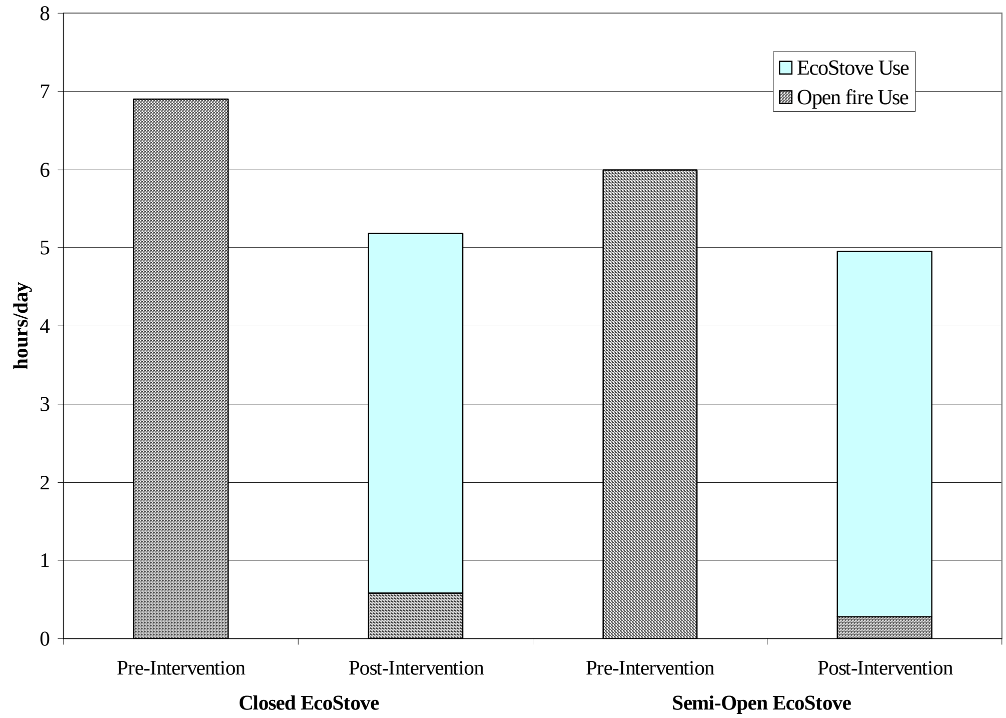
Since the time activity questionnaires distinguished between when the study participant was cooking from the total time that the stove was lit, these variables were analyzed separately. Although time spent cooking over an open fire pre-intervention was associated with higher $PM_{2.5}$ exposures, it was not a significant predictor of the log of exposure (ß = 0.0358, p-value = 0.5052). After excluding the pre-intervention measurements, time spent cooking with EcoStoves was also not a significant predictor of exposure (ß = 0.0757, p-value = 0.1518). However, excluding the pre-intervention measurements, each hour of reported open fire use post-intervention was associated with a 16% increase in kitchen levels of $PM_{2.5}$ (ß = 0.1449, p-value = 0.0306).

The women with the closed EcoStoves reported cooking over the open fire for 33 minutes per day on average, compared to 16 minutes per day among the women who received partially open EcoStoves. As shown in Figure A.3 below, these durations of open fire use are very short compared to EcoStove use on the same days and open fire use pre-

† Residuals (R) are the differences between the observed values (OBS) and predicted (PRED) values from the regression models. For example, the residuals for a concentration (C) model would be: $R = C_{obs} - C_{pred}$.

intervention. The data on open fire use post-intervention are highly skewed because most women in both groups did not report any open fire use after they received their EcoStoves. A non-parametric Kruskal-Wallis test failed to find a statistical difference between reported durations of cooking over the open fire post-intervention between the two groups (p-value = 0.2816).

Figure A.3: Reported Cooking Times with Open Fires and EcoStoves



Other Sources of Air Pollution

The second most important source of air pollution, after cooking stoves, was burning of waste materials. Each hour of reported trash burning by the participants was associated with a 140% increase in personal exposures (ß = 0.8744, p-value = 0.0014) and a 129% increase in kitchen levels (ß = 0.82806, p-value = 0.0398).

Each hour of active smoking was associated with a 46% increase in kitchen concentrations (ß = 0.3793, p-value = 0.2446). Although active smoking was associated with a 7% increase in personal $PM_{2.5}$ exposures, this relationship was less close to being significant (ß = 0.0649, p-value = 0.7941).

In univariate linear regression models, passive smoking was neither a significant predictor of women's exposure (ß = -0.0502, p-value = 0.5141) nor of kitchen concentrations of $PM_{2.5}$ (ß = 0.0862, p-value = 0.4950). However, since passive smoking was somewhat different between the two groups at baseline and it has a potentially strong influence on kitchen concentrations, this variable is a candidate for inclusion in multivariable models.

The amount of time the participants reported sensing moderate smoke levels was associated with an 11% increase in personal exposures (ß = 0.10612, p-value = 0.0012) and a 17% increase in kitchen concentrations (ß = 0.1529, p-value = 0.001). The amount of time the participants reported sensing high smoke levels was associated with associated with a 30% increase in personal exposures (ß = 0.26063, p-value < 0.0001) and a 27% increase in kitchen concentrations (ß = 0.2400, p-value = 0.0002*)*.

