Chapter 3

Energy Services in Developing Countries

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Introduction and Summary

Energy use in the world's developing countries is increasing rapidly. In 1960, developing countries consumed just 15 percent of the world's commercial fuels; by 1985, their share had increased to about 24 percent.[1] Including traditional fuels, the developing country share of world energy consumption was about 28 percent in 1986. Developing countries might consume as much commercial energy as today's industrial countries by early in the next century.[2] Factors driving this rapid increase in energy use include population growth, economic growth, and increasing urbanization (see ch. 2). Even with this rapid growth, overall per-capita energy consumption rates in developing countries in 2025 would be just one-fifth that of the United States in 1987.

The purpose of this chapter is to examine how energy is used in developing countries. As explained in chapter 1, the focus of this report is on the services energy provides rather than the amount of energy consumed. The reason for this approach is simple: energy is not used for its own sake, but rather for the services it makes possible. For example, wood might be burned to cook food, heat water, warm a house on a winter evening, heat an industrial boiler, or to provide other services.[3] Similarly, diesel and gasoline are used primarily to provide transportation services.

There may be many different means of providing a desired service, each with its own costs and benefits. Transportation, for example, might be provided by bicycles, motorcycles, cars, buses, light rail, or aircraft. The consumer chooses among these according to such criteria as cost, comfort, convenience, speed, and aesthetics. Within these consumer constraints, a more efficient car maybe preferable to an increase in refinery capacity in order to reduce capital and/or operating costs or because of its environmental benefits. Thus, in addition to engineering and economics, energy analyses should also consider social, cultural, and institutional factors. Such factors are more readily included in a services framework than in a conventional energy supply analysis.

The amount of energy consumed in the main end use markets-residential and commercial, industry, and transportation-is examined first; then the major services provided by energy are examined within each end-use market. In the household sector, the services examined are cooking,[4] lighting, space conditioning, and refrigeration; in industry, process heat and motor drive; in agriculture, irrigation and traction; and, finally, transportation. These services are chosen on the basis of their current or likely future levels of energy consumption or their social and economic impacts.

Within this services framework, changes in energy use are traced from traditional rural areas to their modern urban counterparts. The progression from the traditional rural to the modern urban illuminates well the wide range of technologies now being used in the developing countries and the dynamics of how energy use can be expected to change in the future.

Energy use in traditional rural villages reflects a much different set of considerations from that of the modern urban economy. First, traditional energy use is part of a complex and interdependent biological system, rather than being based on fossil fuels. The biomass that is used for fuel is part of a system that provides food for humans, fodder for animals, construction materials, fiber for ropes, and even traditional medicines. Similarly, the bullock that pulls a plow also provides milk, meat, leather, and dung for fertilizer or fuel.

Second, people in traditional economies carefully assess their choices and make complex tradeoffs

[1] Jayant Sathaye, Andre Ghirardi, and Lee Schipper, "Energy Demand in Developing Countries: A Sectoral Analysis of Recent Trends," *Annual Review of Energy,* vol. 12, 1987, p. 253.

[2] U.S. Environmental Protection Agency, "Policy Options for Stabilizing Global Climate," vol. 2, February 1989, p. VII-30. Rapidly Changing World Scenario.

[3] In some cases, particularly in the industrialized countries, wood might be burned in a fireplace simply for aesthetic reasons.

[4] Water heating is also an important residential/commercial energy service that is often similar to cooking in terms of the technologies used. It is not, however, explicitly considered here.

between the numerous pressures they face in day-to-day survival, at a level seldom seen in the modern economy. Gathering fuel, for example, is not free: it costs time and personal energy that must be balanced against all the other demands that one faces, particularly during the agricultural season when labor demand is at its peak. There are also complex tradeoffs involved in gaining access to fuels on common lands or on privately owned land.

Third, although people in rural areas may use energy inefficiently in comparison to what is possible with modern commercial technologies, they use energy rather efficiently and wisely given the constraints on their resources, technology, and capitals They have little choice in this if they are to survive on their meager resources. Rather than maximizing production, as is done in modern industrial society, traditional peoples focus on minimizing risk in the face of the vagaries of drought and other natural disasters.

The efficiency and productivity of traditional energy technologies in developing countries can be significantly improved. To do so effectively, however, will require an understanding of the complex linkages of village life. In general, village populations operate rationally within their framework;[6] change then requires that the framework be changed through the introduction of external inputs—financial, managerial, material, and technical. The lack of success of many development programs can be attributed in part to a failure to recognize the rationality of rural lifestyles and the need to address the overall framework in which villagers operate.

For the developing countries as a whole, the residential/commercial and industrial sectors constitute the largest end use energy markets, together accounting for 85 percent of the energy used by final consumers when traditional fuels are included. Transportation accounts for the remaining 15 percent. There are, however, considerable differences among developing nations.[7] The residential/commercial sector accounts for a particularly high share of energy use in African countries (mostly in the form of biomass fuels for cooking), while industry's share is quite low. Transportation accounts for an exceptionally high share of the total in Latin America, whereas its share in India and China is low. Tables 3-1,3-2, and 3-3 provide sectoral and energy service breakdowns for the developing countries; figure 3-1 shows per-capita energy use in rural households as determined by village surveys in Africa, Asia, and Latin America. Residential cooking and industrial process heat account for almost two-thirds of all the energy used in the developing world. About 40 percent of all energy consumed in providing these services in developing countries, or well over a quarter of the total energy consumed in developing countries, is used in India and China.

Cooking is the single largest energy use in many developing countries. There is a well-established transition in cooking fuels associated with higher incomes, improved supply availability, and urbanization. In rural areas, and in poor urban households, traditional fuels (wood, crop wastes, and dung) are used in simple stoves. In more affluent households, people switch to modern stoves and clean, convenient fuels such as kerosene, Liquefied Petroleum Gases (LPG), and electricity. Because wood stoves are relatively inefficient, households that use kerosene or LPG can consume significantly less energy for cooking than those using wood and charcoal.

Lighting technologies follow a similar technological progression, from candles or light from wood frees in some rural areas, to kerosene and butane lamps, to electricity, which is a highly prized energy service. Electricity use for lighting rises rapidly with household income.

Relatively little energy is used for residential space cooling in developing countries. Space cooling is becoming significant in commercial and government buildings, however, and energy use for space cooling is likely to grow rapidly in the future.

[5]Notable examples of studies on this topic include: N.H. Ravindranath et al., "An Indian Village Agricultural Ecosystem-Case Study of Ungra Village, Part I: Main Observations," *Biomass*, vol. 1, No. 1, September 1981, pp. 61-76; Amulya Kumar N. Reddy, "An Indian Village Agricultural Ecosystem—Case Study of Ungra Village, Part II: Discussion" *Biomass*, vol. 1, No. 1, September 1981, pp. 77-88; M.B. Coughenour et al., "EnergyExtraction and Use in a Nomadic Pastoral Ecosystem," *Science*, vol. *230, No. 4726, Nov. 8, 1985*, pp. 619-625.

[6]Ibid.

[7]Energy use at the village level is fairly similar in both quantity and source (biomass), and in application (cooking, subsistence agriculture) throughout the world. Energy use by the economically well off is also reasonably similar throughout the industrial countries as well as among the urban elite in developing countries. The large differences in energy use between countries are due primarily to the relative numbers of villagers and economically well off in the population; the form and quantity of energy use by those who are making the transition between these two extremes; and the development path being followed.

Table 3-l—Total Delivered Energy by Sector, in Selected Regions of the World, 1985 (Exajoules)

Region	Residential/commercial: Commercial fuels	Residential/commercial: Traditional fuels[a]	Industry: Commercial fuels	Industry: Traditional fuels[a]	Transport: Commercial fuels	Transport: Traditional fuels[a]	Total: Commercial fuels	Total: Traditional fuels[a]	Total energy
Africa	1.0	4.0	2.0	0.2	1.5	—	4.4	4.1	8.5
Latin America	2.3	2.6	4.1	0.8	3.8	—	10.1	3.4	13.5
India and China	7.3	4.7	13.0	0.2	2.0	—	22.2	4.8	27.1
Other Asia	1.9	3.2	4.0	0.4	1.9	—	7.8	3.6	11.3
United States	16.8	—	16.4	—	18.6	—	51.8	—	51.8

-Not available or not applicable.

a these estimates of traditional fuels are lower than those generally observed in field studies. See figure 3-1, app. 3-A, and ch. 4.

b this is delivered energy and does not include conversion losses.

