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Prospects for Coal Briquettes as a Substitute Fuel for Wood and Charcoal in U.S. Agency for International Development Assisted Countries

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ABSTRACT

Fuelwood shortages and potential shortages are widespread throughout the developing world, and are becoming increasingly more prevalent because of the clearing of land for subsistence and plantation agriculture, excessive and inefficient commercial timber harvesting for domestic and export construction, and charcoal production to meet rising urban demands. It is estimated that three billion people will live in acute wood scarcity and wood deficit regions by the year 2000. Further, the environmental and socioeconomic consequences of the resulting deforestation are both pervasive and complex. There are three energy policy options for mitigating the onslaught of deforestation and the inevitable and pernicious effects of fuelwood scarcities -- conservation, reforestation, and substitution. This report focuses on the substitution of coal briquettes for fuelwood. Coal briquetting is a process by which raw coal is compacted into uniform, usually hard, and impact resistant agglomerations. Although substantial adverse health effects could be expected from burning non-anthracite coal or coal briquettes, a well-developed technique, carbonization, exists to convert coal to a safer form for combustion. The costs associated with briquetting and carbonizing coal indicate that "smokeless" coal briquettes can be produced at costs competitive with fuelwood and charcoal. Coal briquetting and carbonization have been practiced extensively in India, and this experience is instructive because of the wide range of technologies and coal types utilized. The U.S. Agency for International Development (USAID) is working on implementing this energy option in Haiti and Pakistan by (1) evaluating resources, (2) assessing markets, (3) analyzing technologies, (4) studying government policy and planning, and (5) packaging the idea for the private sector to implement. A preliminary examination of other USAID assisted countries indicates that an additional fifteen countries have the necessary coal reserves to become candidates for somkeless coal briquetting.

EXECUTIVE SUMMARY

I. INTRODUCTION

- THE U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT (A.I.D.) IS WORKING ON A PROBLEM THAT IS CRITICAL IN DOZENS OF DEVELOPING COUNTRIES. THAT PROBLEM IS FUELWOOD SHORTAGES. IMPLEMENTATION OF ONE POTENTIAL SOLUTION IS OCCURRING IN HAITI AND PAKISTAN--SMOKELESS COAL BRIQUETTES.

- TRADITIONAL ENERGY SOURCES ARE A SIGNIFICANT FRACTION OF ENERGY DEMAND IN DEVELOPING COUNTRIES. THESE TRADITIONAL SOURCES, ESPECIALLY FIREWOOD AND CHARCOAL, HAVE BECOME INCREASINGLY SCARCE BECAUSE OF THE CLEARING OF LAND FOR AGRICULTURE, CHARCOAL PRODUCTION, AND EXCESSIVE TIMBER HARVESTING.

- THE ENVIRONMENTAL AND SOCIOECONOMIC IMPACTS OF DEFORESTATION ARE BOTH PERVASIVE AND COMPLEX.

- THERE ARE THREE POLICY OPTIONS FOR MITIGATING THE FUELWOOD CRISIS: CONSERVATION, REFORESTATION, AND SUBSTITUTING COAL BRIQUETTES. THIS PROSPECTUS ADDRESSES THE LAST OF THESE OPTIONS -- USE OF SMOKELESS COAL BRIQUETTES.

- RESOURCE AND MARKET CONDITIONS ARE EXCELLENT IN SOME DEVELOPING COUNTRIES FOR THE SUBSTITUTION OF COAL BRIQUETTES FOR FUELWOOD. THE POTENTIAL FOR SUBSTITUTION IS GREATEST IN URBAN AREAS, WHERE FUEL CHOICE IS LARGELY BASED ON RELATIVE FUEL PRICE.

- COAL BRIQUETTING PROVIDES AN EXCELLENT OPPORTUNITY FOR THE PRIVATE SECTOR TO CONTRIBUTE TO SOLVING A DEVELOPING WORLD PROBLEM. MOST ASPECTS OF RESOURCE SUPPLY AND PRODUCT PRODUCTION CAN BE HANDLED BY PRIVATE ENTREPRENEURS.

II. FUELWOOD DEFICIENCIES AND COAL AVAILABILITY IN A.I.D. ASSISTED COUNTRIES

- IF NO CORRECTIVE ACTIONS ARE TAKEN, AN ESTIMATED THREE BILLION PEOPLE WILL LIVE IN ACUTE WOOD SCARCITY AND DEFICIT REGIONS BY THE YEAR 2000. ALMOST ALL A.I.D. SUPPORTED COUNTRIES ARE EXPERIENCING, OR WILL EXPERIENCE, ACUTE OR DEFICIT FUELWOOD SITUATIONS.

- APPROXIMATELY 50 DEVELOPING COUNTRIES REPORT GEOLOGICAL COAL RESOURCES. TWENTY A.I.D. COUNTRIES REPORT COAL RESERVES. THERE ARE 17 A.I.D. COUNTRIES THAT ESPECIALLY APPEAR TO BE CANDIDATES FOR INTRODUCING COAL BRIQUETTES -- EIGHT IN AFRICA, SEVEN IN ASIA, AND TWO IN LATIN AMERICA.

III. SMOKELESS COAL BRIQUETTES AS A POSSIBLE SUBSTITUTE FOR FUELWOOD

- SOME COAL BRIQUETTING TECHNIQUES MAKE COAL AN ATTRACTIVE FUELWOOD SUBSTITUTE BY CONVERTING IT INTO A SMOKELESS, COMPACT, STABLE, AND INEXPENSIVE FORM OF FUEL.

- COAL BRIQUETTING HAS BEEN SHOWN WORLD-WIDE TO BE A TECHNOLOGY CAPABLE OF USING COAL OF VARIOUS GRADES AND PRODUCING BRIQUETTES WITH DIFFERENT CHARACTERISTICS FOR DIFFERENT USES.

- BURNING RAW OR UNTREATED BRIQUETTED COAL PRODUCES EMISSIONS THAT CAN HAVE SERIOUS HEALTH EFFECTS.

- HOWEVER, COAL CARBONIZATION SIGNIFICANTLY REDUCES THE ADVERSE HEALTH EFFECTS FROM BURNING COAL OR COAL BRIQUETTES. THE RESULT OF CARBONIZATION IS A "SOFT SMOKELESS COKE." WHILE TESTING IS CURRENTLY IN PROGRESS, EMISSIONS FROM SMOKELESS COAL ARE PREDICTED TO BE NO WORSE THAN THOSE EMANATING FROM THE CURRENT FUELS OF CHARCOAL AND FIREWOOD.

- THE COSTS ASSOCIATED WITH BRIQUETTING AND CARBONIZING COAL INDICATE A SELLING PRICE FOR SMOKELESS COAL BRIQUETTES IN SOME URBAN AREAS THAT MAKE THEM COMPETITIVE WITH FUELWOOD AND CHARCOAL.

IV. INTERNATIONAL EXPERIENCES WITH COAL BRIQUETTING: INDIA AND KOREA

- COAL CARBONIZATION HAS BEEN PRACTICED EXTENSIVELY IN INDIA. THE INDIAN EXPERIENCE IS INSTRUCTIVE BECAUSE A WIDE RANGE OF TECHNOLOGIES AND COAL TYPES HAS BEEN UTILIZED. INDIA HAS DEPOSITS OF BITUMINOUS, SUBBITUMINOUS, AND LIGNITE COALS, AND ALL HAVE BEEN USED FOR CARBONIZATION. TECHNOLOGIES RANGE FROM ONE-PERSON, "VILLAGE COAL PILES" TO ADVANCED TECHNOLOGY CARBONIZATION PLANTS.

- INDIA HAS DEVELOPED A SMOKELESS COOKING STOVE WHICH CAN USE RAW COAL AS A FUEL SOURCE WITH NO SIGNIFICANT ADVERSE HEALTH EFFECTS.

- KOREANS HAVE USED RAW ANTHRACITE COAL BRIQUETTES EXTENSIVELY FOR COOKING AND HEATING. THE KOREANS STARTED COAL BRIQUETTING IN 1930, AND THERE ARE NOW APPROXIMATELY 20 LARGE BRIQUETTING PLANTS IN THE COUNTRY.

V. THE POTENTIAL FOR COAL BRIQUETTE SUBSTITUTION IN A.I.D. ASSISTED COUNTRIES

- SIGNIFICANT OPPORTUNITIES EXIST TO MITIGATE THE FUELWOOD CRISIS AROUND THE WORLD. A PRELIMINARY EXAMINATION OF THE SEVENTEEN A.I.D. COUNTRIES IDENTIFIED AS HAVING BOTH COAL RESERVES AND A FUELWOOD SHORTAGE INDICATES THAT FOUR APPEAR TO HAVE AN IMMEDIATE POTENTIAL: BOTSWANA, HAITI, INDIA, AND PAKISTAN. ANOTHER EIGHT COUNTRIES APPEAR TO HAVE A NEAR-TERM (3 TO 5 YEARS) POTENTIAL: INDONESIA, MOROCCO, NIGER, PERU, PHILIPPINES, TANZANIA, THAILAND, SWAZILAND, ZAIRE, ZAMBIA, AND ZIMBABWE.

VI. STRATEGIES FOR REALIZING THE POTENTIAL FOR COAL BRIQUETTING IN A.I.D. ASSISTED COUNTRIES

- IMPLEMENTING SMOKELESS COAL BRIQUETTING IN A.I.D ASSISTED COUNTRIES WILL BE BASED ON EXPERIENCES GAINED BY A.I.D. IN HAITI AND PAKISTAN.

- FIVE STEPS ARE NECESSARY TO SUCCESSFULLY IMPLEMENT SMOKELESS COAL BRIQUETTING AND MARKETING IN A.I.D. COUNTRIES. THESE INCLUDE A RESOURCE EVALUATION, A MARKET ASSESSMENT, A TECHNOLOGY ASSESSMENT, A STUDY OF GOVERNMENT POLICY AND PLANNING, AND PACKAGING THE IDEA FOR THE PRIVATE SECTOR TO IMPLEMENT.

- USAID/WASHINGTON, OFFICE OF ENERGY, WILL PROVIDE TECHNICAL ASSISTANCE TO MISSIONS IN IMPLEMENTING THE SMOKELESS COAL BRIQUETTE TECHNOLOGY.

PROSPECTS FOR COAL BRIQUETTES AS A
SUBSTITUTE FUEL FOR WOOD AND CHARCOAL
IN U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
ASSISTED COUNTRIES

I. INTRODUCTION

A. A.I.D. IS WORKING ON A PROBLEM THAT IS CRITICAL IN DOZENS OF DEVELOPING COUNTRIES. THAT PROBLEM IS FUELWOOD SHORTAGES. IMPLEMENTATION OF ONE POTENTIAL SOLUTION IS OCCURRING IN HAITI AND PAKISTAN--SMOKELESS COAL BRIQUETTES.

Fuelwood shortages and potential shortages are pervasive throughout the developing world, as the following sections document. One proposed solution is the substitution of a smokeless, coal-based cooking fuel where coal resources are available. The idea is even moving towards realization in two developing countries, Haiti and Pakistan. This prospectus describes the problem of fuelwood shortage, the smokeless coal alternative, and A.I.D.'s active role in bringing the alternative solution to fruition.

B. TRADITIONAL ENERGY SOURCES ARE A SIGNIFICANT FRACTION OF ENERGY DEMAND IN DEVELOPING COUNTRIES. THESE TRADITIONAL SOURCES, ESPECIALLY FIREWOOD AND CHARCOAL, HAVE BECOME INCREASINGLY SCARCE BECAUSE OF THE CLEARING OF LAND FOR AGRICULTURE, CHARCOAL PRODUCTION, AND EXCESSIVE TIMBER HARVESTING.

The traditional energy sources, firewood, charcoal, animal dung, and agricultural residues, account for nearly all of the rural household energy demand, and a significant portion of the energy demand among the urban poor. In Africa, it has been estimated that traditional fuels account for about 65 percent of total per capita energy consumption; in Asia they account for nearly 30 percent; and in Latin America traditional energy comprises approximately 25 percent of total per capita energy consumption (see Figure 1).[14] In many of these countries, the percentage of traditional energy consumption is expected to increase concomitantly with expanding populations, particularly in urban areas. As stated in the A.I.D. Policy Paper on Energy, "Assuring adequate domestic energy supplies for cooking presents a significant challenge in the years ahead." [22]

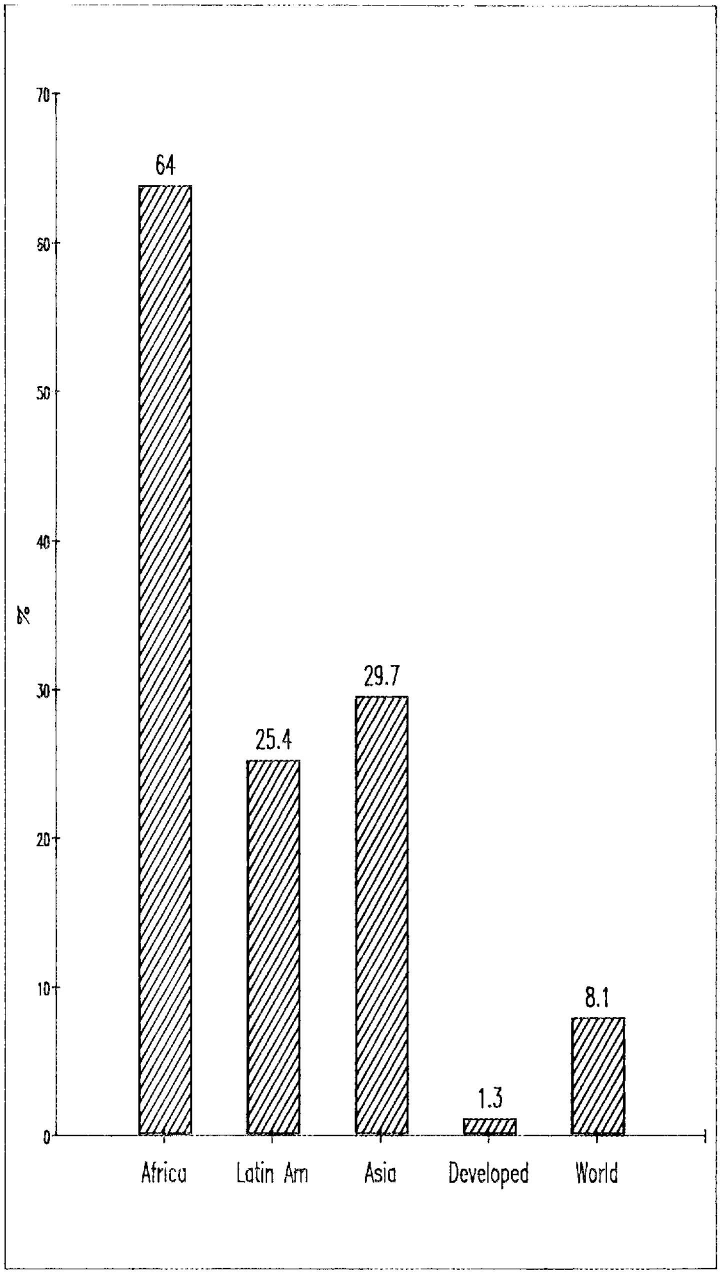

Fig. 1. Percentage of traditional fuels in total energy consumption

The principal causes of deforestation in developing countries usually can be attributed to three factors: (1) the clearing of land for subsistence and plantation agriculture; (2) the production of charcoal to meet rapidly rising demands by urban populations; and (3) excessive and inefficient commercial timber harvesting for domestic and export construction and manufacturing industries. The demand for firewood by rural populations is generally not the major cause of deforestation. Rural firewood demand is often characterized by the cutting of branches from live trees, shrubs, and bushes, and gathering of seed wood and does not always require the destruction of whole trees. In Haiti, for example, studies indicate that household cooking is done most often with scavenged deadwood. On the other hand, small industrial and commercial fuelwood consumers in Haiti do cut live trees.