Meteorological Conditions

In the univariate analysis, daily average temperature was associated with a 32% decrease in personal exposures (ß = -0.39134, p-value <0.0001) and a 40% decrease in kitchen levels of $PM_{2.5}$ (ß = -0.5141, p-value < 0.0001). Daily average relative humidity was associated with a 4% increase in personal exposures (ß = 0.3887, p-value = 0.066) and a 2% increase in kitchen levels of PM2.5 (ß = =0.0198, p-value = 0.5302).

Other

The CEIHD research analyst then tested for the effects of all other household, time-activity-location, and weather variables on personal exposures in univariate analyses. The significant or nearly significant (p-value <0.25) predictors of the natural logarithm of women's $PM_{2.5}$ exposures include relative humidity, temperature, total time reported high smoke levels, time reported moderate smoke levels, reported time participant burnt trash, reported time fire lit, and reported time cooking.

Multivariable Models

EcoStove Efficacy for Reducing $PM_{2.5}$ Exposures

The CEIHD research analyst began the model selection by building a "kitchen sink" model including the variables necessary to compare the study groups and stove types, all the variables not well-balanced between the two groups at baseline (p-value < 0.25), and all the variables even weakly associated with exposures (p-value < 0.25). The "kitchen sink" model for women's exposures included round (0 for pre-intervention and 1 for post-intervention), randomization group (0 for those that received the close EcoStove), the interaction of round and group, kitchen volume (m^3), amount of time spent cooking, amount of time cooking over the open fire post-intervention, amount of time somebody else smoked in the participant's house, amount of time participant household burned trash, amount of time neighbor burned trash, average ambient temperature, and average relative humidity. The interaction between round and study group estimates the difference in exposure reductions among the women who received semi-open EcoStoves relative to the exposure reductions among the women who received the closed EcoStoves. Since this model included a variable for the amount of time cooking over the open fire post-intervention, the effect is stove type is a measure of efficacy for reducing IAP.

Although the variable for study group was the least significant predictor (β = -0.033, p-value = 0.8763), it was kept in the model to respect the analysis plan that would compare the IAP changes in the two intervention arms by controlling for baseline IAP levels. Kitchen volume was the next least significant variable in the model (ß = -0.004, p-value =

0.6122) and the first to be eliminated in the backwards elimination procedure. Relative humidity was the next least significant variable ($\beta = 0.005$, p-value = 0.7873). The rest of the variables were significant at the p-value = 0.25 level. However, time exposed to passive smoking and neighbors burning trash were removed because they were both associated with decreases in exposure, contrary to expectations, due to single outliers. The following predictors remained in the model after backwards elimination and removal of statistical outliers: study round, study group, the interaction of round and group, reported cooking time, reported amount of time using the open fire after the EcoStove intervention, reported amount of time burning trash, and average daily temperature.

This main effects model was then compared to a mixed effects model with the same main effects and with the addition of a random effect for intercept. This model accounts for the correlation among repeated measures within each home. The precision of the model was improved with this approach. The results of this refined version of the model for women's exposures are presented in Table A.3. Controlling for the effects of study group, cooking time, duration of open fire use post-intervention, trash burning, and ambient temperature, the introduction of closed EcoStoves resulted in an 89% $((e^{-2.174} - 1) * 100)$ reduction in women's exposures, whereas the introduction of the semi-open EcoStoves resulted in an 83% $((e^{-2.174 + 0.391} - 1) * 100)$ exposure reduction. The interaction term for estimating the differential reduction in exposure offered by the semi-open compared to closed EcoStoves indicates a small difference between the stove types, though not statistically significant (p-value = 0.158).

Table A.3: Linear Mixed-Effects Model to Estimate EcoStove Efficacy for Reducing Women's Exposures to $PM_{2.5}$ (Full Set of Predictors)

Variable	β estimate (95% CI)	Predicted Percent Change (95% CI)	p-value
Intercept	-1.317 (-6.850, 4.216)		0.636
Stove/Group Combination*			
Round (Group 1 Closed ES vs. Group 1 OF)	-2.174 (-2.771, -1.578)	-88.6 (-93.7, -79.4)	< 0.0001
Group (Group 2 OF vs. Group 1 OF)	0.081 (-0.366, 0.528)	8.4 (-30.6, 69.6)	0.717
Round*Group (Differential Change with Semi-Open vs. Change with Closed ES)	0.391 (-0.157, 0.938)	47.8 (-14.5, 155.5)	0.158
Cooking Time (hr)	0.045 (-0.032, 0.122)	4.6 (-3.1, 13.0)	0.247
Open fire use post-intervention (hr)	0.196 (0.040, 0.352)	21.7 (4.1, 42.2)	0.015
Burning Trash (hr)	0.334 (-0.096, 0.764)	39.7 (-9.2, 114.7)	0.125
Avg. Daily Temp (deg C)	0.233 (0.032, 0.434)	26.2 (3.3, 54.3)	0.024

* Reference is Group 1 with open fire (OF) during pre-intervention round.

The CEIHD research analyst then started with this full set of predictors of women's $PM_{2.5}$ exposure and began to work towards a more parsimonious model, while observing changes in effect estimates to maintain unbiased stove comparisons. Since the least significant predictor of exposure was study group, this variable was eliminated first.