NOTES: 1 exajoule (10^{18} Joules) equals 0.9478 Quads. The residential and commercial sector also includes others (e.g., public services, etc.) that do not fit in industry or transport. Traditional fuels such as wood are included under commercial fuels for the United States. These figures do not include conversion losses (from fuel to electricity, in refineries, etc).

SOURCE: International Energy Agency (IE/l), *World Energy Statistics and Balances* 1971-1987 (Paris: OECD, 1989); IEA, *Energy Balances of OECD Countries 1970-1985* (Paris: OECD, 1987); and IEA, *Energy Balances of Developing Counties 1971-1982* (Paris: OECD, 1984).

Table 3-2—Delivered Energy Per Capita by Sector in Selected Regions, 1985 (gigajoules) (Includes traditional fuels)

Region	Residential/commercial	Industry	Transport	Total
Africa	11.8	5.2	3.5	20.5
Latin America	12.7	12.5	9.7	34.9
India and China	6.7	7.3	1.1	15.1
Other Asia	7.2	6.2	2.7	16.1
United States	69.8	68.5	77.5	215.8

NOTE: These estimates do not include conversion losses in the energy sector and underestimate the quantity of traditional fuels used compared to that observed in field studies. See app. 3-A for better estimates of traditional fuel use and for sectoral energy use including conversion losses.

SOURCE: Derived from table 3-1.

Table 3-3-Per Capita Energy Use by Service in Selected Countries (Gigajoules)

	Brazil	China	India	Kenya	Taiwan	U.S.A.
Residential	6.2	11.7	5.5	16.9	8.9	64.9
cooking	5.3	8.5	5.0	16.4	4.7	3.5
lighting	0.3	0.4	0.5	0.5	0.7	—
appliances	0.6	—	0.05	—	3.1	13.0[a]
Commercial	1.5	0.7	0.26	0.4	4.2	45.2
cooling	0.4	—	0.13	0.24	1.9	—
lighting	0.5	—	0.05	0.16	0.8	7.2
appliances	0.6	—	0.07	—	1.5	·
Industrial	19.4	13.8	4.1	4.8	39.2	94.1
process heat	17.5	10.2	2.7	—	—	55.8
motor drive	1.6	3.6	1.3	—	—	20.4
lighting	0.1	—	0.05	—	—	—
Transport	13.3	1.2	1.3	2.7	11.5	80.8
road	12.0	0.2	0.8	1.8	10.1	66.7
rail	0.2	0.7	0.4	0.2	0.1	2.0
air	0.7	—	0.1	0.7	0.7	11.3
Agriculture	2.1	1.8	0.6	0.5	2.6	2.5
Total	43.4	27.0	11.7	25.6	67.7	288.0

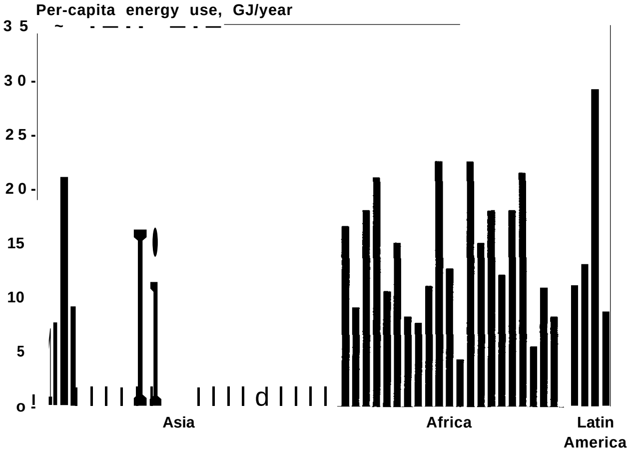
— Not available or not applicable.

[a]This is the combined total for applicances and lighting.

NOTE: These estimates include the upstream conversion losses in the energy sector, such as the loss in going from fuel to electricity or crude to refined petroleum products. This in in contrast to tables 3-1 and 3-2 where energy sector conversion losses were not included.

SOURCE: Adapted from app. 3-A, tables 1 through 6.

Figure 3-l—Per-Capita Energy Use in Village Households in Developing Countries



This figure shows per-capita use of biomass fuels as found in household energy surveys in Asia, Africa, and Latin America. The observed energy use depends on such factors as fuel availability, climate, diet, income, and other factors. The generally higher levels of energy use in Africa and Latin America reflect, in large part, the greater availability and accessibility of wood and other biomass fuels. The sporadic peaks in energy use shown in the figure are typically for villages in colder, more mountainous regions.

SOURCES: D.O. Hall, G.W. Barnard, and P.A. Moss, *Biomass for Energy in the Developing Countries* (Oxford: Pergamon Press, 1982, pp. 212; World Bank, "Bolivia: Issues and Options in the Energy Sector," UNDP/WB Energy Sector Assessment Program, Rpt. 4213-60, April 1983; J.S. Singh, U. Pandey, and A.K. Tiwari, "Man and Forests: A Central Himalayan Case Study," *AMBIO*, vol. 12, No. 2, 1984, pp. 80-87; Issoufou Boureima and Gilles De Chambre, *Rapport sur l'Evaluation du Programme Foyers Ameliores* (Niamey, Niger: Association des Femmes du Niger and Church World Service, November 1982).

Also, electric appliances are quickly penetrating the residential sector. Many of these air conditioners and appliances, notably refrigerators, have low efficiencies. These end uses are having strong impacts on the electric power infrastructure.

Many commercial and industrial processes require process heat, ranging from the low-temperature heat provided by biomass used to dry food in cottage industries to the high-temperature processes used in the large-scale steel and cement industries. With some exceptions, the efficiencies of these processes are typically much lower than those found in industrialized countries.

Much of the population in developing countries depend for their mechanical work in both industry and agriculture on human or animal muscle, with low efficiencies and power outputs that seriously limit productivity. The efficiencies of modern diesel and electric motors are significantly lower in developing countries than in the industrialized countries as well.

As in other sectors, there is a transition in transportation technologies. Walking and use of domesticated animals are the dominant transport technologies in poorer and rural areas. The next step up is bicycles, and then the internal combustion engine. Transport services in the developing world, as in the industrial world, are based largely on highways. In the developing countries, however, freight rather than passenger traffic is the most important transport activity in terms of energy consumption.

The Residential/Commercial Sector[8]

Energy use in the residential/commercial sector of developing countries typically accounts for about 30 percent of commercial energy use and two-thirds or more of traditional fuel use (see app. 3-A). Cooking is by far the largest use of fuel in rural areas; in urban and more developed areas, lighting and appliances (refrigerators and electric fans, for example) are also large energy users. Air conditioning is likely to become important in the future in residences and is already widely used in commercial, institutional, and government buildings in developing countries.

The average energy efficiency of the most common cooking, lighting, and appliance technologies in use in developing countries today can be improved dramatically,[9] but usually at a significant additional capital cost to the consumer. Nevertheless, the advantages of these more modern technologies--convenience, comfort, effectiveness-are incentive enough for consumers to make the investment where the technologies and the necessary fuel supplies are available, affordable,[10] and reasonably reliable.

[8] In this analysis, the residential/commercial sector includes other energy uses such as public buildings not included in the industrial and transportation sectors.

[9] This can be accomplished by changing both the mix of technology (e.g., shifting users from low-efficiency wood stoves to high-efficiency LPG stoves) and by improving the individual technologies themselves (e.g., moving toward higher efficiency refrigerators).

[10] Appropriate financial mechanisms may be needed.

Table 3-4-Principal Cooking Fuels Used by the World Population, 1976

Region	Percent of people using fuel: Fossil energy[a]	Fuelwood	Dung and crop waste
Africa South of Sahara	10	63	27
India	10	47	43
Rest of South Asia	12	46	42
East Asia, developing Pacific	36	41	23
Asia centrally planned economies	22	51	27
Middle East, North Africa	53	17	30
Latin America and Caribbean	71	26	3
North America, OECD Pacific	100	0	0
Western Europe	100	0	0
Europe, centrally planned economies	100	0	0
Total	47	33	20

a Includes electric cooking.

SOURCE: Adapted from David Hughart, *Prospects for Traditional and Non-Conventional Energy Sources in Developing Countries,* World Bank staff working paper No. 346,132 pp., July 1979.