C. THE ENVIRONMENTAL AND SOCIOECONOMIC IMPACTS OF DEFORESTATION ARE BOTH PERVASIVE AND COMPLEX.

The rate of deforestation has been estimated at about 7.3 million hectares per year for tropical forests and about 4 million hectares per year in semi-arid regions.[8] New wood supplies from reforestation programs have had little real impact to date. The Food and Agriculture Organization (FAO) estimates that for every ten hectares of cleared forest there is only one hectare replanted.[8] The environmental impacts of land clearance are cumulative and usually begin with reduced infiltration rates, increased water runoff, and increased soil temperatures. Water and wind erosion quickly sets in motion an almost irreversible process of soil degradation. In West Africa, soil loss from cultivated fields is as much as 6300 times greater than that for forest land; in Senegal, soil loss from groundnut cultivation is nearly 750 times greater than that for dry forest.[15] Deforestation also reduces upland water storage and intensifies siltation of reservoirs and rivers resulting in higher incidences of seasonal flooding, which leads to additional soil erosion. Moreover, the removal of bush vegetation in arid and semi-arid regions contributes to the onslaught of desertification. In some areas, particularly the Indian subcontinent, the rural population has turned to the burning of dung and agricultural residues. The use of these fuels deprives the land of crucially needed nutrients and soil conditioners. The end result is a dramatic decline in agricultural productivity--the backbone of all developing countries.

Reduced agricultural productivity sets in motion a cycle of unemployment and underemployment that serves only to accelerate the migration of rural populations to overly crowded urban centers. The scarcity of fuelwood also means that wood gatherers, primarily women and children, must now spend considerably more time in search of fuelwood. For example, in upland areas of Nepal households are spending from 60 to 230 workdays per year on firewood collection, and up to 300 workdays per year in some parts of Tanzania have been observed.[1] The scarcity of wood has, in most urban areas, resulted in the creation of markets for fuelwood. These markets have placed a heavy burden on the cash resources of the rural and poor urban populations. In the capital of

Burundi, households are spending as much as 30 percent of their income for fuel. As prices rise for wood and charcoal, populations begin to cut back on their consumption, and in some cases are reduced to cooking only once per day. In acute scarcity regions, fuelwood disappears altogether from the urban markets.[2] The fuelwood crisis can become so severe that in some African towns the cost of fuelwood exceeds the costs of commercial fuels such as kerosene and electricity.

D. THERE ARE THREE POLICY OPTIONS FOR MITIGATING THE FUELWOOD CRISIS: CONSERVATION, REFORESTATION, AND SUBSTITUTING COAL BRIQUETTES. THIS PROSPECTUS ADDRESSES THE LAST OF THESE OPTIONS -- USE OF SMOKELESS COAL BRIQUETTES.

There are three energy policy options that have been advanced for mitigating the onslaught of deforestation and the inevitable and pernicious effects of fuelwood scarcities, all of which are consistent with A.I.D.'s Policy Paper on Energy. They include: (1) conservation through improvements in fuelwood end-use efficiencies, specifically the diffusion of fuel-efficient cooking stoves and reduction in conversion losses in charcoal production with use of earthen, transportable metal and masonry kilns; (2) increasing the supply of fuelwood through reforestation, agroforestry, and improved forest management; and (3) substituting other sources of energy for fuelwood. This prospectus concentrates on option (3).

E. RESOURCE AND MARKET CONDITIONS ARE EXCELLENT IN SOME DEVELOPING COUNTRIES FOR THE SUBSTITUTION OF COAL BRIQUETTES FOR FUELWOOD. THE POTENTIAL FOR SUBSTITUTION IS GREATEST IN URBAN AREAS, WHERE FUEL CHOICE IS LARGELY BASED ON RELATIVE FUEL PRICE.

As the real costs of using fuelwood increase, the substitution of other fuels for firewood and charcoal will become more favorable. Because of fuelwood scarcities, the costs of traditional fuels are, in some locations, higher than commercial substitutes.[1] In other locations, such as Peru and Indonesia, commercial substitutes like kerosene are heavily subsidized to help the poor or to reduce deforestation.[18, 19] Yet, despite higher fuelwood prices substitution often does not take place until fuelwood supplies have been virtually depleted for as much as 100 kilometers or more surrounding urban areas.[1] In rural areas, high distribution costs do not favor commercial fuel substitutes, and besides, the people in these areas often live outside the commercial economy which makes the penetration of commercial substitutes less likely. Still, commercial substitutes do have potential where the costs of firewood and charcoal have risen sufficiently, particularly in concentrated urban markets.

F. COAL BRIQUETTING PROVIDES AN EXCELLENT OPPORTUNITY FOR THE PRIVATE SECTOR TO CONTRIBUTE TO SOLVING A DEVELOPING WORLD PROBLEM. MOST ASPECTS OF RESOURCE SUPPLY AND PRODUCT PRODUCTION CAN BE HANDLED BY PRIVATE ENTREPRENEURS.

On the supply side, virtually all aspects of coal briquetting manufacture and distribution can be controlled by the private sector. Under agreement with the government, which most often has ownership rights to coal in developing countries, private enterprises can mine the needed coal. Whether this means expanding existing mining operations or establishing new ones, significant new employment is possible. Private manufacturers can briquette and carbonize the coal--especially if an intermediate level of technology with reasonable capital costs is used. In some countries, the needed machinery can be manufactured locally, as is the case in India. Finally, the distribution network can easily consist of private dealers. Indeed, in many countries where fuelwood or charcoal is traded as a commercial item in urban areas, the potential private distributors already exist in the form of wood and charcoal dealers.

The substitution of coal briquettes for fuelwood, including the reasons for it, a nontechnical discussion of the technologies involved, and some possible market strategies, is the focus of the remainder of this Prospectus.

II. FUELWOOD DEFICIENCIES AND COAL AVAILABILITY IN A.I.D. ASSISTED COUNTRIES

A. IF NO CORRECTIVE ACTIONS ARE TAKEN, AN ESTIMATED THREE BILLION PEOPLE WILL LIVE IN ACUTE WOOD SCARCITY AND DEFICIT REGIONS BY THE YEAR 2000. ALMOST ALL A.I.D. SUPPORTED COUNTRIES ARE EXPERIENCING, OR WILL EXPERIENCE, ACUTE OR DEFICIT FUELWOOD SITUATIONS.

The traditional energy crisis in developing countries is in part a consequence of utilizing wood resources over many years at a rate much faster than they can be renewed naturally or by afforestation. In accordance with a recommendation by a United Nations Technical Panel on Fuelwood, the FAO identified regions with fuelwood shortages, the severity of the shortages in these regions, and the affected population involved. The FAO concluded that some 96 million rural people and 16 million urban people now live in acute wood scarcity situations (see Figure 2).[11] These acute wood scarcity regions are defined as negative wood energy balance areas where existing resources have been depleted through overcutting to the point where populations cannot obtain sufficient fuelwood.

Acute fuelwood scarcity areas include the arid and semi-arid regions south of the Sahara, East and Southeast Africa, the Himalayas and mountainous regions of South Asia, the Andean Plateau, the arid areas in western South America, and in many of the densely populated urban areas in Latin America. Further, the FAO estimates that over one billion rural people and 230 million urban people live in wood deficit situations (see Figure 2). Wood deficit areas are defined as regions where populations are still able to meet minimum fuelwood needs, but only by harvesting in excess of the sustainable fuelwood supply. Deficit areas include the African savannah regions, the Indo-Gangetic Plains in southern Asia, the plains and islands in Southeast Asia, and the populated semi-arid areas and Andean zones of South America. The FAO study goes on to project that if no immediate corrective actions are taken, then some three billion people will live in acute wood scarcity and deficit regions by the year 2000. Moreover, the prices of firewood and charcoal will continue to increase with the scarcity and only exacerbate an already intolerable situation.

Current fuelwood deficiencies in A.I.D. assisted countries are summarized in Table 1. This tabulation shows that nearly all of the A.I.D. supported countries are now experiencing acute or deficit fuelwood scarcities or will have fuelwood problems by the year 2000. The pervasiveness and severity of the problem underscores the urgency with which it should be handled.

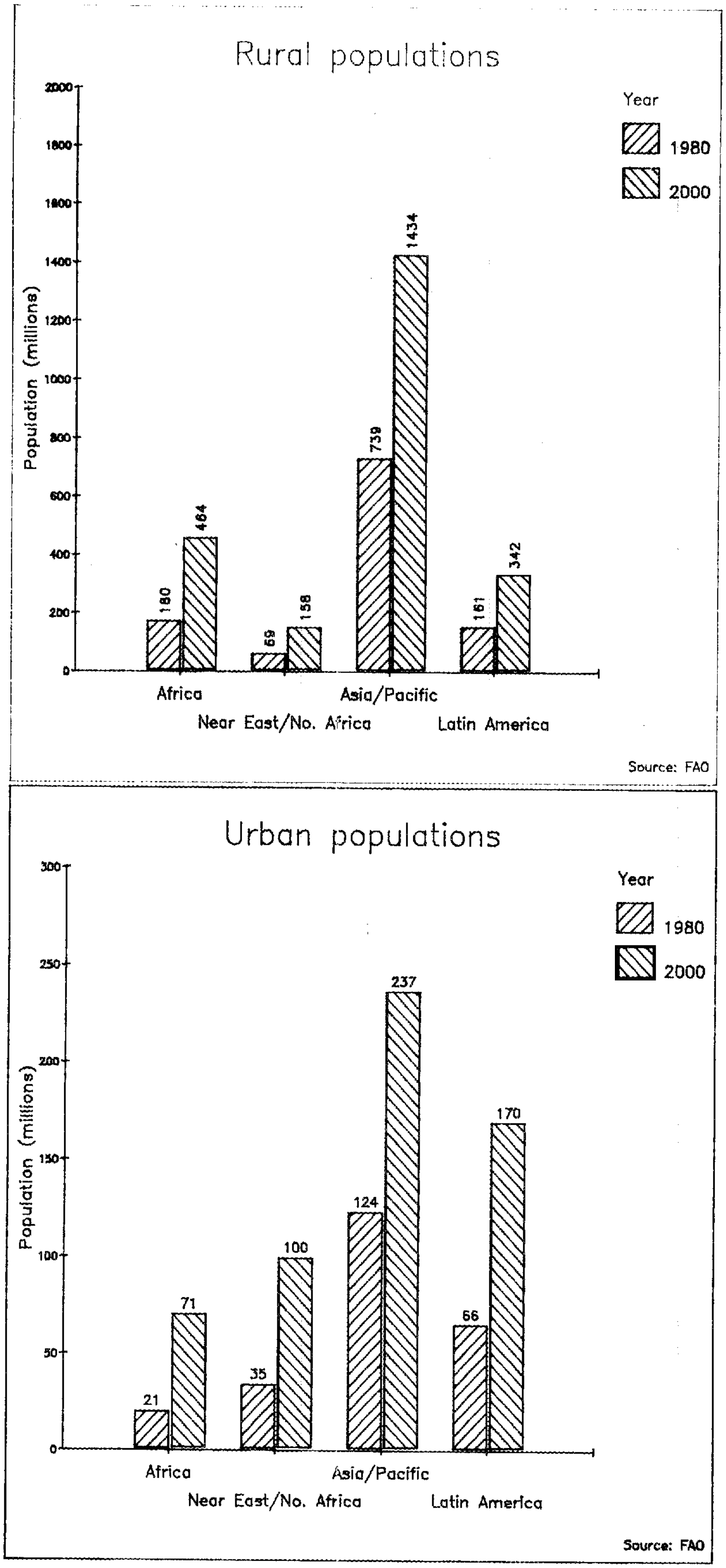

Fig. 2. Total rural and urban populations affected by acute fuelwood scarcities and fuelwood deficits in 1980 and 2000

Table 1. FAO qualitative fuelwood deficiencies in A.I.D assisted countries

Country	Deficiency
AFRICA	
Botswana (Western)	Acute
Burundi	Acute
Cameroon (Northern & Western)	Deficit
Cape Verde	Satisfactory
Chad (North)	Acute
(Southern & Central)	Prospective
Djibouti	Acute
Gambia	Deficit
Ghana	Prospective
Guinea (Northern)	Deficit
(Southern)	Prospective
Guinea-Bissau	Satisfactory
Kenya (Northern)	Acute
(Coastal & Central)	Deficit
Lesotho	Acute
Liberia	Satisfactory
Madagascar	Deficit
Malawi	Deficit
Mali (Northern)	Acute
(Southern)	Prospective
Mauritania	Acute
Niger (Southwest)	Deficit
(Southern & Eastern)	Prospective
(Northern)	Acute
Rwanda	Acute
Senegal (Central West & River Plain)	Deficit
Sierra Leone	Prospective
Somalia	Acute
Sudan (Northern)	Acute
(Central)	Prospective
Swaziland	Acute
Tanzania (Northern)	Deficit
(Southern)	Prospective
Togo (Northern)	Prospective
(Southern)	Deficit
Uganda	Deficit
Upper Volta (Central)	Deficit
(Eastern & Western)	Prospective
Zaire (Northern)	Prospective
(Southern)	Deficit
Zambia (Eastern)	Deficit
Zimbabwe	Prospective
NORTH AFRICA & NEAR EAST	
Egypt	Deficit
Jordan	Deficit
Lebanon	Deficit
Morocco	Deficit

Table 1. (Continued)

Oman	Satisfactory
Tunisia	Deficit
Yemen	Deficit
LATIN AMERICA	
Barbados	Satisfactory
Belize	Satisfactory
Bolivia (Western)	Acute
Costa Rica	Satisfactory
Dominican Republic	Deficit
Ecuador (Central)	Deficit
El Salvador	Acute
Guatemala (Southern)	Deficit
Guyana	Satisfactory
Haiti	Acute
Honduras	Satisfactory
Jamaica	Acute
Nicaragua	Satisfactory
Panama	Satisfactory
Paraguay (Eastern)	Prospective
Peru (Coastal)	Acute
(Central)	Deficit
ASIA & FAR EAST	
Bangladesh	Deficit
Burma (Southern)	Prospective
Fiji	Satisfactory
India (Western Himalayas)	Acute
(Remainder)	Deficit
Indonesia (Java)	Deficit
(Sumatra, Sulawesi, Timor)	Prospective
Nepal (Hills)	Acute
(Foothills)	Deficit
Pakistan	Deficit
Philippines (Luzon)	Prospective
(Central)	Deficit
Sri Lanka	Deficit
Thailand (Coastal)	Prospective
(Central)	Deficit

Acute scarcity = Fuelwood resources have been so reduced that the population is no longer able to obtain a minimal supply.
Deficit = Present fuelwood resources are below requirements, obliging the population to overexploit.
Prospective deficit = Present fuelwood resources are higher than requirements, but situation evolving toward a crisis in 2000.
Satisfactory = Resources considerably exceed present and foreseeable needs.
Source: M. R. de Montalembert and J. Clement, Fuelwood Supplies in the Developing Countries, Food and Agriculture Organization of the United Nations, Rome, 1983.