Removing this variable is tantamount to assuming that the randomization procedure was successful and that it is not necessary to adjust for differences in exposure at baseline. Table A.2 and Figure A.2 demonstrate that exposures were very similar between groups prior to the EcoStove intervention. Reported hours of cooking during the 24-hour sampling periods, which was the next least significant predictor (p-value = 0.2635), was then excluded from the model without any important influence on the other effect estimates. This model resulted in an insignificant β estimate for reported hours burning trash near the home (β = 0335, p-value = 0.1149). Removal of this variable did not significantly alter the estimates of the effects of stove types.

Table A.4: Linear Mixed-Effects Model to Estimate EcoStove Efficacy for Reducing Women's Exposures to $PM_{2.5}$ (Parsimonious Model)

Variable	β estimate (95% CI)	Predicted Percent Change (95% CI)	p-value
Intercept	-0.860 (-6.314, 4.595)		0.754
Stove/Group Combination*			
Round (Group 1 Closed ES vs. Group 1 OF)	-2.342 (-2.907, -1.778)	-90.4 (-94.5, -83.1)	< 0.0001
Round*Group (Differential Change with Semi-Open vs. Change with Closed ES)	0.467 (0.046, 0.887)	59.5 (4.7, 142.8)	0.030
Open fire use post-intervention (hr)	0.210 (0.055, 0.365)	23.4 (5.7, 44.1)	0.009
Avg. Daily Temp (deg C)	0.231 (0.031, 0.432)	26.0 (3.1, 54.0)	0.025

* Reference is Group 1 with open fire (OF) during pre-intervention round.

The inclusion of the variable for reported durations of open fire use post-intervention causes the term for the interaction between round and study group to be a comparison of the two EcoStove models assuming equal open fire use. The inclusion of this variable also causes the term for round (post-intervention versus pre-intervention) to be an estimate of exposure reductions offered by EcoStoves relative to the traditional open fire after eliminating the influence of open fire use post-intervention. Since the stove comparisons in the models from Tables A.3 and A.4 relate to exclusive use of the EcoStoves, the parameter estimates provide information on the efficacy of the EcoStoves for reducing IAP exposure. With these models we can estimate the proportion of $PM_{2.5}$ exposures attributable directly to the EcoStoves. In other words, we can estimate the exposures that would occur if people completely substituted the EcoStove for the traditional open fire. The model can be expressed:

$$\ln(\text{exposure}) = ß_0 + ß_1\text{*round} + ß_2\text{*group} + ß_3\text{*round*group} + ß_4\text{*hours of cooking} + ß_5\text{*hours open fire use post-intervention} + ß_6\text{*hours burning trash} + ß_7\text{*temperature},$$

Filling in ß estimates from the exposure efficacy model with the full set of variables (Table A.3) and assuming the average hours of cooking among households with the closed EcoStove (5.18 hours), zero hours of open fire use post-intervention, zero hours of trash burning, and the average temperature during the study (25.75 ºC), we estimate for the closed EcoStove:

$$\ln(\text{exposure}) = (-1.317) + (-2.174 * 1) + (0.081 * 0) + (0.391 * 0) + (0.045 * 5.18) + (0.196 * 0) + (0.334 * 0) + (0.231 * 25.75),$$

Exponentiating both sides of the equation, we have:

$$\text{exposure} = e^{(-1.317 + (-2.174 * 1) + (0.081 * 0) + (0.391 * 0) + (0.045*5.18) + (0.196*0) + (0.334*0) + (0.231 * 25.75))} = 15\ \mu g/m^3,$$

which is the amount of exposure attributable to the closed EcoStove, assuming no open fire use and no trash burning by the participants.

The same estimate for the semi-open EcoStove is calculated:

$$\ln(\text{exposure}) = (-1.317) + (-2.174 * 1) + (0.081 * 1) + (0.391 * 1) + (0.045 * 4.95) + (0.196 * 0) + (0.334 * 0) + (0.231 * 25.75),$$

Exponentiating both sides of the equation, we have:

$$\text{exposure} = e^{(-1.317 + (-2.174 * 1) + (0.081 * 1) + (0.391 * 1) + (0.045*4.95) + (0.196*0) + (0.334*0) + (0.231 * 25.75))} = 23\ \mu g/m^3,$$

which is the amount of exposure attributable to the semi-open EcoStove, assuming no open fire use and no trash burning by the participants. Though this exposure is higher than that attributed to the closed EcoStove, recall that the difference was not statistically significant.

Filling in ß estimates from the parsimonious exposure reduction efficacy model (Table A.4) and assuming zero hours of open fire use post-intervention and the average temperature during the study, we estimate women's exposure at 16 $\mu g/m^3$. The same assumptions produce an estimate of 25 $\mu g/m^3$ for exposure among women cooking exclusively with the semi-open EcoStoves. Note that these estimates differ slightly because the parsimonious model does not control for hours of cooking, burning trash, nor study group as in the model with the full set of predictors.