Cooking[11]

The most important single energy service in many developing countries is cooking. In rural areas of developing countries, traditional fuels--wood, crop wastes, and dung-are used for cooking; in many urban areas, charcoal is also used. More than half of the world's people depend on these crude fuels for their cooking and other energy needs (see table 3-4).[12] Higher incomes and reliable fuel supplies enable people to switch to modern stoves and clean fuels such as kerosene, LPG, and electricity.

Traditional Fuels

Traditional fuels are predominant in rural areas because they can be gathered at no financial cost and used in very simple stoves—as simple as an open free. At the national level, the use of biomass for fuel reduces expensive energy imports. These are substantial benefits.

Use of traditional fuels also exacts substantial costs. Large amounts of labor are expended to gather these fuels in rural areas, and a significant portion of household income is spent for them in poor urban areas (see ch. 2). Cooking with traditional fuels is awkward and time-consuming. Unlike modern gas or electric stoves, stoves that use traditional biomass fuels must be constantly tended to maintain an adequate flame. This demands a large share of women's time in developing countries-averaging perhaps 3 to 5 hours per day[13]—and interferes with other activities.

Cooking with traditional fuels is also usually unpleasant and unhealthy due to the large amount of noxious smoke emitted (see table 3-5). Measurements of indoor concentrations in homes in developing countries have found levels of carbon monoxide, particulate, and hydrocarbons 10 to 100 times higher than World Health Organization standards. Cooks can be exposed to as much or more carbon monoxide, formaldehyde, benzo(a)pyrene, and other toxins and carcinogens as heavy cigarette smokers.[14] Smoke from cooking stoves is therefore thought to be a significant factor in ill-health in developing

11 Although the discussion here focuses on household cooking, the same considerations apply to commercial and institutional settings.

12 Heating water for bathing and cleaning and boiling water for drinking are implicitly included in the discussion here, as the technologies used are often the same for the lower and middle income groups in developing countries, and separation of energy use for these purposes i:difficult.

13 Richard Morse et al., "Organizing Current Information for Rural Energy and Development Planning," M. Nurul Islam, Richard Morse, and M. Hadi Soesastro (eds.), *Rural Energy to MeetDevelopment Needs: Asian Village Approaches* (Boulder, CO: Westview Press, 1984), table 7, p. 498.

14 Kirk R. Smith, *Biomass Fuels, Air Pollution, and Health: A* Global Review (New York, NY: Plenum Press, 1987)

Table 3-5-Typical Air Pollution Emissions From Various Cooking Fuels

Fuel	Efficiency (percent)	Grams per gigajoule of delivered energy[a]				
		TSP	SO_2	NO_x	HC	GO
Wood (tropical)	15	3,800	250	300	3,200	34,000
Cow dung (Hawaiian)	15	10,000	3,200	·	—	44,000
Coal (Indian)	20	280	2,200	460	2,200	27,000
Coconut husk	15	17,000	—	—		54,000
Natural gas	60	0.7	—	13	' 7	330

— Not available or not applicable.
a TSP, total Suspended particulates; SO_2, sulfur dioxide; NO_x, nitrogen oxides; HC, hydrocarbons; CO, carbon monoxide.
SOURCE: Adapted from Kirk R. Smith, Biomass *Fuels, Air Pollution, and Health: A Global Review (New York, NY:* Plenum Press, 1987).

countries. The diseases implicated include severe eye irritation, respiratory diseases, and cancer.[15]

Finally, although the expansion of agricultural and grazing lands and commercial logging are the most important causes of deforestation globally, the use of wood for fuel may also contribute to deforestation in some local areas, particularly where the population density is high and the climate is dry such as the West African Sahel (see ch. 5).

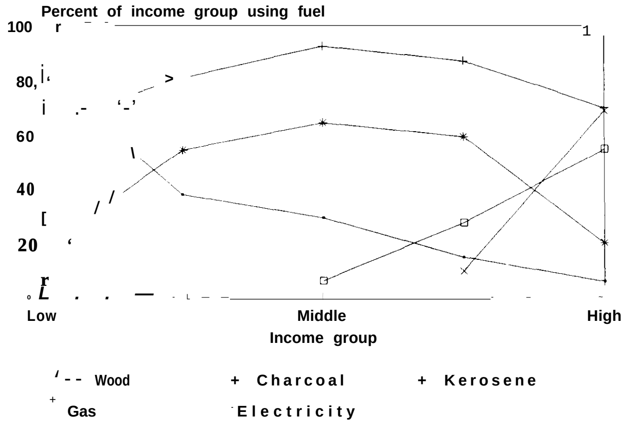
The Transition to Modern Stoves and Clean Fuels

People are generally observed to make the transition to modern, efficient stoves and clean fuels as soon as they are available and affordable (see figure 3-2).[16] These technologies are preferred for their convenience, comfort, cleanliness, ease of operation, speed, and other attributes.

There is a natural progression in efficiency, cost, and performance as consumers shift from wood stoves to charcoal, kerosene, LPG or gas, and electric stoves (see figure 3-3). Improved wood and charcoal stoves have also begun to fill a potentially important niche between traditional wood or charcoal stoves and modern kerosene or gas stoves.

Cultural factors are often cited as a barrier to the adoption of improved biomass stoves and fuels.

Figure 3-2-Choice of Cooking Fuel by Income for Five Medium-Sized Towns in Kenya



Many households use more than one fuel depending on the particular food cooked and the supply and cost of fuel. Note the shift in fuel choice from wood to charcoal and kerosene, and then from charcoal and kerosene to gas and electricity.

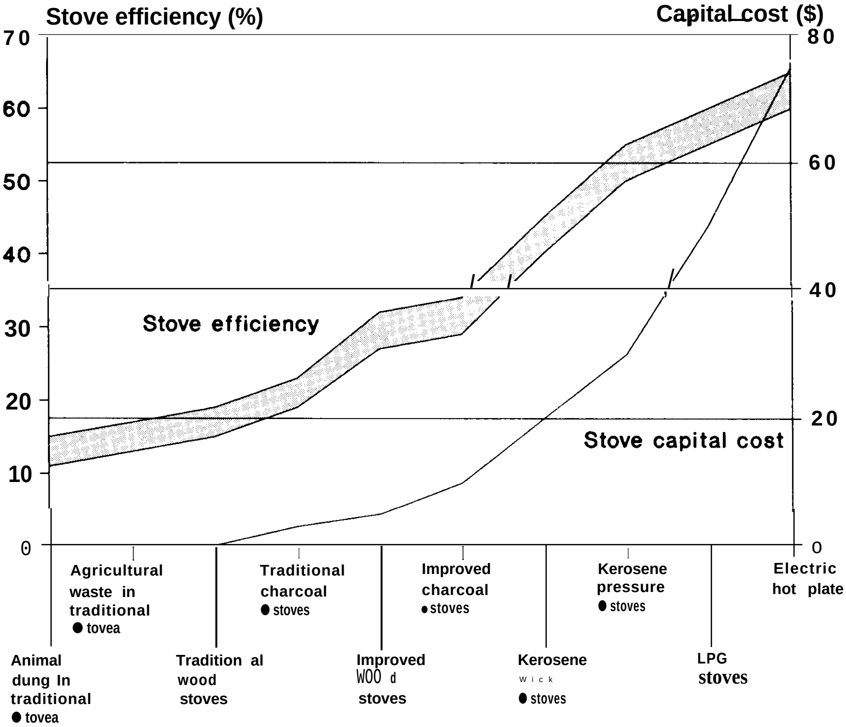
SOURCE: John Soussan, "Fuel Transitions Within Households," Discussion paper No. 35, Walter Elkan et al. (eds.), *Transitions Between Traditional and Commercial Energy in the Third World* (Guildford, Surrey, United Kingdom: Surrey Energy Economics Center, University of Surrey, January 1987).