B. APPROXIMATELY 50 DEVELOPING COUNTRIES REPORT GEOLOGICAL COAL RESOURCES. TWENTY-ONE A.I.D. COUNTRIES REPORT COAL RESERVES. THERE ARE 17 A.I.D. COUNTRIES THAT ESPECIALLY APPEAR TO BE CANDIDATES FOR INTRODUCING COAL BRIQUETTES -- EIGHT IN AFRICA, SEVEN IN ASIA, AND TWO IN LATIN AMERICA.

Exploration of coal in developing countries has been very limited to date, and only began in earnest since the second major oil price increase in the late 1970s. Despite the lack of exploration, about 50 developing countries now report geological coal resources and 19 have technically and economically-recoverable reserves.[25] The distribution and size of proven coal reserves are, however, skewed and are concentrated in a few developing countries. To be sure, coal resources are broadly distributed throughout the world, and the reported occurrences of coal in the developing countries are widely recognized to be vastly understated.

The availability and current production of coal in A.I.D. assisted countries is reported in Table 2. The data indicate that 21 A.I.D. countries have coal reserves. These coal reserve data are very encouraging, but development of coal reserves has high front-end costs and long lead times. Consequently, the countries that have ongoing production or the potential for immediate development are likely to be the best candidates for coal briquetting.

The A.I.D. assisted countries that appear to have the requisites for coal briquetting technology (i.e., fuelwood deficiencies and availability of coal) are:

AFRICA	ASIA	LATIN AMERICA
Botswana	Bangladesh	Haiti
Morocco	Burma	Peru
Niger	India	
Swaziland	Indonesia	
Tanzania	Pakistan	
Zaire	Philippines	
Zambia	Thailand	
Zimbabwe		

Table 2. Coal availability in A.I.D. assisted countries with fuelwood deficiencies

Country	Resources (MMtonnes)*	Reserves (MMtonnes)*	Production (MMtonnes)*
AFRICA			
Botswana (1)	100,000	17,000	0.415
Burundi (3)(1)	n.a.	n.a.	n.a.
Cameroon (3)	500	n.a.	n.a.
Chad	--	--	--
Djibouti	--	--	--
Gambia (1)	n.a.	n.a.	n.a.
Ghana	--	--	--
Guinea	--	--	--
Kenya (1)	n.a.	n.a.	n.a.
Lesotho (1)	n.a.	n.a.	n.a.
Madagascar (2)	92	n.a.	--
Malawi (3)	14	n.a.	n.a.
Mali	--	--	--
Mauritania	--	--	--
Niger (1)	n.a.	12	n.a.
Rwanda (1)	n.a.	n.a.	n.a.
Senegal (1)	n.a.	n.a.	n.a.
Sierra Leone (3)	n.a.	n.a.	n.a.
Somalia (3)	n.a.	n.a.	n.a.
Sudan (1)	n.a.	n.a.	n.a.
Swaziland (3)	5,000	1,820	0.100
Tanzania (1)	1,900	304	0.010
Togo	--	--	--
Uganda (1)	n.a.	n.a.	n.a.
Upper Volta	--	--	--
Zaire (3)	73	n.a.	0.100
Zambia (1)	228	58	0.610
Zimbabwe (1)	29,000	2,200	3.20
NORTH AFRICA & NEAR EAST			
Egypt (3)	80	n.a.	n.a
Jordan	--	--	--
Lebanon	--	--	--
Morocoo (1)	96	16	0.750
Oman	--	--	--
Tunisia (3)	n.a.	n.a.	n.a.
Yemen	--	--	--
LATIN AMERICA			
Bolivia (1)(2)	n.a.	n.a.	n.a.
Dominican Republic	--	--	--
Eucador (3)	22	n.a.	n.a.

El Salvador (2)	n.a.	n.a.	n.a.
Guatemala (2)	n.a.	n.a.	n.a.
Haiti (5)	--	6.2.	<0.001
Jamaica (2)	n.a.	n.a.	n.a.
Paraguay (1)	n.a.	n.a.	n.a.
Peru (1)	997	126	0.106
ASIA & FAR EAST			
Bangladesh (1)	n.a.	n.a.	n.a.
(4)	1,056	n.a.	0.20
Burma (3)	286	n.a.	n.a.
(4)	4.5	n.a.	n.a.
India (3)	56,799	33,700	n.a.
(4)	82,900	n.a.	107
Indonesia (1)	10,000	300	n.a.
(4)	674	n.a.	0.30
Nepal (1)(4)	n.a.	n.a.	n.a.
Pakistan (6)	n.a.	508	1.47
(3)	1,375	n.a.	n.a.
(4)	95	n.a.	1.47
Philippines (3)	87	n.a.	n.a.
(4)	270	n.a.	0.31
Sari Lanka (1)(4)	n.a.	n.a.	n.a.
Thailand (3)	78	n.a.	n.a.
(4)	246	n.a.	1.5

*MMtonnes = million metric tons.

n.a. - indicates information not available or reported.
-- - indicates no sources.

Sources:

(1) World Bank, Issues and Options in Thirty Developing Countries, Report of the Joint UNDP/World Bank Energy Sector Assessment Program, No. 5230, August 1984.

(2) Wocol, Future Coal Prospects: Country and Regional Assessments, Ballinger, Cambridge, MA, 1980.

(3) World Bank, Coal Development Potential and Prospects in the Developing Countries, Washington, D.C., October 1979.

(4) ESCAP (Economic and Social Commission for Asia and the Pacific), Coal Resources in the ESCAP Region: Trends and Salient Issues, UN Economic and Social Council, E/ESCAP/NR.9/19, 1982.

(5) U.S. Agency for International Development, in-country assessment.

(6) Directorate General of Energy Resources, Government of Pakistan. Energy Year Book, 1983.

III. SMOKELESS COAL BRIQUETTES AS A POSSIBLE SUBSTITUTE FOR FUELWOOD

A. SOME COAL BRIQUETTING TECHNIQUES MAKE COAL AN ATTRACTIVE FUEL-WOOD SUBSTITUTE BY CONVERTING IT INTO A SMOKELESS, COMPACT, STABLE, AND INEXPENSIVE FORM OF FUEL.

Coal is often described as a "dirty" fuel, emitting smoke that is offensive and containing constituents that are harmful to human health. Moreover, some raw coals are highly friable and are not easily handled or distributed in their natural state. However, by briquetting and carbonizing when necessary, coal can be put into a relatively clean, compact, and stable form for use. The resulting fuel is also not expensive.

B. COAL BRIQUETTING HAS BEEN SHOWN WORLD-WIDE TO BE A TECHNOLOGY CAPABLE OF USING COAL OF VARIOUS GRADES AND PRODUCING BRIQUETTES WITH DIFFERENT CHARACTERISTICS FOR DIFFERENT USES.

Coal briquetting is a process by which raw coal is compacted into uniform, usually hard, and impact-resistant agglomerations, making it more suitable for use, transport, and/or further processing. It has been practiced for many years, at least since the beginning of this century.[12] It is also a technology that has been researched worldwide, in such widely dispersed places as Germany, USSR, Australia, Korea, India, and the United States. The wide extent of the research has several reasons. First, all coals are not alike, and often research has been aimed at developing an improved briquetting process for a particular coal. Second, briquetting can be done with or without an additive (binder) to help in agglomerating and giving cohesive strength to the briquette. Much research has gone into suitable binders, as well as into processes by which briquetting can be performed without a binder. Third, some research has been directed at improving the properties of the briquettes, such as maintaining ignitability while keeping volatile matter low as well as reducing smoke and sulfur emissions upon burning.

It should be emphasized that there is not just a single briquetting technology, nor even a set of two or three or a half dozen well-defined technologies for coal briquetting. Rather, a set of parameters for the briquetting of coal, such as temperature, pressure, pressing time, binder, type of coal, type of press, pretreatment, etc., can be varied to produce unique briquetting processes.

Coal briquetting can be performed on lump coal or on coal fines, the latter application often being an attempt to salvage an otherwise wasted product of coal handling. The usual process of coal briquetting consists of crushing, sizing, drying, possibly mixing with a binder, often heating, pressing in molds, cooling, and packaging or loading. [See Appendix A for a more detailed description of coal briquetting process.]

In the United States in recent years, coal briquetting research has been directed mainly at manufacturing an agglomerate suitable for coal gasification. Because this is an industrial application and not one aimed at domestic use, properties such as smokiness or sulfur emissions have received secondary attention. A domestic industry in "charcoal" briquettes supplying the "backyard barbeque market" also exists, and the producers of this product use some coal as a constituent. However, it may be mixed with true charcoal in the production process. The amount of coal used varies, depending upon the location of the plant relative to a coal source and the type of coal available. Bituminous and lignite coals must be carbonized, as described in a later section, before they can be used in the "backyard barbeque briquette." Anthracite coal does not need to be carbonized in the manufacture of the "charcoal" briquette.

In other parts of the world, coal briquettes play other roles. In Europe and the Soviet Union, they continue to be used for domestic purposes, especially home heating, and some attention has been paid to the smokiness of the product. In India, where briquettes derived from coal are used not only in space heating but also cooking, emissions are a primary concern.

C. BURNING RAW OR UNTREATED BRIQUETTED COAL PRODUCES EMISSIONS THAT CAN HAVE SERIOUS HEALTH EFFECTS.

Whether raw or briquetted, the burning of coal produces emissions that can be harmful to human health. This is especially relevant to the substitution of a coal-based product for fuelwood, since the latter is used extensively in developing countries for cooking, often in unventilated situations. Depending on the composition of the coal and the completeness of combustion, burning coal releases volatile organic matter, sulfur compounds, nitrogen oxides, particulates, and trace elements. Each of these has potential adverse effects on human health, and are discussed in more detail in Appendix B.

D. HOWEVER, COAL CARBONIZATION SIGNIFICANTLY REDUCES THE ADVERSE HEALTH EFFECTS FROM BURNING COAL OR COAL BRIQUETTES. THE RESULT OF CARBONIZATION IS A "SOFT SMOKELESS COKE." WHILE TESTING IS CURRENTLY IN PROGRESS, EMISSIONS FROM SMOKELESS COAL ARE PREDICTED TO BE NO WORSE THAN THOSE EMANATING FROM THE CURRENT FUELS OF CHARCOAL AND FIREWOOD.

Although substantial adverse health effects could be expected from burning coal or coal briquettes for cooking purposes, a well-developed technique exists to convert coal to a safer form for combustion. This is coal carbonization, converting it to a "soft coke" by pyrolysis. This is similar to the conversion of wood to charcoal. During the heating of the coal without its combustion, volatile content is reduced, and gases and tars containing some of the other harmful constituents are given off. The result is a product high in fixed carbon, which can be burned with little or no smoke and emissions no worse than the present practice of burning coal and firewood. Carbonization can be performed before or after briquetting -- or even without briquetting, if irregular "soft coke" lumps and loss of the coal fines are acceptable. [See Appendix A.] Because the soft coke is virtually smokeless, it will be referred to often as "smokeless coal" in the remainder of this document.

One of the important aspects of the coal carbonization process is that many of the potentially harmful constituents of coal are removed. As mentioned, most of the volatiles are driven off during pyrolysis into the off-gases, tars, or liquors. A certain level of volatiles is left in the soft coke (approximately 15% to 20%) to promote its easy ignition [6], but this level is deemed safe and does not allow the fuel to smoke significantly. Many of the potentially carcinogenic and other organic constituents, such as benzo(a)pyrene (BaP), toluene, benzene, etc., come out in the tar.

The sulfur content is also reduced as the sulfur is converted to hydrogen sulfide gas. Actually, several steps can be taken for sulfur removal to make the final smokeless coal lump or briquette rather clean with respect to sulfur oxide emissions. Washing the coal with water prior to pyrolysis is a simple, inexpensive, and effective step. More sulfur is removed during the carbonization process. Finally, if the coal is a higher sulfur coal, lime or limestone can be added to the final briquette so that any remaining sulfur combines with it and remains in the ash upon combustion. The cost of lime, if needed, is also very low, representing only 1% of the price of a soft coke briquette in a model plant scenario constructed by Fabuss and Tatom.[6]

Particulates are considerably reduced by the process of carbonization. Only minor fly ash results from combustion of the carbonized fuel. Also, while the temperature of carbonization is not high enough to remove many of the trace elements by volatization, neither is the temperature of combustion of the smokeless coal. Thus, without particulates to which to adsorb, the trace elements remain in the ash when the smokeless coal briquettes are burned. This keeps the level of human exposure to trace elements at an insignificant level.

One remaining health effect should be mentioned. The production of soft coke can expose workers to dangerous conditions unless strict controls are imposed. Coal dust in coking plants is often very high and difficult to suppress. The potential carcinogens in the coal tars, such as BaP, suggest careful handling of these by-products. In developing countries, attention to worker safety in carbonization plants is not always given due attention.[16]

It should be noted that carbonization is only needed for coals below the rank of anthracite, that is, for bituminous, subbituminous, and lignite coals. Anthracite in its natural state is sufficiently low in volatile and ash contents and high in fixed carbon that carbonization is unnecessary for a smokeless fuel. However, anthracites are relatively rare.

E. THE COSTS ASSOCIATED WITH BRIQUETTING AND CARBONIZING COAL INDICATE A SELLING PRICE FOR SMOKELESS COAL BRIQUETTES IN SOME URBAN AREAS THAT MAKE THEM COMPETITIVE WITH FUELWOOD AND CHARCOAL.

Fabuss and Tatom [6] estimate the costs of constructing a 100 metric ton per day (coal input) briquetting and carbonization plant for Pakistan. While this is a moderately sized plant and to a certain extent tied to conditions found in Pakistan, a review of their estimates can give an idea of the economic viability of the coal briquetting/carbonization technology.