EcoStove Effectiveness for Reducing $PM_{2.5}$ Exposures

The models for personal exposure discussed below exclude the variable for open fire use post-intervention and therefore estimate the effectiveness of EcoStoves for reducing IAP under real-life conditions. This type of model is an "intention-to-treat" analysis, which refers to the evaluation of the effect of allocating people to a treatment group rather than the actual effect of using the treatment.[‡]

[‡] Typical analyses of randomized trials use the "intention-to-treat" rule, in which subjects are compared based on their assigned treatment, regardless of compliance. Estimates of intervention effects based on this rule are likely to be biased because noncompliance causes assigned improved stove to become a misclassified version of used improved stove. On the other hand, noncompliers tend to differ from compliers with respect to exposure risk, and hence the analyses of the effect of use of a particular stove may be confounded. In the case of the two EcoStoves, we assume that the difference in compliance between the two groups is more likely due differences in the EcoStoves rather than the cooks.

Table A.5: Linear Mixed-Effects Model to Estimate EcoStove Effectiveness for Reducing Women's Exposures to $PM_{2.5}$ (Full Set of Predictors)

Variable	β estimate (95% CI)	Predicted Percent Change (95% CI)	p-value
Intercept	-1.005 (-6.627, 4.617)		0.722
Stove/Group Combination*			
Round (Group 1 Closed ES vs. Group 1 OF)	-1.997 (-2.602, -1.392)	-86.4 (-92.6, -75.1)	< 0.0001
Group (Group 2 OF vs. Group 1 OF)	0.093 (-0.359, 0.546)	9.7 (-30.2, 72.6)	0.681
Round*Group (Differential Change with Semi-Open vs. Change with Closed ES)	0.312 (-0.267, 0.890)	36.6 (-23.4, 143.5)	0.285
Cooking Time (hr)	0.058 (-0.019, 0.134)	6.0 (-1.9 14.3)	0.136
Burning Trash (hr)	0.341 (-0.096, 0.778)	40.6 (-9.2, 117.7)	0.124
Avg. Daily Temp (deg C)	0.218 (0.014, 0.422)	24.4 (1.4, 52.5)	0.037

* Reference is Group 1 with open fire (OF) during pre-intervention round.

Adjusting for the effects of study group, duration of cooking, burning trash and average daily temperature, the introduction of the closed EcoStove was associated with an 86% reduction in $PM_{2.5}$ exposure, while the introduction of the semi-open model was associated with an 80% reduction. The difference between the effects of the two EcoStove models on $PM_{2.5}$ exposures was not significant (p-value = 0.285).

A similar process of backward selection as for the efficacy model was used to derive a more parsimonious model for the "intention-to-treat" (effectiveness) analyses. The same variables were eliminated as neither significant predictors of exposures nor confounders of the relationship between stove types and exposures.

Table A.6: Linear Mixed-Effects Model to Estimate EcoStove Effectiveness for Reducing Women's Exposures to $PM_{2.5}$ (Parsimonious Model)

Variable	β estimate (95% CI)	Predicted Percent Change (95% CI)	p-value
Intercept	-0.376 (-5.947, 5.195)		0.893
Stove/Group Combination*			
Round (Group 1 Closed ES vs. Group 1 OF)	-2.179 (-2.754, -1.603)	-88.7 (-93.6, -79.9)	< 0.0001
Round*Group (Differential Change with Semi-Open vs. Change with Closed ES)	0.402 (-0.029, 0.834)	49.5 (-2.9, 130.3)	0.067
Avg. Daily Temp (deg C)	0.214 (0.009, 0.418)	23.9 (0.9, 51.9)	0.041

* Reference is Group 1 with open fire (OF) during pre-intervention round.

Adjusting for the effect of average daily temperature, introduction of the closed EcoStove was associated with an 89% reduction in $PM_{2.5}$ exposure, while the introduction of the semi-open model was associated with an 83% reduction. The difference between the effects of the two EcoStove models on $PM_{2.5}$ exposures was almost significant at the traditional p-value < 0.05 level (p-value = 0.067). However, note that this model may be less correct than the full model, since it does not control for the differences in kitchen $PM_{2.5}$ levels between the study groups at baseline.

EcoStove Efficacy for Reducing Kitchen $PM_{2.5}$ Levels

The CEIHD research analyst took a similar approach to building a model for kitchen concentrations. The "kitchen sink" model included the variables necessary to compare the study groups and stove types, all the variables not balanced between the two groups at baseline (p-value < 0.25), and all the variables even weakly associated with kitchen concentrations (p-value < 0.25). The significant or nearly significant predictors of kitchen concentrations are temperature, total time reported high smoke levels, time reported moderate smoke levels, reported time participant burned trash, reported time participant smoked, reported time fire lit, reported time cooking, and reported time using open fire post-intervention. The "kitchen sink" model for kitchen concentrations included round (0 for pre-intervention and 1 for post-intervention), randomization group (0 for those that received the closed EcoStove), the interaction of round and group, time during which the fire was lit, time cooking over the open fire post-intervention, amount of time participants reportedly burned trash, reported amount of time neighbors burned trash, reported time participant smoked, reported time exposed to passive tobacco smoke, and average daily temperature. A random effect for intercept was added to this main effects model to account for correlation among the repeated measures.