Although cultural factors may play a role in choices of stoves or fuels, it is hardly a dominant one, as evidenced by the wide variety of stoves and fuels that have already been adopted across the full range of class, cultural, and income groups in developing countries. More typically, the reason that various stoves have not been adopted by targeted groups in

[15] Although the limited data available linking human exposure to the smoke from wood fires to lung cancer is still ambiguous (but may indicate anomalously low cancer rates), there is now evidence of excess lung cancer among cooks using certain types of coal in China. Overall, the World Health Organization now cites respiratory disease from all causes as the leading cause of mortality in developing countries. See Kirk R. Smith, "PAH and the Household Cook in Developing Countries: The Lung Cancer Anomaly," paper presented at the Symposium on Polynuclear Aromatic Hydrocarbons in the Workplace, International Chemical Congress of Pacific Basin Societies, Honolulu, HI, December 1984, to be published in M. Cooke and A.J. Dennis (eds.), *Polynuclear Aromatic Hydrocarbons: Formation, Metabolism and Measurement* (Columbus, OH: Batelle Press); J.L. Mumford et al., "Lung Cancer and Indoor Air Pollution in Xuan Wei, China," *Science*, vol. *235*, Jan. 9, 1987, pp. 217-220; H.W. de Koning, K.R. Smith, and J.M. Last, "Biomass Fuel Combustion and Health," *Bulletin of the World Health Organization* (EFP/84.64).

[16] This transition is complex and *not* yet well understood. Factors that affect a household's shift to modern stoves and fuels include household income and fuel-producing assets (land, trees, animals, etc.); reliability of access to modern fuels; relative cost of traditional and modern fuels and stoves; level of education of the head of household; cooking habits; division of labor and control of finances within the household; and the relative performance of the stoves and fuels available.

Figure 3-3-Representative Efficiencies and Direct Capital Costs for Various Stoves



The range of performance both in the laboratory and in the field is much larger than that suggested by this figure and is affected by such factors as the size of the stove and pot, the climate (wind), the quality of the fuel used, the care with which the stove is operated, the type of cooking done, and many other factors. The type of material that the pot is made of is also a significant factor: aluminum pots are almost twice as efficient as traditional clay pots due to their better conduction of heat. Although the efficiency of improved charcoal stoves is shown as slightly higher than improved wood stoves-the case today for the simplest uninsulated metal woodstoves--the potential performance of wood stoves is higher than that for charcoal stoves.

SOURCE: Samuel F. Baldwin, *Biomass Stoves: Engineering Design, Development, and Dissemination* (Arlington, VA: VITA, 1986); and OTA estimates.

the developing countries is that they simply have not worked well.[17]

The transition to modern stoves and fuels is often sharply constrained due to their higher capital costs (figure 3-3) and uncertainty in the supply of fuel. In Colombo, Sri Lanka, for example, the cost of converting to LPG in 1983 was equivalent to 1 month's income for 70 percent of the population and 5 months' income for the poorest 20 percent.[18] Yet cooking with gas can be the lowest cost alternative when both capital and operating costs are included. In Raipur, India, the cost of cooking with LPG is less than that for wood for household discount rates of 30 percent or less; yet many households continue to use wood, presumably because effective household discount rates are higher[19] (the capital cost of gas stoves was cited as a major reason for the failure to switch from wood to LPG for cooking).

Because of the high cost of LPG cooking, charcoal and kerosene are widely used as an intermediate step in the transition from wood to gas stoves. Charcoal is very popular in some urban areas. For example, it is the fuel of choice in urban Kenya (see figure 3-2) and Senegal-which have a tradition of charcoal production and use remaining from the historical Saharan trade caravans.[20] Consumers

[17] Samuel F. Baldwin, *Biomass* Stoves: *Engineering Design, Development, and Dissemination* (Arlington, VA: VITA, 1986); Sam Baldwin et al., "Improved Woodburning Cookstoves: Signs of Success," *AMBIO*, vol. 14, No. 4-5, 1985.

[18] Gerald Leach, *Household Energy in South Asia (New* York, *NY:* Elsevier Applied Science, 1987).

[19] J. Dunkerley et al., "Consumption of Fuelwood and Other Household Cooking Fuels in Indian Cities," *Energy Policy,* January/February 1990, pp. 92-99. "Discount rates" are a measure of the time value that households place on their available cash income.

[20] World Bank, Energy Department, "Review of Household Energy Issues in Africa," draft report, May 1987, p. 3, p. 1.6.

prefer charcoal to wood because it gives off less smoke,[21] blackens pots less, requires little tending of the fire, and in some areas costs less.[22] At the national level, however, cooking with charcoal consumes far more forest resources than cooking directly with wood, due to the low energy efficiency of converting wood to charcoal-typically just 40 to 60 percent and often much lower.[23]

Kerosene is usually the next step up in the progression of cooking fuels. In many areas, kerosene prices-often subsidized or freed by the government—form a reasonably effective cap on the price of wood and charcoal.[24] Consumers switch between these fuels according to price and availability.

LPG or natural gas is often the final step in the progression in cooking fuels. LPG is widely used by higher income groups in many urban areas, and natural gas is widely used where it is available. In Dhaka, Bangladesh, for example, over 50 percent of the urban population use natural gas; less than 10 percent use kerosene; and none use charcoal.[25] In some cases, electricity is also used for cooking by the highest income groups.

As households make the transition from wood to modern fuels, overall energy use for cooking can vary dramatically, depending on the choice of technology and the situation in which it is used. Total household energy use for cooking with kerosene (see figure 3-4) or with LPG can be significantly less[26] than that for wood or charcoal, due to the higher efficiency of kerosene and gas stoves.[27] Total household energy use for cooking with kerosene or LPG is also significantly less than for cooking with charcoal or (non-hydro) electricity, due to the low conversion efficiency of wood to charcoal and of fuel to electricity.[28]

The transition to modern stoves and fuels thus offers users many benefits-reduced time, labor, and possibly fuel use for cooking, and reduced local air pollution. Means of lowering capital and operating costs and ensuring the reliability of supply are needed if the poor are to gain access to these clean, high-efficiency technologies. At the national level, the transition to modern stoves and fuels could improve the local environment[29] and significantly reduce biomass energy consumption for cooking; to realize these benefits, however, could impose a substantial financial burden on poor nations.

A large-scale transition to LPG would require a significant investment in both capital equipment and ongoing fuel costs. optimistically assuming that the cost of LPG systems would average $10 per capita, the investment would be roughly 3.5 percent of GNP and 20 percent of the value added in manufacturing

[21]Charcoal stoves can, however, give off hi@ levels of carbon monoxide-a serious health hazard in inadequately ventilated kitchens--but this does not cause as much obvious discomfort to the user as the smoke from a wood fire.

[22]Douglas F. Barnes, World Bank, Household Energy Unit, Industry and Energy Department, ''Understanding Fuelwood Prices in Developing Nations," Oct. 31, 1989, table 1. Conversion to dollars per unit of energy was done using 30 MJ/kg for charcoal, and using 700 kg per cubic meter multiplied by 16MJ/kg for wood with typical moisture contents observed in the market.

[23]The energy efficiency of the conversion process is variously given as 15 percent in Tanzania, 24 percent in Kenya with an additional loss of 5 percent of the charcoal itself during distribution% 29 percent in Senegal and Ethiopia, and over 50 percent in Brazil with brick kilns. Advanced retorts are claimed to be capable of achieving 72 percent energy efficiencies in converting wood to charcoal if there is complete recovery of all the gaseous byproducts. See E. Uhart, *Preliminary Charcoal Survey in Ethiopia,* U.N. Economic Commission for Africa, FAO Forest Industries Advisory for Africa, Dec. M75-1 122, 1975,30 pp.; M.J. and M.L. Luhanga, *Energy Demand Structures in Rural Tanzania,* Department of Electrical Engineering, University of Dar-es-Salaam, Tanzania, 1984; Phil O'Keefe, Paul Raskin, and Steve Bemow, *Energy and Development in Kenya: Opportunities and Constraints* (Sweden: Beijen Institute, 1984); G.E. Karch, *Carbonization: Final Technical Report of Forest Energy Specialist,* UNFAO, SEN/78/002, 1980.; T.S. *Wood, Report on Domestic Energy Usefor Cooking* (Energy Assessment Mission, Ethiopia) (Washington, DC: World Bank, 1983), p. 33; FLORASA, *Man-h-fade Forests for Wood and Charcoal in Brazil* (Minas *Gerais,* Brazil: Florestal Acesita, S.A., Belo Horizonte, October 1983), p. 53.

[24]Douglas F, Barnes, "Understanding Fuelwood Prices in Developing Nations," op. cit., footnote 22.