The plant viewed in their scenario takes the path of an "intermediate technology." It would be capable of recovering the coal tar and oil, but none of the aqueous liquors. The process off-gas would be used to generate 100% of the power requirements for the plant. Utilizing Pakistan's high sulfur lignite coal, the briquettes would be formed without a binder, but lime would have to be added prior to briquetting to reduce sulfur emissions. The plant would have 66 tons per day output of smokeless coal briquettes. The ratio of 100 tons per day coal input to 66 tons per day output of smokeless coal briquettes was figured for a particular Pakistani coal, and other coals would give varying yields. However, the 100 to 66 ratio is in the middle of a range of about 55% to 75% that might be expected from various coals.

Total investment costs, including the cost of installed equipment, site preparation, buildings, engineering and contingencies, are put at 2,130,000 U.S. dollars (1982$). About half of this amount would be required in foreign exchange. Operating costs, including coal, lime, labor, maintenance, loan retirement, a 25% profit on these manufacturing costs, and transportation bring the price of smokeless coal briquettes to 1528 Pakistani rupees (Rs.) per metric ton of oil equivalent (TOE) anywhere within a one hundred mile radius of the plant.1/ By varying the scale of the plant, Fabuss and Tatom further estimate that the cost of smokeless coal briquettes per TOE would be Rs. 1622, Rs. 1466, and Rs. 1407 for plants with coal inputs of 25, 300, and 1,000 metric tons (tonnes) per day, respectively. By comparison, firewood costs an average of Rs. 2117/TOE. Thus, the coal briquetting/carbonization operation appears to be economically competitive. Moreover, this is the case without even considering the potential value of the coal tar by-product. If a market for this can be found, even if used only as boiler fuel, either plant profits could be raised or the price of the smokeless

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1/ In 1982 when the cost estimates were made, 1 US$ equalled approximately 12 Rs. In 1985, the exchange rate is approximately 1 US$ to 16 Rs.

coal briquettes could be subsidized with the by-product income and brought to a yet lower level.

Favorable economics for coal briquettes also appear likely for two urban areas in Peru, namely Lima and Huancayo. Moreover, this country provides an example where heavily subsidized kerosene might be displaced by smokeless coal briquettes. As summarized in Table 3, the UNDP/World Bank estimate that coal briquettes as a cooking fuel would cost US$ 9.30 - 13.30 per capita per year.[18]2/ By comparison, fuelwood used in an open fire costs US$ 10.80 - 15.00 per capita per year in Huancayo and US$ 27.50 - 31.70 in Lima. Although the cost of a stove is not included in these estimates, the coal briquettes appear economically competitive with fuelwood on an operating cost basis. With respect to kerosene, Table 3 indicates that it is cheaper than coal briquettes, but only because of a large subsidy. If the subsidy on kerosene were lifted, coal briquettes could displace it as a cooking fuel, at least on a cost-of-fuel basis. Since kerosene is subsidized in other countries as well, this conclusion might be general.

Table 3. Cooking fuel costs in Peru
(US$ per capita per year)

FUEL	HUANCAYO	LIMA
Wood		
used in open fire	10.80 - 15.00	27.50 - 31.70
use in improved stove	5.40 - 11.20	13.80 - 23.70
Charcoal	33.90	58.50
Coal Briquettes	9.30 - 13.30	9.30 - 13.30
Kerosene		
with current subsidy	7.70	7.70
unsubsidized	21.00	18.50

Source: UNDP/World Bank [18]

2/ This translates into US$ 139 - 199 per TOE. Costs of other cooking fuels are not translated into dollars per TOE because the method used by the UNDP/World Bank to estimate their costs per capita per year involved different utilization efficiencies for the different fuels. Giving a cost per TOE for all fuels would be misleading.

IV. INTERNATIONAL EXPERIENCES WITH COAL BRIQUETTING: INDIA AND KOREA

A. COAL CARBONIZATION HAS BEEN PRACTICED EXTENSIVELY IN INDIA. THE INDIAN EXPERIENCE IS INSTRUCTIVE BECAUSE A WIDE RANGE OF TECHNOLOGIES AND COAL TYPES HAS BEEN UTILIZED. INDIA HAS DEPOSITS OF BITUMINOUS, SUB-BITUMINOUS, AND LIGNITE COALS, AND ALL HAVE BEEN USED FOR CARBONIZATION. TECHNOLOGIES RANGE FROM ONE-PERSON, "VILLAGE COAL PILES" TO ADVANCED TECHNOLOGY CARBONIZATION PLANTS.

The advanced technology coal carbonization plants in India demonstrate several different technologies. The most advanced, which are either government pilot plants or commercial plants modeled on government projects, practice full by-product recovery. The smokeless coal (soft coke) is often produced in a continuous process with crushed and sized coal or briquetted coal entering the top of carbonizing retorts and soft coke issuing at the bottom. The gas may be used to cool the soft coke, and, having been heated, reenter the carbonizing section as a fuel. If the cleaned gas is not immediately recycled as fuel, it can be used for electricity generation or for town gas, the latter use being planned for the city of Calcutta. Similarly, the tars and liquors are retained, and may be (1) used as fuel in the carbonizing operation or sold for boiler fuel or (2) be refined into fine chemicals. The scales of the pilot plants run from 20 to 25 tons per day (TPD) of coal input, whereas the full scale plants can have design input of 1500 to 2700 TPD. The plants at the upper end of this range do not generally run at full capacity.

Intermediate technology plants also exist in India. Again, crushed or briquetted coal travels through retorts or possibly on chain grates through a kiln for carbonization. The intermediate technology plants, however, practice limited or no by-product recovery. If no by-product recovery is pursued, these plants can be heavy polluters. Often, the off-gases are passed through a scrubber, but then vented to the atmosphere. Tars and liquors also are not recovered. Still, it is possible to construct intermediate technology plants which, while not recovering every chemical fraction separately, retain useful by-products such as road-surfacing material, boiler fuel, and off-gas fuel. Fabuss and Tatom indicate that such an operation "can be accomplished relatively easily and yet without great cost ...."[6] Additional capital costs can be expected to run on the order of 5% to 10%, and it would reduce the pollution problem. In India, the scale of the intermediate technology plants runs from 25 to 100 TPD coal input.[16]

The "village coal pile" is the simplest technology of all, and the heaviest polluter. A pile of coal and coal fines is ignited and when the smoking stops, it is water quenched. By removing outer ash, an inner char is found that can be used as a smokeless fuel. Smoke from such a process can be seen for miles.

The major difference introduced by the different types of feed coal used in the industrial carbonization plants has to do with briquetting. The bituminous and subbituminous coals may only be crushed and sized, but not briquetted prior to carbonization. However, briquetting of the coal or smokeless coal fines may occur. Coal fines are briquetted with molasses, bentonite (clay), or an inorganic binder by the Indians. Soft coke fines may be briquetted with a starch binder. With the lignitic coals, briquetting prior to carbonization is performed. The producers take advantage of the property of lignite that allows it to be briquetted without a binder. The briquetted form of the smokeless coal output gives it a distinctive appearance. This allows it to be easily distinguished from lump coal, so that it cannot be adulterated by dishonest dealers.

Profitability of the village coal pile and intermediate technology producers is positive, if only marginal at times. Costs are reduced by avoiding capital investment to recover by-products. The high technology producers must often operate unprofitably for seven, eight, or ten years before reaching the break-even point. The difficulties that plague the larger operations, in addition to higher costs, are irregular coal supplies, transportation difficulties, power outages, labor problems, and the inability to sell by-products. Although high technology applications may be more profitable in the long-run, Schwartz and Tatom [16] recommend application of intermediate levels of technology with some by-product recovery for other developing countries. In this fashion, some of the risk of high technology plants as well as the pollution problems of venting by-products can be avoided.

B. INDIA HAS DEVELOPED A SMOKELESS COOKING STOVE WHICH CAN USE RAW COAL AS A FUEL SOURCE WITH NO DETRIMENTAL HEALTH EFFECTS.

Finally, a technology unique unto itself has arisen from the Indian experience. This is the "smokeless cooking stove," which uses raw coal rather than smokeless coal as its initial fuel. It therefore completely avoids the cost of coal carbonization plants. Developed by the Indian Central Fuel Research Institute (CFRI), the stove can be manufactured for about 50 rupees (soft coke stoves cost approximately 30 rupees--1982 rupees). Based on the savings of buying coal rather than smokeless coal, the cost of the stove can be recovered in only a few months. This is based on a 1982 retail coal price in India of about 180 rupees per tonne and the soft coke cost of about 720 rupees per tonne. Assuming a family of five, which would use about a tonne of soft coke per year, a net savings of 490 rupees could be realized by the family in the first year of operation on coal.[16]3/

The stove consists of two cylindrical, concentric compartments, the inner one being a smokeless coal combustion zone, and the outer one being an air-tight coal carbonization zone. Sized or briquetted coal is loaded in the outer zone to be carbonized from the heat of burning smokeless coal in the inner zone, which also supplies cooking and space heating needs. The off-gases are mixed with air below the smokeless coal bed and thus consumed. The next day, the carbonized coal from the outer zone is consumed in the inner zone, while new coal is added to the outer compartment. The only disadvantages appear to be that the coal must be sized carefully, the optimal stove design depends on the type of coal burned--although all types are candidates--and no by-product recovery is possible. Thus, the CFRI smokeless stove potentially represents an extradordinary innovation, being "a clean-burning, self-sustaining system in which tomorrow's [soft] coke is produced today, while the [soft] coke made yesterday is being consumed".[16]

C. KOREANS HAVE USED RAW ANTHRACITE COAL BRIQUETTES EXTENSIVELY FOR COOKING AND HEATING. THE KOREANS STARTED COAL BRIQUETTING IN 1930, AND THERE ARE NOW APPROXIMATELY 20 LARGE BRIQUETTING PLANTS IN THE COUNTRY.

Korean briquettes are comprised of 90% Korean anthracite and 10% Chinese coking coal. They are very large by comparison to other coal briquettes, weighing approximately 8 to 16.5 pounds each. They are pressed at only 170 to 240 psi, and do not meet normal briquette compression strength criteria: they can be broken with the fingers, they crush when dropped, and probably would not stand up to weathering. They really are only "a well compacted coal that is in a convenient form for handling."[6]

It is important to note that the Korean experience could not be transferred to many other countries. First, anthracite (along with a small amount of coking coal) is used to manufacture the Korean briquettes. As mentioned, anthracite can be used as a smokeless fuel for cooking without carbonization. However, anthracites are rare, and thus the Korean method of briquetting without carbonization cannot be transferred to many other countries. Second, the size of the Korean briquettes is abnormally large. This is because they use them for both cooking and heating, involving a 24-hour operation. This would not be required in most A.I.D. countries.

3/ In this example, Schwartz and Tatom [16] have obviously assumed that a family using one tonne of soft coke per year would also use about one tonne of coal per year in the smokeless stove. Since there may be heat losses in converting from coal to soft coke, this may not be completely accurate. Still, the economic advantage of the smokeless cooking stove is large enough that this should not change the conclusion of quick cost recovery.

V. THE POTENTIAL FOR COAL BRIQUETTE SUBSTITUTION IN A.I.D. ASSISTED COUNTRIES

A. SIGNIFICANT OPPORTUNITIES EXIST TO MITIGATE THE FUELWOOD CRISIS AROUND THE WORLD. A PRELIMINARY EXAMINATION OF THE SEVENTEEN PREVIOUSLY IDENTIFIED COUNTRIES INDICATES THAT FOUR APPEAR TO HAVE AN IMMEDIATE POTENTIAL: BOTSWANA, HAITI, INDIA, AND PAKISTAN. ANOTHER ELEVEN COUNTRIES APPEAR TO HAVE A NEAR-TERM (3 TO 5 YEARS) POTENTIAL: INDONESIA, MOROCCO, NIGER, PERU, PHILIPPINES, TANZANIA, THAILAND, SWAZILAND, ZAIRE, ZAMBIA, AND ZIMBABWE.

The pervasiveness of the fuelwood crisis among A.I.D. assisted countries is exemplified by the fact that only two African, one Near Eastern, seven Latin American, and one Asian country have satisfactory wood energy supplies. The reserves and production of coal in A.I.D. assisted countries were also determined. Of the twenty-one previously identified countries sixteen have some measure of current coal production and one country, Haiti, has the potential for immediate coal development.

Although the availability of coal is, of course, a necessary prerequisite for substituting a smokeless coal-derived fuel for firewood and charcoal, other factors are equally important. Among these are: (1) the nature of fuelwood use and supply, (2) the location of coal deposits relative to demand centers, (3) demographics, (4) the extent and adequacy of distribution systems, (5) markets, (6) the extent of government involvement in energy planning, and (7) the compatibility of fuel use with social customs.

The examination of these seventeen countries is based solely on secondary data sources. The uniformity and consistency of information varies considerably among countries, and for some, information is not available. To be sure, some countries have a higher immediate potential for coal briquetting technology. Countries that have especially favorable circumstances are briefly discussed below. Appendix C provides a more detailed examination of the seventeen identified countries.

In Africa, Botswana appears to have an immediate potential for coal briquetting. Botswana has large coal reserves and relatively low coal extraction and transportation costs. Further, the population is concentrated in the eastern third of the country and is favorably located to railroads and roads. Because there is no charcoal production in the country, smokeless coal briquettes would have to substitute directly for firewood. However, the diffusion of coal briquettes could be coordinated with the USAID program to develop and demonstrate fuel-efficient stoves. Morocco, Niger, Tanzania, Zambia, and Zimbabwe all have a near-term potential that depends largely on the additional development of coal reserves. Information is not available on two countries, Swaziland and Zaire, with which to make an evaluation. However, the UNDP/World Bank will have completed an energy assessment in both of these countries within the next six months.

Coal carbonization and briquetting has been ongoing in India for a number of years as has been reported by Schwartz and Tatom [16]. The issue in India is not whether coal briquetting has any potential, but whether their experience can be transferred to other developing countries. Pakistan is one country that shares many similarities to India, including pervasive fuelwood deficits and major deposits of coal. An investigation by Fabuss and Tatom [6] concluded that the carbonizing and briquetting of coal and/or the briquetting and direct utilization of coal in a smokeless stove is both technically and economically feasible in Pakistan. Two other countries in the region appear to have a near term potential, the Philippines, and Thailand. Indonesia also has the potential from the perspective of having large coal deposits and fuelwood shortages, although the location of coal reserves, a heavy subsidy on kerosene, and the potential availability of an alternative fuel in liquid propane gas complicate Indonesia's prospects.

In Latin America, Haiti stands out as a country with an immediate potential for coal briquetting. The country has acute fuelwood deficits throughout the island and large deposits of lignite. Because of low estimated lignite extraction costs, adequate transportation networks, and a dense urban population, the costs of coal briquettes should easily prove to be competitive with charcoal in spite of the lack of enforcement of stumpage fees and low wood severance taxes. In the near term, Peru has a potential for coal briquetting, although high subsidies on kerosene present an impediment to the price competitiveness of the coal briquettes.