As with the models for personal exposures, backwards elimination were the main technique used to remove unimportant independent variables. After smoking, study group was the next variable to be removed on the basis of statistical significance. Although removal of study group was found to change the ß estimate for the interaction between group and round from 1.00 to 0.844, the decision was made to exclude this from the model since kitchen $PM_{2.5}$ levels were not measured in all of the same homes pre- and post-intervention. Temperature was found to be a negative confounder of the relationship between round and kitchen concentrations. Round represents the overall comparison of both EcoStove models together with the open fire. Reported hours using the open fire post-intervention was found to be a negative confounder of the relationship between the round and study group interaction and kitchen levels. After removing variables that were not significant predictors of kitchen $PM_{2.5}$ (p-value < 0.05) and that did not alter the effect estimates of stove type by more than 10%, the model for EcoStove efficacy remained with the following independent variables: round, interaction of round and group, reported amount of time using open fire post-intervention, and average daily temperature. The results of this model are found in Table A.7.

Table A.7: Linear Mixed-Effects Model to Estimate EcoStove Efficacy for Reducing Kitchen Levels of $PM_{2.5}$ (Parsimonious Model)

Variable	β estimate (95% CI)	Predicted Percent Change (95% CI)	p-value
Intercept	-0.967	Variable	0.812
Stove/Group Combination*			
Round (Group 1 Closed ES vs. Group 1 OF)	-2.841 (-3.655, -2.028)	-94.2 (-97.4, -86.8)	<0.0001
Round*Group (Differential Change with Semi-Open vs. Change with Closed ES)	0.837 (0.170, 1.505)	131.0 (18.5, 35.4)	0.016
Open fire use post-intervention (hr)	0.171 (-0.086, 0.428)	18.6 (-8.2, 53.4)	0.182
Avg. Daily Temp (deg C)	0.255 (-0.049, 0.559)	29.0 (-4.8, 74.9)	0.096

* Reference is Group 1 with open fire (OF) during pre-intervention round.

The model in Table A.7 indicates that exclusive use of the closed EcoStoves would result in a 94% reduction in kitchen $PM_{2.5}$ concentrations, whereas the exclusive use of the semi-open EcoStoves would result in an 86% reduction. The interaction term for estimating the differential reduction in exposure offered by the semi-open compared to the closed EcoStove was significant in the efficacy model ($\beta = 0.837$, p-value = 0.016), suggesting that the reduction in kitchen levels of $PM_{2.5}$ offered by the closed EcoStove is significantly greater than the semi-open EcoStove. It is important to note that these analyses do not control for differences between the groups at baseline. Also, these are estimates of the effects of the EcoStoves controlling for open fire use post-intervention, which is what may be expected if people completely substituted the EcoStoves for the open fires.

EcoStove Effectiveness for Reducing Kitchen $PM_{2.5}$ Levels

The model in Table A.8 provides estimates of the actual effect of having EcoStoves on kitchen levels of $PM_{2.5}$, without subtracting the effect of continued open fire use. The effect estimate for round indicates that the introduction of the closed EcoStoves resulted in a 94% reduction in kitchen levels, whereas multiplication of the effect estimates for round and the round-by-group interaction indicate that the semi-open EcoStove is associated with an 87% reduction ($(e^{-2.775} * e^{0.728} - 1) * 100\% = -87\%$). The interaction term for estimating the differential reduction in kitchen $PM_{2.5}$ levels offered by the semi-open compared to the closed EcoStove was significant in the stove effectiveness model ($\beta = 0.728$, p-value = 0.028), which takes into account the fact that some women in the study did not completely switch to the EcoStove.

Table A.8: Linear Mixed-Effects Model to Estimate EcoStove Effectiveness for Reducing Kitchen Levels of $PM_{2.5}$ (Parsimonious Model)

Variable	β estimate (95% CI)	Predicted Percent Change (95% CI)	p-value
Intercept	-1.659 (-9.763, 6.445)		0.680
Stove/Group Combination*			
Round (Group 1 Closed ES vs. Group 1 OF)	-2.775 (-3.564, -1.985)	-93.8 (-97.2, -86.3)	<0.0001
Round*Group (Differential Change with Semi-Open vs. Change with Closed ES)	0.728 (0.086, 1.370)	107.1 (8.9, 293.5)	0.028
Avg. Daily Temp (deg C)	0.281 (-0.019, 0.580)	32.4 (-1.9, 78.6)	0.065

* Reference is Group 1 with open fire (OF) during pre-intervention round.

As with the exposure comparisons, these results suggest the possibility that the closed EcoStove reduces IAP somewhat better than the semi-open model. However, the difference between the EcoStoves was not statistically significant for the exposure models taking into account the study group differences at baseline and the differences between study groups could not be taken into account in the kitchen analyses, since different households were monitored pre- and post-intervention, due to logistical constraints.

Table A.9: Comparison of Estimates of EcoStove Efficacy and Effectiveness in Reducing Personal Exposures and Kitchen Levels of $PM_{2.5}$

Model	Efficacy		Effectiveness	
	Pers. Exposure	Kitchen Levels	Pers. Exposure	Kitchen Levels
Closed	89%	94%	86%	94%
Semi-Open	83%	86%	80%	87%

In this intervention, the effectiveness of both EcoStoves in reducing both personal exposures and kitchen concentrations of $PM_{2.5}$ was very similar to their estimated efficacy. This indicates that, at least initially, the EcoStove was successfully adopted in the study homes.