[25]M.J. Prior, ''Fuel Markets in Urban Bangladesh,'' *WorldDevelopment,* vol. 14, *No. 7,* pp. **65-872.*

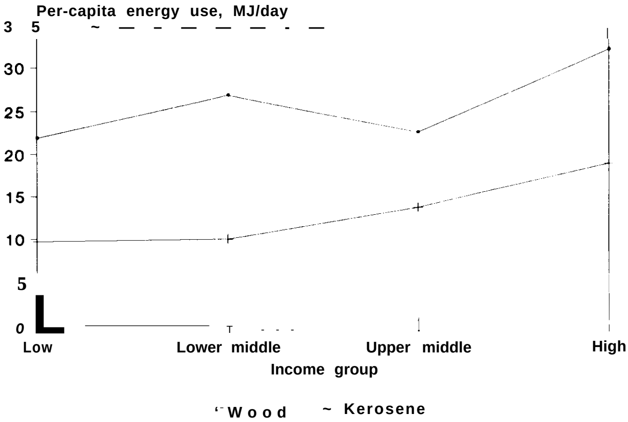
[26]Not all the potential efficiency gains of LPG may be realized by the vex-y poor. For example, one-third to one-half of the poor in hillside shanty towns of Rio de Janeiro own just one LPG bottle. To avoid the risk of running out of gas and having no substitute, many households exchange their gas bottles before they are completely empty. See Alfredo Behrens, *Household Energy Consumption in Rio De Janeiro Shanty Towns (Rio* de Janerio, Brazil: Colegio da America Latina, 1985).

[27]In practice, however, the savings with LPG are not quite as large as would be expected from the higher efficiency and better control of these stoves. This may be due, in part, to less precise control of the stove; to taking advantage of greater useful energy; and other factors. See Kevin B. Fitzgerald, Douglas Barnes, and Gordon McGranahan, ''Interfuel Substitution and Changes in the Way Households Use Energy: The Case of Cooking and Lighting Behavior in Urban Java," U.N. Working Paper on Interfuel Substitution Analysis, June 13, 1990.

[28]Other factors that affect household energy use for cooking include the size of the household, the diet, and the amount of processed or prepared foods eaten.

[29]It might, however, increase global carbon dioxide emissions.

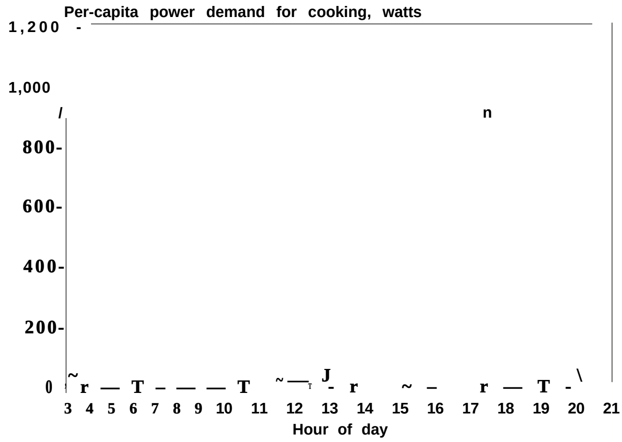
Figure 3-4—Direct Energy Use for Cooking in West Java, Indonesia



This figure compares energy use in households using only wood with that in households using only kerosene within the same income class. Households using kerosene consume roughly half as much energy as households using wood.

SOURCE: M. Hadi Soesastro, "Policy Analysis of Rural Household Energy Needs in West Java," M. Nurul Islam, Richard Morse, and M. Hadi Soesastro (eds.), *Rural Energy to Meet Development Needs: Asian Village Approaches* (Boulder, CO: Westview Press, 1984).

Figure 3-5-Daily Load Profiles for Cooking Energy, Pondicherry, India, 1980



This figure illustrates the highly peaked power demand for cooking energy as measured in a village survey.

SOURCE: C.L. Gupta, K. Usha Rae, and V.A. Vasudevaraju, "Domestic Energy Consumption in India (Pondicherry Region)," *Energy, vol.* 5, pp. 1213-1222.

for the nearly three billion people in the lowest income countries.[30] The LPG used[31] would be equivalent to one-fourth of the total commercial energy consumption today by these countries and would be a significant fraction of their export earnings.[32] Significant economic growth is needed if these costs are to be absorbed.

Costs would be even higher if electricity were used for cooking. Direct capital costs for electric burners typically approach $100 per household or more. Moreover, at the national level, the capital cost of installing generation, transmission, and distribution equipment to power electric burners is much greater, perhaps several thousand dollars per household.[33] If relatively few households are using electricity for cooking, these high capital costs are partially offset by the numerous other uses for electric power throughout the day. If a significant fraction of households switch to electricity for cooking, however, the highly peaked energy demand for cooking (see figure 3-5) will overwhelm other baseload applications, and these costs must increasingly be assigned to cooking alone.

Lighting[34]

Lighting accounts for only a small fraction of total national energy use in both developing and industrial countries. In Kenya, for example, just 1.7 percent of national energy use is for domestic lighting (app. 3-A). Lighting does, however, account for a significant fraction of total electricity use, and the electricity sector is very capital intensive (see ch. 4).

Despite its relatively low energy use, lighting merits particular attention as it plays a very impor-

[30] World Bank, *World Development Report, 1989 (New* York, NY: Oxford University Press, 1989), tables 1 and 6.

[31] Assuming aper-eapitapower rate for cooking with LPG systems of 100 watts. This is comparable to that seen in the United States and about twice that seen in European countries. It is likely that people in developing counties would continue to eat less processed food, less restaurant food, and probably more grains and so would continue to use somewhat more fuel than is used in households in the industrialized countries. Energy use rates for household cooking in different countries are given in K. Krishna Prasad, "Cooking Energy," workshop on end-use focused global energy strategy, Princeton University, Princeton, NJ, Apr. 21-29, 1982.

[32] World Bank, *World Development Report, 1989*, op. cit., footnote 30, table 5. Kilograms of oil equivalent have been converted to energy at42 MJ/kg.

[33] Assuming a peak power demand of 2 kW. A peak power demand is assumed here rather than an average power as for the LPG case above, because electric power systems cannot easily store power and must be able to meet peak demands.

[34] Principal sources for the information in this section are Robert van der Piss and A.B. de Graaf, World Bank, "A Comparison of Lamps for Domestic Lighting in Developing Countries," energy series paper No. 6, June 1988; and Robert van der Plas, World Bank, "Domestic Lighting, " Energy Sector Management and Assessments, Industry and Energy Department, working paper No. WP68, November 1988.

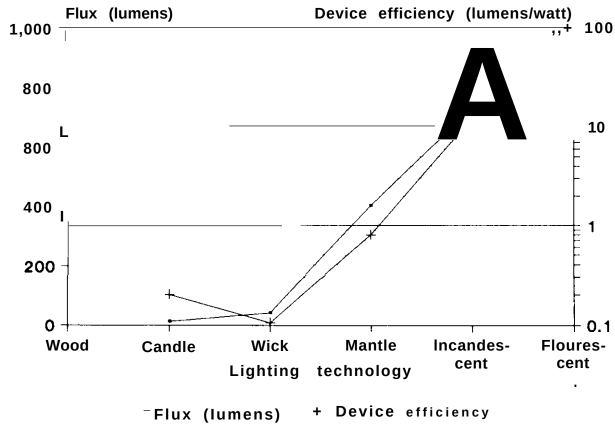
tant social role in domestic life and in commerce and industry, making activities possible at night or where natural lighting is inadequate. As rural incomes increase, or as people move to urban areas and gain greater access to modern fuels and electricity, lighting services and the energy used to provide them increase dramatically.

Lighting technologies follow a fairly clear technological progression in performance, efficiency, and cost (see figure 3-6). Consumers' choices of lighting technologies largely follow the same progression as household incomes increase and as electricity becomes available.

In traditional rural areas, people are often limited to the light available from wood fires, frequently obtained in conjunction with cooking. Kerosene wick lamps are usually the first step up in the progression. These may be as simple as a wick in a jar of kerosene, or as complex as a hurricane lamp with a glass chimney .35 Glass chimney lamps generally provide more light and at a higher efficiency than open wick lamps. Glass chimney lamps also cost slightly more-a few dollars-and use somewhat more fuel. These additional costs can be a substantial barrier to their use in rural areas. For example, a survey of six villages in Bangalore, India, found that three-fourths of the households used simple open-wick lamps, and only one-fourth used lamps with glass chimneys.[36]

The light provided by wood fires, candles, or kerosene wick lamps is sufficient to find one's way, but is generally inadequate for tasks such as reading or fine work. Using two lamps doubles the cost, but does not come close to providing adequate light to work by. Thus, the poorest households tend to use just one lamp. Wealthier households may add an additional lamp or two for other rooms in the house or move up to a kerosene mantle light; however, the amount of kerosene used per household does not generally increase in proportion with income. As a result, the amount of kerosene used for lighting is similar (within a factor of two or so) across different income groups and in different regions of the world.[37]

Figure 3-6-Light Output and Efficiency of Various Lighting Technologies



Includes the candle, kerosene wick lamp, kerosene mantle lamp, 60-watt incandescent lamp, and 22-watt standard fluorescent lamp. No value is given for a wood fire, as its light output depends on size and other factors. The light output of candles and kerosene lamps are similarly highly variable; the values listed are representative. Only the efficiency of the device (plus ballast) itself is considered. System efficiencies-induding refinery losses in kerosene production and generation, transmission, and distribution losses for electricity--will be considered in a later report of this OTA study.