Table 4. Potential of A.I.D. assisted countries for coal briquetting

- Four countries appear to have immediate potential:
  - Botswana
  - Haiti
  - India
  - Pakistan
- Eleven countries appear to have near-term potential:
  - Indonesia
  - Morocco
  - Niger
  - Peru
  - Philippines
  - Tanzania
  - Thailand
  - Swaziland
  - Zaire
  - Zambia
  - Zimbabwe

Source: Table 1 and 2.

VI. STRATEGIES FOR REALIZING THE POTENTIAL FOR COAL BRIQUETTING IN A.I.D. ASSISTED COUNTRIES

A. IMPLEMENTING SMOKELESS COAL BRIQUETTING IN A.I.D ASSISTED COUNTRIES WILL BE BASED ON EXPERIENCES GAINED BY A.I.D. IN HAITI AND PAKISTAN.

A.I.D. Washington/Office of Energy will be gaining experiences on smokeless coal briquetting technology and market potential in two widely dispersed and different developing countries, Haiti and Pakistan. Prior work in Haiti has confirmed the existence of a substantial lignite resource, and the need for a fuelwood/charcoal replacement has been demonstrated. In January 1985, planning began to sample and analyze the coal, define the technical aspects of carbonization needed, perform market studies, define the need for a pilot plant, look at potential by-product recovery, and investigate other aspects of implementing smokeless coal briquetting.

In Pakistan, the A.I.D. Mission provided plans in October 1984 for initial steps to implement smokeless coal briquetting there. These involve assessing the capabilities of local market research firms, surveying consumers and retailers, identifying the potential market segments, undertaking a "seed" market with private distributors using smokeless coal briquettes provided by A.I.D./GOP, and exploring the possibility of army procurement of the briquettes.

As the work goes on in these first two countries to implement smokeless coal briquette manufacturing and marketing, the experience gained by A.I.D./Washington will prove highly useful in application to other A.I.D. countries. In advance of these experiences, many ideas have been presented to help insure the success of smokeless coal briquetting, and they have been organized in this section into an action plan or set of strategies for realizing the potential for coal briquetting in A.I.D. assisted countries.

B. FIVE STEPS ARE NECESSARY TO SUCCESSFULLY IMPLEMENT SMOKELESS COAL BRIQUETTING AND MARKETING IN A.I.D. COUNTRIES. THESE INCLUDE A RESOURCE EVALUATION, A MARKET ASSESSMENT, A TECHNOLOGY ASSESSMENT, A STUDY OF GOVERNMENT POLICY AND PLANNING, AND PACKAGING THE IDEA FOR THE PRIVATE SECTOR TO IMPLEMENT.

1. RESOURCE EVALUATION. This prospectus has attempted to pull together information about coal resources in A.I.D. countries to demonstrate the promise of this idea. However, more detailed work on deposits would be necessary in individual countries planning to implement the strategy. The size and workability of coal deposits from a geological standpoint

must be ascertained. The location of coal deposits, economic viability, and proximity to existing transportation systems and markets must also be defined. The coal deposits' location and their proximity to existing infrastructure will affect the cost of the coal briquetting technology.

2. MARKET ASSESSMENT. In order to determine the best candidate communities and users, a market feasibility study should be undertaken. Where feasible, a preliminary step to carrying out the market study would be to assess the capabilities of local market research firms; one of these firms could implement the actual study. The market assessment itself should include examination of the target population, socioeconomic and cultural characteristics (particularly with respect to cooking), urban fuel use, fuel prices, and obstacles to acceptance of the new coal-based fuel, etc.

The market study should begin with a thorough assessment of current fuels used, their sources, their prices, and the quantities used per year. The assessment will in most cases occur in selected urban centers, for reasons noted below. The fuel types and quantities will affect the volume of coal and briquettes that can potentially penetrate the market. The prices of alternative fuels will be a primary determinant of the potential of smokeless coal briquettes. Not only the current price, but a near-term forecast of fuel prices and quantities would be helpful in determining the necessary entry price for coal briquettes. Also, determining the current sources of firewood and charcoal supply would help evaluate the potential for smokeless coal briquettes to penetrate the fuel use market and reduce deforestation.

An assessment of the country's demographics and a particular examination of the target population's socioeconomic and cultural make-up are a second part to the market study. Examination of the proportion of people in cities versus those in rural areas and the distribution of the inhabitants in these settings will affect the market potential of briquettes. It seems clear that in most countries, the initial introduction of smokeless coal briquettes will take place in urban areas, both to take advantage of a concentrated market and because the fuelwood deficiencies are most acute in cities. Also, the rural population may not be in a commercial firewood market, and generating a commercial market for briquettes could be difficult.

The market assessment should examine energy use by fuel type in different economic sectors, including households, commercial establishments, small industries, and public institutions. The potential for substitution of smokeless coal briquettes in each of these sectors must be evaluated. Besides price, one highly significant factor for substitution possibilities is consumer acceptance. What characteristics must the briquette have to obtain acceptance, e.g., size, shape, ignitibility, packaging, distribution points, needs for new equipment? How does the user feel about using smokeless coal relative to the current fuel used? One approach is to conduct surveys of certain sectors, say the household and commercial sectors. These surveys assessing the potential acceptance of smokeless coal briquettes could be tied together with the information gathering on current fuel use and prices.

3. TECHNOLOGICAL ASSESSMENT. The technological assessment should include an analysis of coal characteristics, an engineering study of the appropriate type and scale of briquetting and carbonizing operations, and capital availability.

The grade of coal and its sulfur and ash contents will affect the type of briquetting and carbonization operation that is appropriate. Therefore, a representative sample of coal must be obtained, shipped to a laboratory, and assayed. Behavior of the coal under briquetting and carbonization conditions must be ascertained, e.g., relation between time/temperature conditions and residual volatile content, ignitability vs. volatile matter content, suppression of residual sulfur content during combustion, the optimal type of binder for briquette strength and durability, etc.

In addition, an engineering study is necessary to design the type of plant appropriate to the coal and the size of plant that is appropriate to the market. Which of the many carbonization and briquetting processes should be used? Should off-gases be recycled or be used off-site? Should by-product electricity by produced? Will the correct binder be reliably available? Where should the plant be sited--taking into consideration coal supply, labor supply, availability of utilities, transportation, and proximity to markets. How labor intensive should the mining and briquetting/carbonization operations be? What measures are needed to protect health, safety, and the environment?

As part of the technological assessment, a survey of the domestic capital available is also needed. It is possible, as in India, that domestic equipment for the briquetting and carbonization operations will be adequate and cheaper, even though not as durable as imported equipment. This can save on foreign exchange costs. The amount of equipment available for briquetting operations of different scales and levels of technology should be determined.

While only an examination of individual country circumstances can ascertain this, an intermediate level of technology in the briquetting/carbonization operation may prove best for implementation in many countries. An intermediate technology approach to producing the smokeless coal briquettes is cheaper than the high technology approach, while also providing the opportunity for some by-product recovery. This helps reduce pollution problems. Also, the by-products might be recycled into the briquetting/carbonization operation, as in the case of the off-gases as a fuel, or sold, as in the case of the tars and liquors for boiler fuel or asphalts for road surfacing (if a market for them can be established). Artisanal manufacture of the smokeless coal briquettes is a second possibility, if no by-product recovery is desired and pollution problems can be avoided. Such questions need to be answered during the technological assessment.

4. GOVERNMENT POLICY AND PLANNING ASSESSMENT. While coal carbonization and briquetting provides an excellent opportunity for eventual control largely by the private sector, the roles of the host country government and A.I.D. in start-up operations must be assessed. For the host

country government, this involves assessing both policies that are directly aimed at coal briquetting and other government policies that have indirect impacts on the new technology.

In general, it must be emphasized that government acceptance of the coal briquetting technology is important if it is to succeed. Not only is government backing necessary for promotion of the smokeless coal briquetting itself, but seemingly unrelated government priorities can hamper the success of the new technology. For instance, if rail cars are in short supply and coal delivery to electric power plants receives priority, a reliable supply of briquettes will be endangered by an irregular coal supply. Another example of an existing policy providing a hindrance is where a state-owned electric utility has monopoly rights to produce electricity. In this case by-product electricity from coal carbonization would not be allowed without a policy change.

The government role also must be assessed when it owns rights to the coal, as it does in many developing countries. Who will do the mining? This, of course, is a task that the private sector can take on, but the issues of whether it should be done under concessions or under joint ventures or by some other arrangements must be faced.

Other direct and indirect effects will result from current government pricing policies. The extent to which smokeless coal briquettes will be accepted in the market place will be affected by such policies as subsidization of alternative fuels, as is the case for kerosene in Indonesia and Peru. Differential taxation or price controls on energy products would have similar effects. While not generally advised, the government might reverse the roles just mentioned by subsidizing smokeless coal prices and promoting their use over fuelwood.

In addition, there are a number of actions that the host government may plan to undertake to promote the use of smokeless coal briquettes directly. The government might provide information on use to potential users and information on production and markets to potential producers. The government might support a small pilot plant or intermediate-sized demonstration plant. This would indicate the viability of the technology, its costs, and the potential market acceptance to entrepreneurs. Also, the output would provide samples for market testing, would demonstrate to consumers the advantages of smokeless coal briquettes, and could establish a "seed" market.

The government might assist in overcoming some of the market uncertainties facing producers by implementing such programs as loan guarenties and purchase agreements. Market uncertainties can affect the ability of private individuals to obtain financing, and loan guarantees are one method to offset these obstacles in the market. This, however, would depend upon the scale and relative capital scarcities in the country. An additional way the government might help in overcoming market uncertainties would be to provide a ready market so that producers would be assured that they can sell at least some portion of their output. For example, the government could enter into long-term contracts for buying coal briquettes for use in public facilities, or for use in the military.

The government can diminish market uncertainties to consumers by minimizing interruptions in smokeless coal briquette supplies. Because reliability of supply is important to consumer acceptance, the government may want to ensure that availability is not interrupted in the marketplace. One way to do this is to ensure that government policy puts priority on delivering inputs to smokeless coal briquetting and carbonizing operations. Another way is for the government to provide a stockpile of coal briquettes which could be distributed to the population if in fact there should be an interruption in manufacture during the initial stages of market development.

Finally, government standards can assist the success of the coal briquetting/carbonization technology. To assure a quality product that the public will accept, the government may wish to set standards on such things as ash content, volatile material content, sulfur emissions, a shatter index, and allowable sizes. The standard for volatile material content would be important both for health reasons and for ignitability. Also, the government may find in necessary to regulate briquetting to make sure that it meets environmental health and safety standards for both production workers and the users.

5. BUSINESS AND MARKET IMPLEMENTATION. Coal briquetting is an excellent technology for private sector initiative, since all phases from mining to manufacture to distribution can be undertaken by private entrepreneurs. Beyond a pilot plant and some of the policies mentioned in the previous section, the goal is for the role of the government to remain minimal. Thus, there should be an assessment of technical talent and potential entrepreneurs for getting production and distribution started. Also, capital markets must be assessed for their sufficiency to finance the ventures.

To involve private individuals who have the expertise, the financial attractiveness of the venture must be well documented. Does the financial attractiveness match the economic attractiveness from a societal standpoint? Have processing risks been considered and solutions proposed? Are there mining risks that affect the costs estimated? A full description of the design and operations must also be provided.

In implementing distribution of the smokeless coal briquettes, the current dealers of firewood and charcoal might provide a ready distribution system. The examination of sources and distribution of fuelwood made under the market assessment can provide valuable information in setting up briquette distribution. The existing dealers should be encouraged to take on the new product.

Finally, initial marketing to consumers is extremely important in assuring the success of the briquettes. It may be advantageous in some locations to concentrate on a certain sector of the market in initial efforts to sell smokeless coal briquettes, such as the commercial sector. Restaurants, hotels, and street vendors currently making use of fuelwood and charcoal may be a ready-made market for the smokeless coal briquette. They are often a small, well-defined group that uses a significant amount of fuel, and they could be instrumental in establishing a market. They also provide free demonstrations for the new product to purchasers of their food products. Moreover, they may have the financial capacity to continue to buy the product once they decide to switch to it.

Special efforts to attract attention in the household market, such as advertising and demonstrations, should also be made. The ordinary household user can be reached in many ways, which will depend upon the social environment and literacy rate. However, some alternatives include radio announcements, fliers, newspaper ads, posters, billboards, house-to-house canvasses, giveaways, fairs, demonstrations, and bazaars. Through one or more of these means, information should be disseminated about the attractiveness of the new product and its competitive price.

Finally, one of the most important aspects of marketing is that users must be assured of a reliable supply of the smokeless coal briquettes. The price can be right, the product can burn well and cleanly, and it may even be packaged nicely, but if the briquettes are not supplied reliably, consumer acceptance is likely to be low.

C. USAID/WASHINGTON, OFFICE OF ENERGY, WILL PROVIDE TECHNICAL ASSISTANCE TO MISSIONS IN IMPLEMENTING THE SMOKELESS COAL BRIQUETTE TECHNOLOGY.

In those A.I.D. countries where a fuelwood shortage exists and the necessary coal supplies can be found, the Office of Energy, USAID/Washington stands prepared to offer technical assistance in implementing the smokeless coal technology. This means support with personnel in implementing the five steps outlined above to bring the smokeless coal briquettes to market. A.I.D. missions in those countries with present or pending fuelwood shortages and deforestation problems should consider whether the coal briquetting technology could help alleviate the problems.

APPENDIX A

COAL BRIQUETTING AND CARBONIZATION PROCESSES

The particular steps of the coal briquetting process are described below. Depending upon the qualities of the coal used, not all of them are always required. However, the sequence described gives a general impression of how coal briquetting and carbonization occurs.

Crushing. Crushing is performed to obtain a fairly uniform particle size for later pressing. In binderless briquetting the particle sizes are 4 mm and smaller, with 60 percent below 1 mm. In briquetting with a binder, they are much smaller: 93 percent less than 0.88 mm and 80 percent less than 0.5 mm.[6] When fines are briquetted, crushing does not need to be performed. Sizing occurs by screening, and is performed to remove particles too large and sometimes those that have become too small for optimal briquetting.

Drying. The extent of drying necessary depends on the type of coal, whether a binder is used or not, the type of binder if one is used, the amount of pressure applied, whether the coal undergoes some type of pretreatment or not, and other parameters of the process. According to Fabuss and Tatom, binderless briquetting requires the coal to be dried to 12 percent to 18 percent moisture content. (However, one process reported by Ellison and Stanmore, which uses a high temperature for binderless briquetting and is perhaps an anomaly, requires a moisture content of only 1 percent.) In contrast, briquetting with a binder requires the feed coal to have a low moisture content of 2 to 4 percent. It should be noted that binderless briquetting is often successful for certain coal types, particularly lignites, while briquetting with binders works for others.