Discussion

The most comparable and widely disseminated improved biomass cook stove in Central America is the improved plancha from Guatemala. A study by Albalak *et al*. in the western highlands of Guatemala found that, compared to open fire kitchens, indoor concentrations of $PM_{3.5}$ were 45% lower in homes with gas (LPG) stoves and open fires, and 85% lower in homes with the improved plancha. However, this study included regular surveillance for stove deterioration, and the research team repaired stoves that had cracked or were leaking smoke. The IAP levels in the Guatemalan study were much higher in an absolute sense than in this Nicaraguan study, which is partially due to the more enclosed households in the colder Guatemalan highland region. In Guatemala, the open fire households had 24-hour average kitchen levels of particulate matter smaller than 3.5 microns ($PM_{3.5}$) of 1930 $\mu g/m^3$ and the improved plancha kitchens had average $PM_{3.5}$ levels of 330 $\mu g/m^3$, while in Nicaragua open fire kitchens had $PM_{2.5}$ levels of 573 $\mu g/m^3$, closed EcoStove kitchens had 53 $\mu g/m^3$ $PM_{2.5}$, and semi-open EcoStove kitchens had 121 $\mu g/m^3$ $PM_{2.5}$. Since the IAP levels in open fire kitchens in Guatemala were much higher, the IAP levels in the improved stove households in Nicaragua and Guatemala are not directly comparable. Comparing the percent reductions in IAP, the EcoStove performed only slightly better than the improved plancha

There are many differences between the studies that should be considered when comparing the performance of the Guatemalan and Nicaraguan improved stoves. While the goal of the Albalak *et al*. study was to determine whether the plancha could be used to reduce concentrations for a health study if the stoves were maintained over time by the study team, the goal of the EcoStove study is to measure the impact of an improved stove under real life conditions. The Guatemala study also did not directly measure personal exposure, as was done in Ciudadela de San Martin. In addition, the improved planchas had been used for several years, roughly ranging from two to four years, whereas the EcoStoves in this study had been used for only an average of 34 days before the IAP assessment. Another difference is that the Albalak *et al*. study evaluated the ability of stoves to maintain reductions in concentrations over time by repeating measurement six times over an eight month period, whereas the EcoStove evaluation compared the tradition open fire to newly installed stoves. While $PM_{3.5}$ was measured by Albalak *et al*., the present study measured $PM_{2.5}$. This should make little difference, since the vast majority of wood smoke particles are less than 1 micron in diameter.

The evidence suggests that the closed EcoStove may offer greater IAP reductions, and therefore greater health benefits, compared to the improved plancha and semi-open EcoStove. However, given the differences between the Albalak *et al*. study and the EcoStove IAP evaluation and the lack of statistical significance in the exposure comparisons between the EcoStove models in the present study, we cannot make strong conclusions regarding which stove is most effective at reducing IAP levels and exposures. At the low cost of about $35 compared to approximately $120 for the improved plancha, the EcoStove has greater potential as a widespread public health intervention.

Conclusions

- The randomized intervention design allowed for efficient comparison of stove types with minimal influence of confounding factors.
- Comparisons of the changes in IAP levels and exposures over time, acknowledging the correlation between IAP levels within households, allowed detection of small differences between the two EcoStove models.
- Both the closed and semi-open EcoStove models achieve large reductions in indoor air pollution and exposure among Nicaraguan women cooking in enclosed kitchens.

- Although the data suggest the possibility that the closed EcoStove model reduces women's $PM_{2.5}$ exposures by a greater amount than the semi-open model, these comparisons are not conclusive.
- The reduction in kitchen levels of $PM_{2.5}$ was significantly greater with the closed EcoStove than semi-open EcoStove.
- Although open fire use after the intervention did not change the results of the stove comparisons, even the very small amount of reported open fire use did have a significant effect on $PM_{2.5}$ exposures and would be a concern if it increased over time.
- The magnitude of these exposure reductions is expected to have great health benefits for Nicaraguan families. Given data on the local incidence or prevalence of diseases related to biomass smoke, these health benefits could be roughly estimated. Since the IAP levels in Nicaragua were lower than those in other developing countries where epidemiological studies of biomass smoke have been conducted, extrapolations of health risks may require careful consideration of the assumptions involved. Since the health benefits will be multiplied by the amount of time the exposure reductions are maintained, an important next step would be to evaluate whether these reductions in exposure are sustained after potential stove deterioration. Repetition of the same data collection protocol is recommended within one to two years.

References

Albalak R, Bruce N, McCracken J, Smith K, Gallardo T. Indoor Respirable Particulate Matter Concentrations from an Open Fire, Improved Cookstove, and an LPG/Open Fire Combination in a Rural Guatemalan Community. Environ. Sci. Technol. 2001; 35(13):2650-2655.

Ezzati M, Kammen DM. Quantifying the Effects of Exposure to Indoor Air Pollution from Biomass Combustion on Acute Respiratory Infections in Developing Countries. Environmental Health Perspectives 2001; 109(5):481-488.

Smith KR. National burden of disease in India from indoor air pollution. PNAS 2000; 97(24):13286-13293.