SOURCES: Robert van der Plas, World Bank, "Domestic Lighting," Energy sector Management and Assessments, Industry and Energy Department, working paper No. WPS 68, November 1988. Van der Plas cites the efficiency of electricity production as 30 percent, but this factor is apparently not taken into account in the incandescent light efficiency figure of 12 lm/W. See, for example, Samuel Berman, "Energy and Lighting," David Hafemeister, Henry Kelly, and Barbara Levi (ads.), *Energy Sources: Conservation and Renewable (New York, NY:* American Institute of Physics, 1985). Berman gives the output of a 1OO-W incandescent as 1,600 lumens and a 50-W fluorescent as 3,300 lumens. The efficiencies shown here are slightly iowereorresponding to the lower, assumed wattage of the light. See also Terry McGowan, "Energy-Efficient Lighting," Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), *Electricity: Efficient End-Use and New Generation Technologies and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989).

Despite the drawbacks of kerosene wick lamps, they are a predominant technology in poor rural and urban areas. Although their light output is low, the capital and operating costs of kerosene wick lamps are also low (see figure 3-7). Further, kerosene can be purchased in small quantities as family finances

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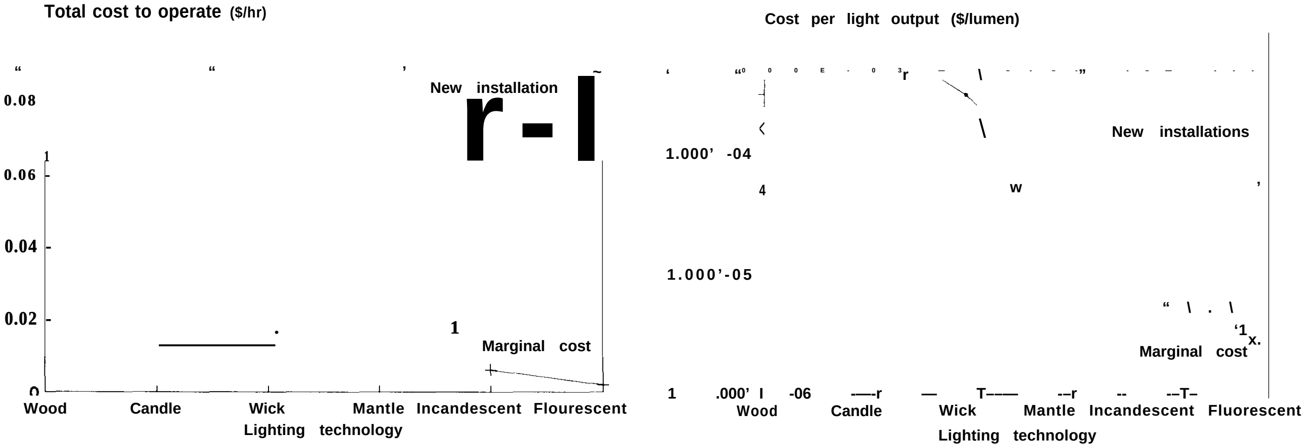
[35]The light given off by wick lamps depends on a host of factors, including size, condition of the wick (unraveled or uneven),and the amount of soot deposited on the glass chimney (if present).

[36]ASTRA, "Rural Energy Consumption Patterns: A Field Study," Bangalore, India, 1981.

[37]Gerald Leach and Marcia Gowen, World Bank, "Household Energy Handbook," technical paper, No. 67, 1987; Suliana Siwatibau, *Rural Energy In Fiji* (Ottawa, Canada: International Development Research Center, 1981); Girja Sharan (cd.), *Energy Use in Rural Gujurat* (New Delhi: Oxford and IBH Publishing Co., 1987). The Gujurat study found that one of the few variables affecting kerosene use was the number of rooms per household. Even this, however, was a relatively weak relationship.

Figure 3-7--Costs of Various Lighting Technologies



(A) Direct costs to the consumer of operating various lighting technologies per hour of service. (B) Direct costs to the consumer of various lighting technologies per unit of light output. The costs shown include only cash expenditures; they do not include labor costs for maintaining kerosene lamps, etc. The high value for electric lights shows the effect of applying all the grid connection charges to a single light corresponding to the situation faced by the poor rural household that will initially use but one or two lights. The low value for electric lights ignores the cost of grid connection charges, corresponding to the marginal cost of adding additional lights after being connected to the grid. The assumed discount rate is 10 percent. In practice, individuals in both the developing and industrialized world tend to apply much higher discount rates when making investment decisions in energy-conserving technologies. Rates observed in the United States are typically in the range of 40 to 80 percent. Similarly, high effective discount rates have been observed in developing countries. If higher effective discount rates are applied, the higher capital costs of kerosene mantle lamps and, especially, electric grid connections will tend to present more of a barrier to investment.

SOURCES: Derived from figures 3-6 and 3-7A. See also: Harry Chernoff, “individual Purchase Criteria for Energy-Related Durables: The Misuse of Life Cycle Cost,” *Energy Journal, vol. 4, No. 4,* October 1983, pp. 81-86; David French, “The Economies of Renewable Energy Systems for Developing Countries,” ‘Washington, DC, June 1979.

permit. Kerosene wick lamps are thus well matched to the reality of rural life in developing countries, where capital and resources are sharply limited. Wood fires and/or kerosene wick lamps are the primary sources of light for more than two billion people worldwide.

Next in the progression are butane or pressurized kerosene mantle lamps. These are much like the gas lamps used for camping in the United States. Mantle lamps give substantially more light and are more efficient than wick lamps; they also cost more to purchase and operate, tend to be hot and noisy, and can cause considerable glare.

Finally, in contrast to kerosene lamps or other nonelectric lighting technologies, electric lighting is clean, relatively safe, easy to operate, efficient, and provides high-quality light. People in rural areas and small towns of developing countries place electric lighting high on their list of desired energy services. For example, a survey of 320 households in several villages and small towns of Nigeria found that 90 percent ranked electricity--primarily for lighting—as their top choice in desired energy services.[38]

Even where electric lighting is available, however, the high cost of connecting to the electric grid creates a substantial barrier for poor families that use only one or a few lightbulbs (see figure 3-7),[39] and this substantially slows penetration. A study in Gujurat, India, found that 10 years after villages had gained access to the electric grid, less than a third of the households had connected; this increased to about two-thirds after 20 years.[40] Uncertain electric supply in many developing countries-including blackouts and brownouts-also tends to discourage potential users and forces those who have connected to the grid to simultaneously maintain alternative kerosene lighting systems.

[38] Edward I. Onyebuchi, “Analysis of Rural Energy Choices in Nigeria,” *Natural Resources Forum,* vol. 12, No. 2, 1988, pp. 181-186.

[39] Figure 3-7 tends t. understate the barrier that grid connection costs present to people in poor rural areas. The perceived and usually the real costs to finance connection charges are often much higher in developing countries than the 10 percent discount rate assumed for this figure. Using more realistic effective discount rates of 50 percent, the cost of electric lighting—if the villager could raise the money at all—per operating hour would rise from $0.07 to $0.34, compared to $0.02 for a kerosene mantle light and $0,01 for a kerosene wick lamp. The choice of kerosene wick or mantle lamps is thus logical given the financial constraints that the poor face.

[40] Girja Sharan (ed.), *Energy Use in Rural Gujurat, Op. cit.,* footnote 37.