Binder. If a binder is used, it is next added to the coal particles in either solid or liquid form. The two are mixed in a "pug" or mixing mill. There are two main classes of binders: organic and inorganic. Among the organic binders there are two subtypes: (1) tars, pitches, and asphalts, and (2) industrial waste and byproduct binders.[12] To the first group of organic binders belong coal tar pitch, asphalt, petroleum bitumen, maltha, producer-gas tar, coke-oven tar, coal-tar creosote and similar products. To the second type of organic binders belong lignosulfonate (a waste product from paper production), corn starch, wheat starch, vegetable pulp, and rosin. Among the inorganic binders are sodium silicate, lime, magnesia (magnesium oxide), dolomite, clay, brine, and cement.

Organic and inorganic binders each have their advantages and disadvantages.[12] The advantages of the organic binders are:

1) being combustible, they add little to the ash produced;
2) they add heat units per given weight of the agglomerate;
3) they have been used extensively as a coal binder in the past.

The disadvantages of organic binders are:

1) they tend to produce a greater quantity of foul-smelling smoke; however, this is unimportant if the coal is carbonized after briquetting;
2) some are difficult to handle and present a health hazard; in particular, some of the tars, pitches, and asphalts contain carcinogenic constituents.

The advantages of the inorganic binders are:

1) being non-volatile, they produce an agglomerate that will stand up well upon heating without disintegration;
2) they promote a slower, more complete combustion of the agglomerate;
3) they produce much less smoke than organic binders when burned; and
4) certain inorganic binders (lime, dolomite, magnesia) are sulfur-capturing; the calcium or magnesium in the binder reacts with the sulfur in the coal, and less sulfur-containing gas is given off during combustion; this is an important property for coals that are to be used for smokeless coal briquetting, particularly high sulfur coals.

The disadvantages of inorganic binders are:

1) they produce more ash on the grate;
2) they add additional weight to the agglomerate without adding heat value; this adds to transportation costs and less heat returned per unit weight;
3) the agglomerates containing inorganics are generally weak immediately after preparation and require drying to add strength; this increases costs; and
4) the agglomerates formed using inorganic binders often do not weather well, since the binder is often water soluble.

Briquetting of lignites and brown coals can often be successful without a binder because they have built-in binders such as moisture, humic compounds, resins, and waxes. Addition of heat, either directly or as a result of applying pressure, can cause the resinoid materials to exude and act as binders [12]. It is believed that the moisture content may also work to reduce friction and strengthen the briquette bond.

Temperature. Whether a binder is used or not, the temperature of the material is adjusted to a certain range prior to pressing. In the case of briquetting with a binder, heating helps soften the binder and assures more complete coating of the surfaces of the coal particles. surfaces. In binderless briquetting, the coal might actually have to be cooled after having been dried by heat; or, for a coal with low moisture content, steaming might be required. Even though the initial binding temperature may be lower in binderless briquetting, the heat rise during pressing can be considerable. This brings the coal constituents near their softening point, promoting a more cohesive bond in the briquette. In the standard briquetting procedure the initial temperature is raised to 95 to 100 degrees C for briquetting.[6] However, experimental processes utilize much higher temperatures, ranging from 130 degree to 170 degree C, for briquetting both with and without a binder.[3,4,11]

Pressing. Pressing can be performed either in extrusion presses or mold presses. The latter are probably more prevalent, and are of two types: the rotary table press and the double roll press. The rotary table press develops pressures of 720 to 3600 psi for 0.25 to 0.4 seconds. The double roll press uses pressures at the upper end of the same range for 0.05 seconds.[6] Other processes described in the literature indicate much higher pressures being used. Miller, et al., found an optimum pressure for their process of briquetting bituminous coal fines without a binder to lie in the range of 10,000 to 12,000 psi. Crossmore, et al., used pressures of 20,000, 25,000, and 30,000 psi for a brine-binder briquette. Some commercial, binderless briquetting operations in Europe standardly use pressures of 30,000 to 80,000 psi.[12] Also, longer pressing times are sometimes practiced, at least in briquetting technology research. Ellison and Stanmore reported "full curing" of binderless, Australian brown coal briquettes after 30 seconds, although 8 to 10 second pressing times were adequate for strength. Miller, et al., used experimental pressing times between 20 and 300 seconds for their binderless briquette.

Drying and Cooling. After pressing, the briquettes are dried for curing. If they are to be used as raw coal briquettes, they are cooled before packaging and loading for transport. The cooling stage is especially important for raw coal briquettes produced by high pressure and/or temperature (e.g., in Europe), since they have been known to combust spontaneously if piled too high after manufacture. If the briquettes are to be carbonized, they enter this stage after drying.

Carbonization. Carbonization is the step by which the coal is converted to a char, which when burned produces little or no smoke and is safe with respect to the health hazards of burning raw coal [see Appendix B]. Carbonization is accomplished by heating coal in a controlled atmosphere to a temperature at which it decompses chemically and/or physically to simpler compounds.[16] The outputs are the residual solid char, gas, tar, and aqueous liquors. When coal is heated to 120 to 150 degrees C, moisture is driven off. At 480 degrees to 600 degrees C, most of the volatiles are driven off. This is low temperature carbonization, and the resulting char is the the "soft coke" that can be used for a smokeless domestic cooking fuel. Enough of the volatiles are left at this temperature to assure fairly easy ignition. If the carbonization temperature is raised higher, to between 800 degrees and 1100 degrees C, essentially all of the volatiles are driven off and a residue that is highly carbonaceous and difficult to ignite is left. Using certain coals with the right properties, high temperature carbonization can produce (hard) coke, which is used for metallurgical purposes.

Techniques to produce soft coke are variations on a packed bed process in which coal is carbonized as it passes downwards through a vertical retort. Moisture comes off first, and then other constituents are driven off as the coal is heated on its downward path. Off-gas, which contains a number of combustible coal by-products, is removed at the top of the retort. The gas can be used for fuel or for fine chemical production. Tars and liquors that can be used for fuel or for chemicals are also removed. Hot gases to heat the coal can be produced by burning either the off-gas or some of the soft coke.

Briquetting of soft coke fines. Soft coke ("smokeless coal") fines may also be briquetted, to salvage this useful product. Schwartz and Tatom [16] report that soft coke fines are briquetted in India with the use of molasses, clay, or starch binders--although this may not be an exhaustive list of the binders used. In the formation of smokeless coal briquettes from fines, it would be important to avoid the tars, pitches, and asphalt binders. The resulting briquette is not to be carbonized again, and these binders would produce a foul-smelling smoke as well as present a health hazard upon combustion.

APPENDIX B

POTENTIAL HEALTH EFFECTS OF BURNING RAW COAL

Introduction. This appendix reviews some of the potential ill health effects of coal burning. It should be emphasized that the adverse health effects described here are based upon studies of the effects from large scale coal burning, such as in electric utilities. Still, the same combustion products would result from burning coal in a domestic situation, so a look at the effects of coal burning on the larger scale can be indicative of dangers. It should also be emphasized that the adverse health impacts outlined here are largely mitigated by carbonization of the coal as described in Appendix A. Thus, the ill health effects recounted below underscore the necessity of carbonizing some coals to make them useful as a domestic cooking fuel.

Volatiles. Polynuclear organic matter (POM) is one product formed during the combustion or pyrolysis of fossil fuels.[23] Compounds in this class originate from volatile organic matter in coal, and some of the POM species are carcinogenic. One is the potent carcinogen benzo(a)pyrene (BaP).

Good evidence on the ill effects of POMs exists. Exposure to POMs by workers in occupations utilizing coal tar, coal tar pitch, creosote, asphalt and petroleum products has led to nonallergic and allergic dermatitus, phototoxicity and photoallergic reactions, folliculitis, and acne and pigment disturbances. Also acute eye effects, including inflammation, conjunctivitis, and reduction in visual acuity have been observed. Finally, skin carcinomas are found more prevalently in workers of these industries.[23] It should be noted that not only are POMs produced from the coal itself, but also from some of the products just mentioned which are common coal briquetting binders.

BaP is the most prevalently measured POM in ambient air, and urban concentrations in the U. S. have been declining: 6 nanograms/cubic meter in 1958, 3.2 nanograms/cubic meter in 1966, and 0.5 nanograms, cubic meter in 1975.[23] The decline is connected with the decreases in residential coal combustion and open burning. This indicates the serious effect that coal as a fuel can have on ambient air quality.

The amount of POMs that reach the ambient air during coal burning depends upon the completeness of combustion. Quoting Walsh, et al.:

> "The concentrations of BaP associated with coal combustion can vary by a factor of 10,000, depending on the efficiency of the system in question; the BaP emission factor for efficient,

modern utility plants is 20-400 micrograms/MMBtu, while the corresponding figure for hand-stoked residential coal furnaces is 1,700,000-3,300,000 micrograms/MMBtu."

Thus, raw coal burning for cooking and heating purposes in developing countries, where the efficiency of combustion is unlikely to be well controlled and ventilation is unsure, runs the risk of exposing people to undesirable amounts of unhealthy volatile matter and cancer risk. This is not the case for anthracite, however.

Sulfur compounds. Upon the combustion of coal, the sulfur content forms sulfur oxides, which can have ill health effects. The more complete is combustion, the more sulfur oxides are formed. Long-term, elevated exposure to sulfur oxides has been implicated in chronic respiratory disease, changes in pulmonary function, and acute lower respiratory tract illnesses.[23] Health problems are not caused by sulfur oxides alone, but by their oxidation products as well, including sulfates and sulfuric acid. Exposure to sulfates increases the rate of asthma attacks, increases respiratory disease, and is associated with chronic bronchitis. As though the effects of sulfur oxides and their oxidation products were not enough, the results of incomplete combustion are also undesirable. Under incomplete combustion, acid gases (mainly hydrogen sulfide) are given off. Hydrogen sulfide is poisonous.[17] The undesirable results of incomplete combustion are noteworthy in considering domestic uses of coal, since the efficiency of coal burning cannot be guaranteed in simple stoves. However, some of these same effects apply to the incomplete combustion of biomass.

The sulfur in coal is of two types, organic and inorganic. The inorganic component is mainly pyritic sulfur, but some sulfate sulfur is also present. Standard coal washing techniques can remove much of the pyritic and sulfate sulfur, but the organic sulfur remains. Attempts to remove organic sulfur by chemical means have not been extremely successful. One reference indicates that processes can now remove 50% to 95% of pyritic sulfur and 25% to 85% of organic sulfur [13]. Singh, however, indicates that the processes to remove organic sulfur are still developmental in nature.

Nitrogen oxides. Nitrogen oxides are also produced by combustion of coal. These produce respiratory problems. The amount known about the effects of nitrogen oxide poisoning is less than for other pollutants, because a critical concentration must be reached before a reaction in humans is observed. Also, it is usually associated with other pollutants, and not much work has been done on the effects of this compound.

Particulates and trace elements. Respirable particulates are crystalline or amorphous forms, fibers, spheres, or aggregate meshes with a diameter of less than 5 microns, on which transformation products, toxic elements, and organic molecules can adsorb.[23] They are associated with both sulfur compounds and trace elements. Approximately 50% of total sulfur release is associated with fine particulates. Many trace elements and other elements are also found in association with particulates. These include lead, thallium, antimony, cadmium, selenium, arsenic, nickel, chromium, zinc, manganese, vanadium, magnesium, beryllium, fluorine, mercury, uranium, bromine, copper, gallium, iodine, iridium, molybdenum, tin, titanium, radon, and thorium. Some of these are toxic. Some are suspected carcinogens.

Fine particulates (less than 2.5 microns) can be deposited in the alveoli of the lungs, in the range of 15 to 25%. Very small particulates (less than 0.5 microns) can even be transported across membranes by diffusion. Given this fact and the number of noxious elements associated with particulates, this pollutant from coal presents a danger to all bodily functions and not just pulmonary function.

APPENDIX C

REVIEW OF COAL BRIQUETTING POTENTIAL IN A.I.D ASSISTED COUNTRIES

The purpose of this Appendix is to briefly summarize some of the salient characteristics of countries identified as possible candidates for coal briquetting. Most of the information was gleaned from UNDP/World Bank Energy Issues and Options Reports.

Africa

Eight African A.I.D. assisted countries appear to have the requisites for coal briquetting. These countries are Botswana, Morocco, Niger, Swaziland, Tanzania, Zaire, Zambia, and Zimbabwe.

Botswana. Located in South Central Africa, Botswana has one of the highest per capita GNP's (US$910) in Africa. The traditional economy, agriculture and cattle ranching, provides income for about 80% of the population. The modern sector is composed principally of mining for diamonds, copper, nickel, and coal. The country is mostly semi-arid and arid and is generally unsuitable for agriculture. Consequently, about 75% of the population lives in the eastern section of the country on 10% of the land area. The population is considered predominantly rural (87%), and is increasing at a rate of 3% per year. The small urban population is growing rapidly at 5.8% per year.

Firewood is the main energy source in rural and low-income households in the urban centers of Botswana. Charcoal is not produced domestically, and there are only very small quantities imported. Total annual firewood consumption has not been adequately surveyed, but is crudely estimated at 0.35 million TOE (or 1 million tonnes) based on a per capita consumption of 1.5 tonnes per year.[20] Firewood consumption is expected to increase at an average annual rate of 2 percent per year for the remainder of the decade. Table C.1 summarizes the fuelwood energy balance for Botswana.

There are acute firewood scarcities in western sections of the country and growing deficits in the major eastern villages and urban areas of Gaborone and Lobatse. Reforestation efforts have been disappointing because of high establishment costs and inadequate technical support. The difficult growing conditions and, in particular, recurring droughts have resulted in low productivity on reforested hectares. All of the firewood demand in Botswana is consumed in the residential sector, which accounted for 45 percent of total energy demand.[20]

Table C.1 . Fuelwood energy balance for Botswana (1981)
(Tonnes of oil equivalent)

	Firewood	Charcoal
Supply		
Production	350,000	0
Imports	0	~17
Transformation	0	0
Demand		
Households	350,000	~17
Balance	0	0

Source: UNDP/World Bank [1984]

Total coal reserves are estimated at 17 billion tonnes and are located in ten areas of the country. The coal quality is variable from one field to another but, in general, calorific value is about 6100 kcal/kg, ash content is 16 to 18%, volatility ranges from 24 to 34%, and sulfur content ranges from 1 to 2.5%. Approximately 90% of the country's coal requirements come from the Morupule coal field. Production is currently about 0.415 MMtonnes and there are plans for expansion of output. The coal field is linked by railroad to the major demand centers, Gaborone and Lobatse, and other towns in eastern Botswana. The selling price of coal in Gaborone is about US$20 to 22/tonne including transportation charges of US$7/tonne.