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Region/Country	***Activity/Report Title***	***Date***	***Number***
	SUB-SAHARAN AFRICA (AFR)		
Africa	Power Trade in Nile Basin Initiative Phase II (CD Only): *Part I: Minutes of the High-level Power Experts Meeting; and Part II: Minutes of the First Meeting of the Nile Basin Ministers Responsible for Electricity*	04/05	067/05
Chad	Revenue Management Seminar. Oslo, June 25-26, 2003. (CD Only)	06/05	075/05
Côte d'Ivoire	Workshop on Rural Energy and Sustainable Development, January 30-31, 2002. (French Only)	04/05	068/05
Ethiopia	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Ethiopia - Action Plan.	12/03	038/03
	Sub-Saharan Petroleum Products Transportation Corridor: Analysis And Case Studies	03/03	033/03
	Phase-Out of Leaded Gasoline in Sub-Saharan Africa	04/02	028/02
	Energy and Poverty: How can Modern Energy Services Contribute to Poverty Reduction	03/03	032/03
East Africa	Sub-Regional Conference on the Phase-out Leaded Gasoline in East Africa. June 5-7, 2002.	11/03	044/03
Kenya	Field Performance Evaluation of Amorphous Silicon (a-Si) Photovoltaic Systems in Kenya: Methods and Measurement in Support of a Sustainable Commercial Solar Energy Industry	08/00	005/00
	The Kenya Portable Battery Pack Experience: Test Marketing an Alternative for Low-Income Rural Household Electrification	12/01	05/01
Malawi	Rural Energy and Institutional Development	04/05	069/05
Mali	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Mali - Action Plan. (French)	12/03	041/03
Mauritania	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Mauritania - Action Plan. (French)	12/03	040/03
Nigeria	Phase-Out of Leaded Gasoline in Nigeria	11/02	029/02
	Nigerian LP Gas Sector Improvement Study	03/04	056/04
	Taxation and State Participation in Nigeria's Oil and Gas Sector	08/04	057/04
Regional	Second Steering Committee: The Road Ahead. Clean Air Initiative In Sub-Saharan African Cities. Paris, March 13-14, 2003.	12/03	045/03
	Lead Elimination from Gasoline in Sub-Saharan Africa. Sub-regional Conference of the West-Africa group. Dakar, Senegal March 26-27, 2002 (French only)	12/03	046/03
	1998-2002 Progress Report. The World Bank Clean Air Initiative in Sub-Saharan African Cities. Working Paper #10 (Clean Air Initiative/ESMAP)	02/02	048/04
	Landfill Gas Capture Opportunity in Sub Saharan Africa	06/05	074/05
	The Evolution of Enterprise Reform in Africa: From State-owned Enterprises to Private Participation in Infrastructure —and Back?	11/05	084/05
Senegal	Regional Conference on the Phase-Out of Leaded Gasoline in Sub-Saharan Africa	03/02	022/02
	Elimination du Plomb dans I'Essence en Afrique Sub-Saharienne Conference Sous Regionales du Groupe Afrique de I'Quest. Dakar, Senegal. March 26-27, 2002.	12/03	046/03

Region/Country	*Activity/Report Title*	*Date*	*Number*
Senegal	Alleviating Fuel Adulteration Practices in the Downstream Oil Sector in Senegal	09/05	079/05
South Africa	South Africa Workshop: People's Power Workshop.	12/04	064/04
Swaziland	Solar Electrification Program 2001—2010: Phase 1: 2001—2002 (Solar Energy in the Pilot Area)	12/01	019/01
Tanzania	Mini Hydropower Development Case Studies on the Malagarasi, Muhuwesi, and Kikuletwa Rivers Volumes I, II, and III	04/02	024/02
	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Tanzania - Action Plan.	12/03	039/03
Uganda	Report on the Uganda Power Sector Reform and Regulation Strategy Workshop	08/00	004/00

WEST AFRICA (AFR)

Regional	Market Development	12/01	017/01

EAST ASIA AND PACIFIC (EAP)

Cambodia	Efficiency Improvement for Commercialization of the Power Sector	10/02	031/02
	TA For Capacity Building of the Electricity Authority	09/05	076/05
China	Assessing Markets for Renewable Energy in Rural Areas of Northwestern China	08/00	003/00
	Technology Assessment of Clean Coal Technologies for China Volume I—Electric Power Production	05/01	011/01
	Technology Assessment of Clean Coal Technologies for China Volume II—Environmental and Energy Efficiency Improvements for Non-power Uses of Coal	05/01	011/01
	Technology Assessment of Clean Coal Technologies for China Volume III—Environmental Compliance in the Energy Sector: Methodological Approach and Least-Cost Strategies	12/01	011/01
Philippines	Rural Electrification Regulation Framework. (CD Only).	10/05	080/05
Thailand	DSM in Thailand: A Case Study	10/00	008/00
	Development of a Regional Power Market in the Greater Mekong Sub-Region (GMS)	12/01	015/01
Vietnam	Options for Renewable Energy in Vietnam	07/00	001/00
	Renewable Energy Action Plan	03/02	021/02
	Vietnam's Petroleum Sector: Technical Assistance for the Revision of the Existing Legal and Regulatory Framework	03/04	053/04

SOUTH ASIA (SAS)

Bangladesh	Workshop on Bangladesh Power Sector Reform	12/01	018/01
	Integrating Gender in Energy Provision: The Case of Bangladesh	04/04	054/04
	Opportunities for Women in Renewable Energy Technology Use In Bangladesh, Phase I	04/04	055/04