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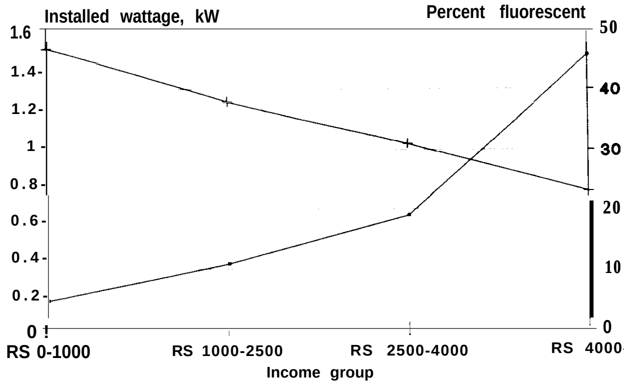
Electricity use for lighting rises rapidly with household income. For example, in South Bombay, India, rates of household electricity use during the evening varied from 93 watts for the lowest income group to 365 watts for the highest income group.[41] The "choice of electric lighting technology also varies as incomes increase. Low-income households in South Bombay installed more conventional fluorescent lights-despite their higher capital cost—and operated them more intensively due to their lower operating costs. As incomes increased, households shifted away from the harsh light of conventional fluorescent to the more natural light of incandescent (see figure 3-8).[42]

As incomes increase with economic development, households begin to buy other appliances-radios, TVs, fans, refrigerators, and air conditioners. Electricity use for lighting usually continues to increase, but it becomes only a small fraction of total residential electricity use (see figure 3-9). Electricity use for lighting in the commercial and service sectors also grows rapidly as the economy expands.

The demand for lighting has also continued to increase in the industrialized countries over the past 30 years as incomes have increased. Today, the average rate of lighting use ranges from roughly 20 to 100 million lumen-hours per capita per year (Mlmhr/cap-yr) in the industrial countries.[43] In comparison, annual household light production in South Bombay varies with household income from about 1 to 3 Mlmhr/cap-yr;[44] light production in the commercial sector might double these numbers. This is equivalent to a per-capita consumption level that is only 10 to 30 percent of the lowest levels among industrialized countries.

If lighting services equal to half the minimum level observed in the industrialized countries-10 Mlmhr/cap-yr--are to be provided in developing countries, then per-capita demand for lighting electricity will be about 500 (kWh) kilowatthours per year. This is equivalent to an evening power demand of perhaps 150 watts per capita.[45] If that level of evening demand occurred at the utility system peak load, as is typical in developing countries, then the capital cost to provide electricity for lighting would be roughly $300 per person.[46]

Figure 3-3-Changes in Capacity and Type of Installed Electric Lighting Per Household With Income Level in South Bombay, India



Installed wattage per household and the fraction of installed wattage that is fluorescent (the remainder is incandescent) is shown versus household income in rupees. The intensity of use of this installed wattage varied with the type of lighting and the household income. The lowest income group used 80 percent of their installed capacity of fluorescent and 45 percent of their incandescent during the evening. The highest income group used just 25 percent of their installed capacity of both fluorescents and incandescents during the evening.

SOURCE: Aehok Gadgil and Bhaskar Natarajan, "Impact of Socio-Economic and Architectural Factors on Peak Electricity Demand: A Case Study of South Bombay," *Energy*, vol. 14, No. 4, 1969, pp. 229-236.

Space Conditioning, Refrigeration, and Other Appliances

Space Conditioning

Heating residential or commercial buildings will never bean important energy service in the majority of developing countries since most have tropical climates. Space heating will be important in some

[41]Calculated from data in Ashok Gadgil and Bhaskar Natarajan, "Impact of Socio-Economic and Architectural Factors on Peak Electricity Demand: A Case Study of South Bombay," Energy, vol. 14, No. 4, 1989, pp. 229-236. The lowest income group uses 80 percent of their installed 71 watts of fluorescent and 45 percent of their installed 81 watts of incandescent; the highest income group uses 25 percent of their installed 1,460 watts of fluorescents and incandescent.

[42]This particular case contrasts with the more typical situation, as discussed for cooking, where the poor are particularly sensitive to first costs.

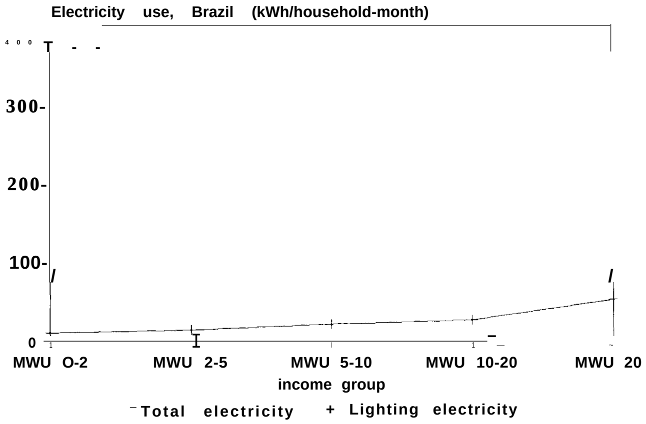
[43]Terry McGowan, "Energy-Efficient Lighting," in Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), *Electricity: Efficient En&Use and New Generation Technologies, and Their Planning Implications* (Lund, Sweden: Lund University Press, 1988).

[44]Calculated from Gadgil and Natarajan, op. cit., footnote 41.

[45]This assumes that light output is equally split between incandescent and fluorescent lighting, and that the demand is in the 5 hews of the evening.

[46]Assuming an installed capital cost for the system of $2,000 perkW of generating capacity.

Figure 3-9-Household Electricity Use for Lighting v. Household Income, in Brazil



This graph shows that electricity use for lighting continues to grow with income even in a relatively properous developing country such as Brazil. Lighting electricity is, however, only a small fraction of total household electricity use in this case. MWU are minimum wage units.

SOURCE: Ashok Gadgil and Gilberto De Martino Jannuzzi, Conservation *Potential of Compact fluorescent Lamps in India and Brazil,* Lawrence Berkeley Laboratory and Universidade Estadual de Campinas (Brazil: June 23, 1989).

areas, however, such as mountainous regions and high-latitude areas like northern China. Beijing, for example, has about the same annual average low temperature as Chicago. Nearly 20 percent of China's total annual coal consumption and 5 percent of its annual biomass consumption are used for space heating (app. 3-A).[47]

In China, residences rarely have any insulation and often have large gaps around doors and win-dews.[48] Indoor temperatures in these homes are controlled not by a thermostat or by comfort requirements, but by fuel supply-and fuel, though cheap, is scarce. In Kezuo county, Northeast China, for example, average indoor temperatures are at the freezing point during the winter, compared to average outdoor temperatures of–3'C to-5 °C with lows of –25 °C.[49] Additions to coal supply, more efficient stoves, or better wall insulation would thus result mainly in comfort improvements but not in energy savings.

Similarly, although many developing countries have hot climates,[50] little energy is used at present for space cooling in developing countries. Tradi-tional building designs somewhat moderate the extremes in temperature through natural ventilation and other techniques that make use of local materials and do not require additional energy inputs.[51] Increasing urbanization and the use of commercial building materials, however, have made these tradi-tional practices less practical and less popular. Active space ventilation by electric fans has become popular in many areas where there is reliable electric service and costs are affordable. For example, electric fan ownership in Beijing, China, jumped from 47 percent of households in 1981 to 77 percent in 1984.[52]

Air conditioning in residences is a luxury item found only in the highest income households in developing countries (see figure 3-10).[53] In contrast, 60 percent of all homes in the United States-nearly all who need it—have air conditioners.[54] A substan-tial proportion of commercial, institutional, and government buildings in developing countries are air conditioned.

Air conditioning systems in developing countries are also often less efficient than those in industrial-ized countries. Buildings usually are poorly insu-lated, with large amounts of air infiltration; and air conditioners are generally less efficient than those in the west and are poorly maintained and controlled.

47Vaclav Smil, ''China's Energy,'' contractor report prepared for the Office of Technology Assessment 1990.

48Robert M. Wirtshafter, ''Energy-Conservation Standards for Buildings in China,'' ***Energy, vol.*** **13, No. 3,1988, pp.265-274; Robert M. Wirtshafter and Chang Song-ying, "Energy Conservation in Chinese Housing,"** ***Energy Policy,*** **vol. 15, No. 2, pp. 158-168.**

@World Bank, ''China: County-Level Rural Energy Assessments: A Joint Study of ESMAP and Chinese Experts,'' Activity Completion Report No. 101/89, May 1989.