The proximity of villages and towns in eastern Botswana to the railroad and road corridor provides a number of options to alleviate fuelwood deficits. One option is to substitute charcoal produced from logging residues and/or from northern forest reserves. The UNDP/World Bank believes that despite favorable transporation rates (US$0.09/tonne km), the long haul distances (e.g, Kasane to Gaborone -- 1170km) would preclude economic delivery of charcoal to eastern demand centers. Transportation charges alone from Kasane to Gaborone would be US$92/tonne. Based on favorable coal extraction and transportation costs and the proximity of populations to railways and roads, the evaluation of coal briquettes should be undertaken. Currently, firewood prices in Gaborone are about 9 thebe/kg or US$230/Toe (US$0.08/kg), while the selling price of coal is only US$40/Toe.

Morocco. The economy of Morocco is based on the export of mineral resources, principally phosphate and to a lesser extent iron ore, lead, zinc, and manganese. By African standards it has a relatively high per capita income (US$870, 1982). However, a considerable fraction of its mineral export earnings (50%) is for payment of imported oil, which is creating severe problems for the Moroccon economy.[19] In the traditional energy sector, a sizable fraction of the population relies on fuelwood as its energy source. In 1981 it accounted for 35% of total energy consumption. The population is estimated to be growing at an annual rate of 3%, about 41% of this is considered urban, and is concentrated along the northwestern coast.

The UNDP/World Bank estimates that about 11 million cubic meters of fuelwood are harvested, yet only 3 million cubic meters are regenerated each year. Consequently, deforestation is occurring at the rate of 20,000 ha/yr. Reforestation efforts are lagging and are currently at 10,000 ha/yr. Some 50,000 ha/yr will be required to meet the firewood demand in the year 2000. The fuelwood energy balance for Morocco is reported in Table C.2. Approximately 16% of wood production is lost in charcoal conversion.

Table C.2. Fuelwood energy balance for Morocco(1981)
(Tonnes of oil equivalent)

	Firewood	Charcoal
Supply		
Production	2,725,000	0
Transformation		
Charcoal production	(79,000)	79,000
Losses	(363,000)	
Demand		
Households	2,283,000	79,000
Balance	0	0

Source: UNDP/World Bank [1984]

The coal resources of Morocco are significant, but according to the UNDP/World Bank, mining conditions are difficult and new investments will be necessary to maintain existing (0.73 MMtonnes/yr) and proposed levels of production (1.0 MMtonnes in the first stage and 2.0 MMtonnes in the second stage). Further, the revision of government controlled prices will be required to stimulate coal substitution and new investments.[19] The market for an annual production of 1.0 MMtonnes is assured, and the market for production above 1.0 MMtonnes is not established.

The potential of coal briquette technology in Morocco depends on a number of factors including the relative costs of charcoal, coal extraction costs, the concentration of fuelwood consumers and transportation networks among others. The existence of a large, concentrated, charcoal-dependent urban population is the right requirement for the diffusion of coal briquettes. The costs of charcoal, including distribution systems and coal pricing policies, needs further evaluation.

Niger. Located in the Sahel, Niger has one of the lowest per capita incomes (US$330) and energy intensities in Africa. The country is mostly desert with only 12% of the land base arable. In recent years, recurring droughts, declining soil fertility, and increasing desertification have created severe hardships for the population. The rate of growth of the population has, in fact, declined over the last decade. However, rural migration is increasing, and the urban population now accounts for 10% of the total. A sizable proportion, about 16%, of the rural population is still nomadic.

The country's principal export commodity and primary source of foreign exchange is uranium. In 1981, Niger was the fourth largest supplier of uranium in the world. The prospects for further development of this export commodity are not favorable. The development of other mineral resources is also unlikely because of depressed world prices and remoteness of the deposits.

Firewood is the traditional fuel in Niger accounting for over 85% of total energy consumption. In 1981, there were 742,155 Toe consumed in the household sector and 82,460 Toe consumed by small industry. Additionally, some charcoal was used by small industry (2,245 Toe). Because the population is concentrated, there is considerable overexploitation and scarcities of the wood resources around major population centers. The wood energy balance for Niger is summarized in Table C.3.

Table C.3. Fuelwood energy balance for Niger (1981)
(Tonnes of oil equivalent)

	Firewood	Charcoal
Supply		
Production	838,590	0
Transformation		
Charcoal production	(2,425)	2,425
Conversion Losses	(11,550)	0
Demand		
Small industry	82,460	2,425
Households	742,155	
Balance	0	0

Source: UNDP/World Bank [1984]

Reforestation, substitution of kerosene and butane, and fuel efficient stove programs have been or are under consideration as possible options for alleviating fuelwood scarcities. The development of indigenous coal resources for household use is also under consideration. There are significant coal reserves (9.4 MMtonnes) located in the northern Niger that are now under production to generate electricity for uranium mining. Coal deposits of higher quality of unknown amounts are located about 30 km farther north. The location of these reserves relative to the populated areas, and hence the high transportation costs, makes their use for production of coal briquettes doubtful. However, there have been discoveries of lignite deposits much closer to populated areas, which would be useful for briquetting. Probable reserves of lignite have been estimated at some 2.6 MMtonnes. The calorific value of the coal is 4000 kcal/kg. The UNDP/World Bank [1984] estimates that these lignite reserves could supply 20% of the cooking needs in Niger for about 8 years.

The recommendations of the UNDP/World Bank regarding traditional energy are (1) to pursue cook stove programs to provide some immediate alleviation of the fuelwood crisis, and (2) to pursue the development of lignite as a possible substitute for fuelwood by further reconnaissance and drilling to determine the extent of reserves and costs of mining.

Swaziland. The Kingdom of Swaziland, landlocked between South Africa and Mozambique, has a relatively high per capita GDP (US$890) by African standards. The country is well-endowed with natural resources, but is experiencing rapid population growth, low productivity in agriculture, and acute fuelwood deficits. The population is 85% rural and growing at 2.4% per year. The urban population is rapidly expanding at nearly 6% per year.

Sixty percent of total energy consumption is derived from fuelwood. In 1980, 550,000 cubic meters (or 126,000 Toe) of wood were produced. Information on the extent of the fuelwood crisis was unavailable, but it is known that large quantities of land have been denuded.

Coal reserves are estimated at almost 2,000 MMtonnes including 200 MMtonnes of good-quality steam coal. At present, about 90% of total production is extracted from the Mpaka colliery. Seventy percent of the coal is used domestically with the remainder exported to Kenya, Mozambique, and the Republic of Korea. The development of an 800,000 tonnes/yr anthracite mine is presently under consideration. The rail system for coal is under modernization, and overall, the transportation infrastructure is in good condition.

The potential for coal briquetting depends on a number of factors for which there is no available information, particularly with regards to charcoal production and costs and selling prices of coal. On the basis of existing information, further evaluation is clearly warranted. An energy sector assessment by the UNDP/World Bank is planned or is to be completed within the next six months.

Tanzania. The economy of Tanzania is primarily agricultural, providing 80% of export earnings and 90% of total employment.[21] Approximately 89% of the population is considered rural and the remaining 11% is scattered in small towns. The rate of population growth is 3.0% per year in rural areas and 6.1% in urban locations.

Tanzania is one of the most highly dependent countries on traditional energy in the African continent, with over 90% of the population relying almost exclusively on firewood and charcoal for basic energy needs. Fuelwood accounts for approximately 87% of total energy consumption. Current consumption of fuelwood is placed at 39.1 million cubic meters per year, while total available supply (mean annual incremental growth) is just 15.6 million cubic meters per year. The annual fuelwood deficit in Tanzania is thus some 23.5 million cubic meters per year. The clearing of land for agriculture, the erosion and nutrient depletion of soils, and the fuelwood deficit is responsible for the destruction of 500,000 hectares of forest each year. The fact that 17 out of 20 regions in Tanzania are in a fuelwood deficit shows the pervasiveness of the crisis. The UNDP/World Bank [1984] estimates that an annual fuelwood plantation program of 75,000 hectares per year would be necessary to alleviate the crisis over the next 20 years. Current plantation efforts are about 6,200 hectares per year.

Table C.4. shows the energy balance for fuelwood among the household and industrial sectors in Tanzania for the year 1981.[21] Household firewood consumption accounts for most of total fuelwood demand. Losses from charcoal production are about 16% of total wood supply. The demand for fuelwood is projected to increase at the current rate of population growth over the next ten years or so.

Table C.4. Fuelwood energy balance for Tanzania (1981)
(Tonnes of oil equivalent)

	Firewood	Charcoal
Supply		
Production	9,400,000	
Transformation		
Charcoal production	(350,000)	350,000
Conversion Losses	(1,100,000)	
Demand		
Industry	600,000	150,000
Households	7,350,000	200,000
Balance	0	0

Source: UNDP/World Bank [1984]

In Tanzania, coal resources are estimated at 1,900 million tonnes including 304 million tonnes of proven reserves. Although the occurrences of coal are widespread throughout the country, production is currently about 10,000 tonnes per year and is limited to one field. The coal is classified as bituminous and is low in sulfur, has an ash content of 25 to 30%, and has a calorific value of 5,500 kcal/kg. Production is expected to increase to 50,000 tonnes per year by 1988. This coal field has been given some priority for further development based on its close location to transportation and potential urban markets. The development of another mine in this general area is expected to add 150,000 tonnes per year of production capacity by 1988.

The availability of coal for domestic production of briquettes does not appear to be an obstacle.

Zaire. There is little information on the fuelwood crisis, extent of coal reserves, and other characteristics relevant to assessing the potential of coal briquetting. It is known that there is a fuelwood deficit, and it is relegated to the southern regions of the country, principally Shaba. The coal reserves of the country are located in Shaba -- the central and northeast sections. The UNDP/World Bank has completed its energy sector assessment for the country, but it has yet to issue a completed report. The results of their assessment should provide a first step in ascertaining the potential of coal briquetting.

Zambia. In Zambia, per capita income is about US$530, with copper mining the major source of foreign exchange. The fall in export prices of copper along with increasing costs of extraction has disrupted the economy in recent years. The population of the country is growing at 3.3% per year and is increasingly being concentrated in urban areas (40% of the total). The country has abundant energy resources including hydropower, coal, and wood, which account for 31%, 6%, and 45% of total energy consumption, respectively.[19] Imported oil and coke account for the remainder of the energy consumed.

The supply of fuelwood in Zambia is adequate, particularly for the rural population. However, there are increasing scarcities of charcoal in the towns located in the copperbelt and surrounding provinces of Lusaka. Widespread deforestation in these areas is a matter of concern. The fuelwood energy balance for the country is reported in Table C.5. Information on the extent of charcoal consumption and losses in production is not available.

Table C.5. Fuelwood energy balance for Zambia (1981)
(Tonnes of oil equivalent)

	Firewood	Charcoal
Supply		
Production	2,000,000	n.a.
Transformation		
Demand		
Mining	120,000	n.a.
Households	1,880,000	n.a.
Balance	0	n.a.

Source: UNDP/World Bank [1984]

The Government of Zambia attempts to control wholesale prices of charcoal. In real terms controlled charcoal prices have declined considerably in recent years from US$2.45/40kg in 1976 to US$1.52/40kg in 1982. The actual market price was US$4.80/40kg in 1982. The higher actual prices reflect the realities of supply and demand.

Proven coal reserves in the only existing mine, the mid-Zambezi basin at Maamba, are estimated at 58 MMtonnes. Current production is about 0.61 MMtonnes/yr. The major consumers of this coal are the copper mines, the cement industry, and the fertilizer plant. Coal production is currently only about 50% of its design rate. The costs of production at Maamba are unnecessarily high (US$47/tonne) because of mining inefficiencies, lack of foreign exchange to replace and maintain equipment, and poor management.[19] The UNDP/World Bank estimates that investments of the order of US$30 million will be required to rehabilitate the mine, otherwise costs will continue to increase and production will lag. The rail transportation system linking the mine with consumers is also in need of rehabilitation. Transportation costs are high and are about US$13/tonne from minemouth to the copper mines.

Despite the inefficiencies in coal mining, the costs of coal compare quite favorably with charcoal. Assuming 5600 kcal/kg for coal, the delivered price of coal converts to US$33/Toe. Charcoal at 7000 kcal/kg is nearly two and one-half tonnes more expensive at US$82/Toe. The carbonization and briquetting of coal could be a viable substitute for charcoal in urban centers. Further, it is likely that some capital investmemts will be required to rehabilitate the coal mine and transportation system.

Zimbabwe. The energy problems of Zimbabwe are similar to those of Zambia. Most of its energy demand is met with indigenous supplies of coal, hydropower, and woodfuels. The country imports comparatively little commercial energy. Oil and electricity each account for 11.5% of total energy needs.[19] A fuelwood crisis is, however, beginning to manifest itself in a number of densely populated eastern and middle veld rural areas and in and around the major towns and cities. The communal lands in the middle and low veld show advanced signs of deforestation and soil erosion. The population of the country is predominantly rural, about 78%. However, the urban population is expanding at an annual rate of 5.5% as opposed to 2.7% in the rural areas. The fuelwood energy balance is shown in Table C.6. Industry and agriculture use 16% of the total fuelwood supply. Data on the consumption of charcoal were not available.

Table C.6. Fuelwood energy balance for Zimbabwe (1981)
(Tonnes of oil equivalent)

	Firewood	Charcoal
Supply		
Production	1,645,000	0
Transformation	n. a.	n. a.
Demand		
Industry	58,000	n. a.
Agriculture	175,000	n. a.
Households	1,412,000	n. a.
Balance	0	0

Source: UNDP/World Bank [1984]

Total proven recoverable reserves of coal in Zimbabwe have been estimated at 2,200 MMtonnes. Recent production from the mine is about 3.2 MMtonnes, and this supplies 27% of total energy. The Wankie colliery also generates 2 MMtonnes of high ash, self-igniting steam coal each year. This coal is planned for the proposed Wankie thermal power project.

The country is well-endowed with reserves of coal and the deforestation that is taking place suggests that the country is a prospective candidate for coal briquetting technology. Information on the relative costs of coal and fuelwood was not available, but it is known that the Government does regulate the prices of coal and coke. Energy pricing, the spatial characteristics of coal supply and demand, and the extent of shortfalls in fuelwood supply and deforestation require more evaluation.

Asia

The seven Asian countries identified are: Bangladesh, Burma, India, Indonesia, Pakistan, Philippines, and Thailand. India and Pakistan have been evaluated previously for coal briquetting technology. Information on the availability and production of coal was derived from a report by the Economic and Social Commission for Asia and the Pacific. Reports by the UNDP/World Bank and the coal feasibility studies for India and Pakistan were also used.

Bangladesh. The country is unquestionably one of the poorest in the world having a per capita GDP of only US$133 (1980). The economy is primarily agricultural, with over 90% of the population living in rural areas. The country also has the misfortune of being the most densely populated in the world. Moreover, the population is growing at an annual rate of 2.7%. The Ganges-Brahmaputra River divides the country into two sections--the eastern and western. The east section has low-cost natural gas reserves, while the west section is highly dependent on imported oil. On a countrywide basis, oil accounts for one-third of total energy consumption and 60% of its foreign exchange, the remainder of its energy use is largely derived from traditional sources--crop residues, firewood, and cow dung.