Region/Country	*Activity/Report Title*	*Date*	*Number*

EUROPE AND CENTRAL ASIA (ECA)

Russia	Russia Pipeline Oil Spill Study	03/03	034/03
Uzbekistan	Energy Efficiency in Urban Water Utilities in Central Asia	10/05	082/05

MIDDLE EASTERN AND NORTH AFRICA REGION (MENA)

Regional	Roundtable on Opportunities and Challenges in the Water, Sanitation And Power Sectors in the Middle East and North Africa Region. Summary Proceedings, May 26-28, 2003. Beit Mary, Lebanon. (CD)	02/04	049/04
Morocco	Amélioration de d´Efficacité Energie: Environnement de la Zone Industrielle de Sidi Bernoussi, Casablanca	12/05	085/05

LATIN AMERICA AND THE CARIBBEAN REGION (LCR)

Brazil	Background Study for a National Rural Electrification Strategy: Aiming for Universal Access	03/05	066/05
Bolivia	Country Program Phase II: Rural Energy and Energy Efficiency Report on Operational Activities	05/05	072/05
Chile	Desafíos de la Electrificación Rural	10/05	082/05
Ecuador	Programa de Entrenamiento a Representantes de Nacionalidades Amazónicas en Temas Hidrocarburíferos	08/02	025/02
Guatemala	Evaluation of Improved Stove Programs: Final Report of Project Case Studies	12/04	060/04
Mexico	Energy Policies and the Mexican Economy	01/04	047/04
Nicaragua	Aid-Memoir from the Rural Electrification Workshop (Spanish only)	03/03	030/04
	Sustainable Charcoal Production in the Chinandega Region	04/05	071/05
	Pilot Commercialization of Improved Cookstoves in Nicaragua	12/05	086/06
Regional	Regional Electricity Markets Interconnections — Phase I Identification of Issues for the Development of Regional Power Markets in South America	12/01	016/01
	Regional Electricity Markets Interconnections — Phase II Proposals to Facilitate Increased Energy Exchanges in South America	04/02	016/01
	Population, Energy and Environment Program (PEA) Comparative Analysis on the Distribution of Oil Rents (English and Spanish)	02/02	020/02
	Estudio Comparativo sobre la Distribución de la Renta Petrolera Estudio de Casos: Bolivia, Colombia, Ecuador y Perú	03/02	023/02
	Latin American and Caribbean Refinery Sector Development Report – Volumes I and II	08/02	026/02
	The Population, Energy and Environmental Program (EAP) (English and Spanish)	08/02	027/02
	Bank Experience in Non-energy Projects with Rural Electrification Components: A Review of Integration Issues in LCR	02/04	052/04
	Supporting Gender and Sustainable Energy Initiatives in Central America	12/04	061/04
	Energy from Landfill Gas for the LCR Region: Best Practice and Social Issues (CD Only)	01/05	065/05

Region/Country	Activity/Report Title	Date	Number

GLOBAL

	Impact of Power Sector Reform on the Poor: A Review of Issues and the Literature	07/00	002/00
	Best Practices for Sustainable Development of Micro Hydro Power in Developing Countries	08/00	006/00
	Mini-Grid Design Manual	09/00	007/00
	Photovoltaic Applications in Rural Areas of the Developing World	11/00	009/00
	Subsidies and Sustainable Rural Energy Services: Can we Create Incentives Without Distorting Markets?	12/00	010/00
	Sustainable Woodfuel Supplies from the Dry Tropical Woodlands	06/01	013/01
	Key Factors for Private Sector Investment in Power Distribution	08/01	014/01
	Cross-Border Oil and Gas Pipelines: Problems and Prospects	06/03	035/03
	Monitoring and Evaluation in Rural Electrification Projects: A Demand-Oriented Approach	07/03	037/03
	Household Energy Use in Developing Countries: A Multicountry Study	10/03	042/03
	Knowledge Exchange: Online Consultation and Project Profile from South Asia Practitioners Workshop. Colombo, Sri Lanka, June 2-4, 2003	12/03	043/03
	Energy & Environmental Health: A Literature Review and Recommendations	03/04	050/04
	Petroleum Revenue Management Workshop	03/04	051/04
	Operating Utility DSM Programs in a Restructuring Electricity Sector	12/05	058/04
	Evaluation of ESMAP Regional Power Trade Portfolio (TAG Report)	12/04	059/04
	Gender in Sustainable Energy Regional Workshop Series: Mesoamerican Network on Gender in Sustainable Energy (GENES) Winrock and ESMAP	12/04	062/04
	Women in Mining Voices for a Change Conference (CD Only)	12/04	063/04
	Renewable Energy Potential in Selected Countries: Volume I: North Africa, Central Europe, and the Former Soviet Union, Volume II: Latin America	04/05	070/05
	Renewable Energy Toolkit Needs Assessment	08/05	077/05
	Portable Solar Photovoltaic Lanterns: Performance and Certification Specification and Type Approval	08/05	078/05
	Crude Oil Prices Differentials and Differences in Oil Qualities: A Statistical Analysis	10/05	081/05

Last report added to this list: ESMAP Technical Paper 086/05.