The wood resources of the country are rapidly being overexploited to meet increasing demands. Rising population and shifting cultivation are creating massive deforestation, the effects of which are soil erosion, reduced agricultural productivity, and siltation of reservoirs. The growing scarcity is reflected in the fact that fuelwood prices in the period from 1971 to 1978 increased at an annual rate of 40%.[19]

Bangladesh has significant coal reserves.[5] Proved and possible reserves of hard coal are about 1,053 MMtonnes, with 3 MMtonnes of brown coal. The hard coal reserves are located in the northwest of the country and lie in two major deposits. These coals are found at depths of about 900 meters, and the economic recovery of this coal is questionable. Brown coal is being mined in the Sylet area (Northeast) at a rate of about 0.2 MMtonnes per year.[5] The coal has 20% ash, high sulfur, and a calorific value of approximately 6900 kcal/kg.

The possibility of utilizing coal briquettes to relieve the fuelwood deficits would need considerably more evaluation. ESCAP reports that brown coal is being produced at an annual rate of 0.2 MMtonnes, yet the UNDP/World Bank notes that there is no economically exploitable coal in Bangladesh. Existing brown coal production rates and cost needs to be investigated.

Burma. According to the FAO, fuelwood scarcities are limited to the lower central regions of the country. Estimates of coal resources in Burma are placed at approximately 200 MMtonnes including 80 MMtonnes of brown coal. Proved reserves are only 4.5 MMtonnes.[5] The coal resources are scattered throughout the country and possess varied properties. In the Kalaw area, there are small deposits that are suitable for coking.[6] The largest brown coal deposits are in Kalewa. These coals are of varying calorific content but contain about 13.4% moisture, 50% volatiles, 3.9% ash, and a low percentage of sulfur. Although the coal reserves are numerous, coal production is relatively low, ranging from 0.013 to 0.031 MMtonnes per year during the 1970s. The UNDP/World Bank has completed its energy assessment mission to Burma, but a report has not been issued.

India. Firewood is the main energy source of rural populations accounting for 44% of total traditional and commercial energy demand. Currently, there are fuelwood deficits in all regions of India. It has been estimated that the country would require a minimum of 25 million hectares of land in intensive wood production to meet its need for firewood in the year 2000.[5] Recognizing its fuelwood deficits, the country embarked about 20 years ago on a program of carbonizing and briquetting its vast reserves of coal to serve as a domestic fuel. The Indian coal briquetting program has been the focus of an USAID investigation to assess whether their experience can be transferred to other developing countries. The Indian experience is more fully described in the main body of this prospectus.

Indonesia. The country is an oil exporter that heavily subsidizes the domestic consumption of energy, particularly oil-based products. In fact, the subvention of domestic use of kerosene, diesel fuel, and fuel oil now absorbs 20% of the total national budget. The most prominent example of these subsidies involves kerosene, which accounts for about 50% of the government outlays for fuel price reductions.[19]

The subsidy of kerosene was initiated to help the poor and displace fuelwood use for cooking and lighting on Java and Bali. These islands are heavily populated, and deforestation would result if fuelwood were used heavily in these applications. The subsidized price on kerosene has been largely successful in its purpose of limiting fuelwood use. Only wood from backyard woodlots can still be burned more cheaply than kerosene. The subsidy has had the side effects of diverting kerosene to some industrial uses in which it is cheaper to burn than fuel oil; giving more aid to affluent households that still use kerosene than to the poorer households; and ballooning the payments that the government makes to support the subsidized price.

On the other islands besides Java and Bali, fuelwood is in plentiful supply. Taking the country as a whole, nearly 64% of the land area is covered by forest. Indeed, the UNDP/World Bank suggests the possibility of developing wood-based thermal power plants on some of the islands besides Java/Bali. Nevertheless a situation of fuelwood shortage prevails on these latter two, densely populated islands.

Indonesia harbors large and to a great extent, unexplored reserves of coal. Proved reserves amount to about 300 MMtonnes. However, total reserves, including undiscovered reserves, are estimated to be in the neighborhood of 10,000 MMtonnes. These reserves exist in the provinces of Sumatra and Kalimantan, and are expected to play an increasing role in industrial and electric power generation. In fact, there may be a domestic shortfall in coal supply for a period because of a lack of investment in coal development to date.

The place for a coal briquetting scheme to ease fuelwood use in Indonesia would need thorough evaluation. Kerosene has already largely supplanted fuelwood use in those areas where fuelwood is in short supply. However, the government of Indonesia and international agencies are in favor of gradually reducing the substantial price subsidies on petroleum-based fuels, including kerosene. Coal briquettes might provide a substitute cooking fuel without the distortions of subsidization. Another alternative to kerosene for cooking that has received emphasis elsewhere is LPG; cost studies of its use have been suggested.[19] Due to the high population density on Java/Bali, whose increase has made rural areas on these islands almost indistinguishable from urban areas, electrification may be the most viable alternative for lighting purposes. Thus, the viability of coal briquettes in Indonesia is caught up in a complex web of whether kerosene subsidies will be reduced, whether fuelwood will thereby become attractive to certain users again, whether LPG would be economically superior as a cooking fuel, and whether electrification will soon reach most segments of the Java/Bali population.

Pakistan. The fuelwood crisis is pervasive in Pakistan. The coal deposits of Pakistan are located in three different basins -- Kvetta town, Salt Range, and west of Hyderabad. Hard to brown coal types are mined in Kvetta town and annual production ranges from 0.50 to 0.80 MMtonnes. Sub-bituminous coals are mined at Salt town with annual ouput of 0.10 to 0.12 MMtonnes. Numerous other deposits are also found in this basin. Smaller amounts of coal are produced in various other mines. Total coal production for the country has been as high as 1.50 MMtonnes. About 90% of this production is used by the brick industry. The feasibility of using coal for household energy use has been previously studied by USAID.[6] The results of this investigation suggest that coking and briquetting of coal is indeed feasible. The development of a smokeless stove and a 25 tonne/day pilot plant for briquetting/carbonizing was recommended by the assessment team.

Philippines. The country has a relatively high GNP (US$710) by developing country standards and a host of energy supply options including reserves of oil and gas. Approximately 32% of total energy consumption in the Philippines is derived from fuelwood. The fuelwood crisis in the Philippines is largely concentrated on the central islands. A prospective fuelwood deficit exists on Luzon and a satisfactory fuelwood balance exists on Mindanao.[9] To ameliorate the fuelwood crisis, the Government embarked on a massive reforestation program in the late 1970s.

Proved and possible reserves of coal are estimated at 170 MMtonnes of sub- bituminous and lignite and 100 MMtonnes of hard coal. Resources of all types of coal may exceed 1,000 MMtonnes.[5] There are ten known coal basins in the country, four of which have current commercial value. On Cebu Island, located among the central fuelwood deficit islands, bituminous and sub-bituminous coals are being mined. These coals have 7.5 to 12.5% moisture, 3 to 4.5% ash, 38 to 44% volatiles, and calorific values of 5770 to 6800 kcal/kg. Annual production on the island is about 0.20 MMtonnes.

Total coal production in the Philipines was 0.310 MMtonnes in 1980 and was extracted from 36 different mines. American, Japanese, and South Korean companies are actively involved in the exploration and development of coal.[5] Coal for carbonization and briquetting in the Philippines appears to be readily available.

Thailand. The country boasts considerable deposits of brown coal. Proved reserves are estimated at 246 MMtonnes, with some 120 MMtonnes recoverable under existing economic and technical conditions.[5] There are ten known brown coal basins in the country, three of which are in active production. In Lampang Province, the coal is transitional between brown and sub-bituminous. In Lamphon Province, the coal is of high-quality brown grades.[5] Both of these basins are located in northern Thailand. In the south, the coal is located in Krabi Province where there are 10 MMtonnes of recoverable reserves and annual output of 0.3 MMtonnes.[5] On a countrywide basis, the coals in Thailand are used almost exclusively to generate electricity. To a lesser extent coal is used in fertilizer production, tobacco curing, railroad transportation, and for metallurgic processes. Clearly, the technology for extracting, processing, carbonizing, and briquetting coal is already well-established in Thailand.

Latin America

Two Latin American countries are examined for coal briquetting technology -- Haiti and Peru. Other countries that had the requisite coal production and fuelwood deficits, Brazil, Colombia, and Mexico were not examined. A country that was not listed as having available coal production, but has an acute fuelwood deficit is the Dominican Republic. The fact that the Dominican Republic shares the same island with Haiti is cause for further investigation for coal reserves or importation of coal briquettes from Haiti.

Haiti. The dichotomous economy of Haiti is characterized by a large and unproductive agricultural sector and a small, modern urban sector. Soil erosion from the indiscriminate cutting of trees for agriculture and charcoal production is a major cause for the decline in agricultural productivity. These factors largely account for the lowest per capita income of any country in the Western Hemisphere. Moreover, the UNDP/World Bank estimates that three-fourths of the population subsists on incomes below US$100.

Firewood, charcoal, and bagasse provide nearly 81% of total domestic energy requirements. Approximately 17% of the remaining energy bill is derived from imported oil products. The details of the fuelwood energy balance are summarized in Table C.7. The fuelwood energy balance shows that over 17% of wood production is lost in conversion to charcoal. The energy balance also shows that the industrial, commerce and service, and household sectors consume 24.9%, 28.8%, and 46.3% of fuelwood supply, respectively.

Table C.7. Fuelwood energy balance for Haiti (1979)
(Tonnes of oil equivalent)

	Firewood	Charcoal
Supply		
Production	980,000	--
Transformation	(168,600)	61,000
Demand		
Industry	202,000	--
Commerce & service	203,000	30,500
Households	406,400	30,600
Balance	0	0

Source: UNDP/World Bank [1984]

The UNDP/World Bank estimates that current fuelwood consumption is about twice as much as natural growth. A factor in this overexploitation is the treatment of the wood resource base as a virtually free good. There are nonenforced stumpage fees for the harvesting of trees for firewood, and a tax of only US$1.65/tonne is levied on charcoal producers for cutting trees.[19] Increasing taxes to reflect scarcity, reducing charcoal production, and improving end-use efficiency will be required. In addition to these demand side options, massive reforestation will be necessary to reduce soil erosion, to maintain soil productivity, and to reduce sedimentation to protect the small but vital hydropower resource.

Substitution of coal (lignite) briquettes is an energy supply option that needs to be evaluated as a means for replacing charcoal. Coal in the form of lignite is found in the Central Plateau and in two locations in the Southwest Peninsula.[19] The Central Plateau lignite reserves are estimated at 6.2 MMtonnes. This lignite is high in ash and sulfur, and has a low calorific content of 2500 kcal/kg. The cost of mining has been estimated at US$35/tonne. The low energy content of the lignite does not justify its use for generation of electricity; however, it may be suitable for carbonization and briquetting. Levying appropriate taxes on charcoal production could further improve the economics of coal briquetting. The lignite deposits in the Southwest Peninsula are estimated at 0.10 MMtonnes and further reconnaissance of these deposits is needed.

Peru. Due to a unique topography, Peru is a country of regional disparities, not the least of which lies in the area of fuelwood use. There are three major regions. The Costa is the narrow desert strip between the Pacific ocean and the Andes Mountains which contains Lima and 46% of the population. The high plateau/mountain country called the Sierra, with 24% of the population, is the central third of the country. The Selva is the sparsely populated, forested portion of the country in the Amazon basin. In spite of abundant forests in the Selva, acute fuelwood shortages exist in the Costa and prospective shortages exist in the Sierra. Distance and topography make trade between the regions for an item like fuelwood prohibitively expensive.

Biomass energy (fuelwood, charcoal, animal dung, and agricultural residues) met 32% of the total Peruvian energy demand in 1981, and in the residential sector, it was 61% of energy consumption (53% wood, 6% other biomass, and 2% charcoal).[18] The Sierra is an area of special concern for fuelwood and other biomass energy. The region, in which heavy deforestation has occurred, has only 0.2% of the country's forest resources yet consumes 85% of the estimated 5.3 million cubic meters of fuelwood each year. Seventy-five percent of the wood consumed in the Sierra exceeds annual growth there. The wood balance for the Sierra, shown in Table C.8, depends on the inclusion of 5.2 million cubic meters of wood from unknown sources. Thus, the fuelwood deficit in the Sierra could already be considered to be 5.2 million cubic meters per year. The UNDP/World Bank simply considers this wood a residual, which will likely become less available by the year 2000. If less than half of this residual is available by 2000, the region will go into acute fuelwood deficit, given present projections of use in that year.

Table C.8. Fuelwood energy balance for the Sierra of Peru (1981)
(Tonnes of oil equivalent)

	Fuelwood
Supply	
Production	3,538,000
Transformation	(383,000)
Demand	
Households	2,710,000
Industry and construction	445,000
Balance	0

Source: UNDP/World Bank [1984]

Coal deposits exist in 18 of Peru's 24 departments, with existing production in the Sierra. Total reserves are estimated to be approximately 1,000 MMtonnes, with proved reserves amounting to 126 MMtonnes and inferred reserves put at 871 MMtonnes. Production in 1981 was 0.106 MMtonnes. Due to the remoteness and the geology (seams of variable thickness and continuity; some almost vertical), the coal of the Sierra is often difficult to mine. Still, significant production could be brought forth by many small, private producers. Much of the Sierran coal is anthracite, so carbonization may not be necessary to produce a smokeless cooking fuel. Because large portions of this particular coal degenerate into coal dust and fines (as much as 80% of production in some cases), coal fines as well as lump coal could be used in a briquetting operation.

Fuelwood is also in critically short supply in the Costa region of Peru, to such an extent that poor urban dwellers in this region have substantially substituted heavily subsidized kerosene. The possibility exists of transporting coal briquettes from the Sierra, although transportation costs have not been clarified, or briquetting and carbonizing lignitic coal found in the North Costa.

Both in the Sierra and in the Costa, coal briquettes apppear to be an economic alternative to fuelwood. The briquettes used for cooking fuel would cost between US$9.30 to $13.30 per capita per year (based on 200,000 kcal of cooking energy per capita per year). Fuelwood in an open fire, the most prevalent cooking method in Peru, costs US$10.80 to $15.00 per capita per year in Huancayo (Sierra) and US$27.50 to $31.70 in Lima (Costa). The cost of a stove is not included in these estimates. (By comparison, an efficient, wood stove would reduce wood burning costs to US$5.40 to $11.20 per capita per year in Huancayo and US$13.80 to $23.70 in Lima. Subsidized kerosene costs US$7.70 per capita per year, but unsubsidized costs are US$21.00 in Huancayo and US$18.50 in Lima.)

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