50All 50 of the world's hottest cities are in the developing world. The hottest is Djibouti, with an average annual high temperature of 113 °F. None of the 50 coldest cities is in the developing world. See V. Showers, ***World Facts andFigures (New*** **York,** ***NY:*** **John Wiley& Sons, 1979).**

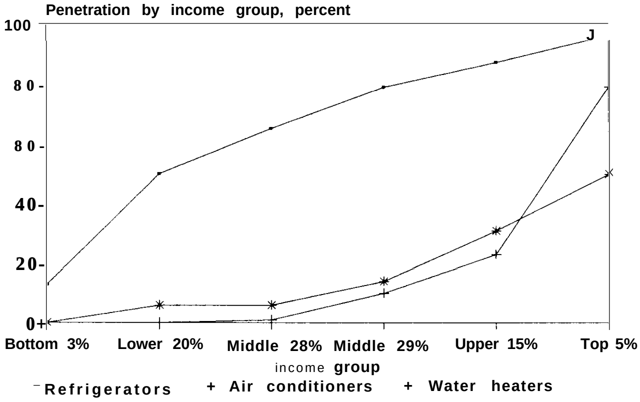
51Lim Jee Yuan, ''Traditional Housing: A Solution to Hopelessness in the Third World: The Malaysian Example,'' ***The Ecologist,*** **vo1. 18, No. 1, 1988, pp. 16-23; Mehdi N. Bahadori, "Passive Cooling Systems in Iranian Architecture,''** ***Scientific American,*** **vol. 238,1978, pp. 144154; R.K. Hill,** ***Utilization of Solar Energy For an Improved Environment Within Housing For the Humid Tropics*** **(Victoria, Australia: CSIRO, 1974).**

52J. Sathaye, A. Ghirardi, and L. Schipper, ''Energy Demand in Developing Countries: A Sectoral Analysis of Recent Trends," ***Annual Review of Energy,*** **vol. 12, 1987, pp. 253-281.**

53Jayant Sathaye and Stephen Meyers, "Energy Use in Cities of the Developing Countries," ***Annual Review of Energy, 1985,*** **vol. 10, pp. 109-133.**

54Energy Information Administration, ***Housing*** **Characteristics** ***1984,*** **DOE/EIA-0314(84) (Washington, DC: U.S. Gov ernment Printing Office, October 1986), p. 5.**

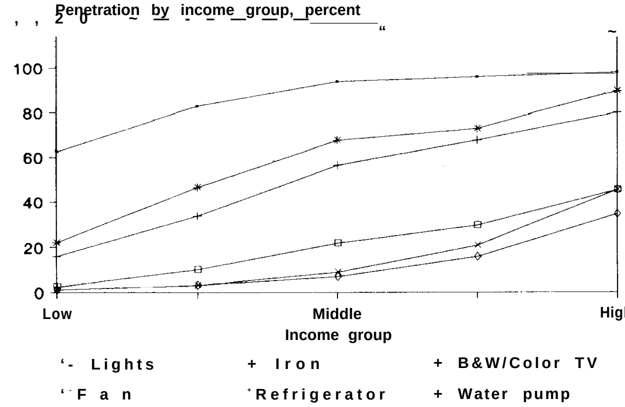
Figure 3-10-Electric Appliance Ownership in Urban Malaysia by Income Group, 1980



This figure shows the rapid penetration of refrigerators, air conditioners, and water heaters as household incomes rise. The incomes (percentage of households) are in ascending order: 150-299 Malaysian dollars per month (M$/month) (3 percent); M$ 300-599 (20 percent); M$ 600-999 (28 percent); M$ 1,000-1,999 (29 percent); M$ 2,000-4,999 (15 percent); and M$ 5,000+ (5 percent).

SOURCE: Jayant Sathaye and Stephen Meyers, "Energy Use in Cities of the Developing Countries," *Annual Review of Energy,* vol. 10, 1965, pp. 109-133.

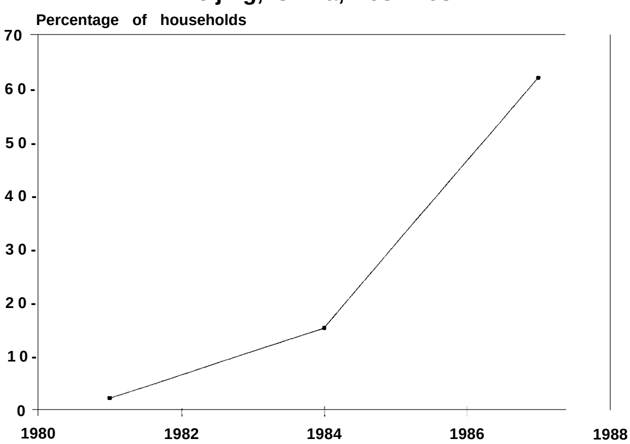
Figure 3-1 I—Electric Appliance Ownership in Urban Java, 1988



This figure shows the rapid penetration and relative importance within household purchasing patterns of lights, TVs, irons, fans, refrigerators, and water pumps. Income groups (share of households) in ascending order are: less than 75 (Rupees)/month (24 percent), 75-120 Rp/month (22 percent), 121-185 Rp/month (21 percent), 186-295 Rp/month (14 percent), and greater than 295 Rp/month (9 percent).

SOURCE: Lee Schipper and Stephen Meyers, "Improving Appliance Efficiency in Indonesia," *Energy Policy* forthcoming.

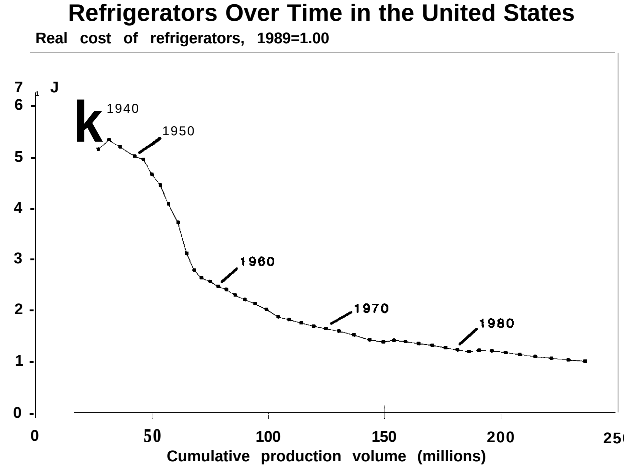
Figure 3-12—Refrigerator Ownership in Beijing, China, 1981-1987



This figure shows the rapid penetration of refrigerators into the household sector over just a 6-year period.

SOURCE: Stephen Meyers and Jayant Sathaye, "Electricity Use in the Developing Countries: Changes Since 1970," *Energy,* vol. 14, No. 8, 19S9, pp. 435-441, table 6.

Figure 3-13-Reduction in the Real Cost of Refrigerators Over Time in the United States



Over the past 40 years, the real price of refrigerators has dropped by almost a factor of 5. For developing countries, such price reductions would allow households to invest in refrigerators at a much earlier point in time than was the case for the United States and other industrialized countries at a similar level of development.

SOURCES: Rick Bahr, Bureau of Labor Statistics, U.S. Department of Labor, personal communication, July 9, 1990 (CPI/ refrigerators); John Chirichiello, National Science Foundation SRS Computer Bulletin Board, personal communication, July 6, 1990 (GNP deflator, 1953-19S9); U.S. Department of Commerce, Bureau of the Census, "Historical Statistics of the United States: Colonial Times to 1970" (Washington, DO: U.S. Government Printing Office, 1975), p. E1-12 (GNP deflator, 1935-53).

Table 3-6-Residential Nonheating Electricity Intensity in Selected Countries, 1970 and 1986 (kilowatthours per capita)

Country	1970	1986
India	7	25
Indonesia	8	33
Pakistan	10	59
Philippines	34	78
Thailand	17	110
Malaysia	37	184
Mexico	75	190
South Korea	25	248
Brazil	90	261
Argentina	210	307
Venezuela	158	422
Taiwan	163	557
Japan	—	975
West Germany	—	1,210
United States	—	3,050

—Not available or not applicable.

SOURCE: Stephen Meyers and Jayant Sathaye, "Electricity Use in the Developing Countries: Changes Since 1970; Energy, vol. 14, No. 8, 1989, pp. 435-441.

The potential for increased energy use for space cooling is very large. The United States now uses about 1,400 kWh of electricity per person per year for space cooling.[55] If India used this much electricity per person for space cooling, its total annual electricity generation would have to increase to more than five times present levels.[56] The hotter climate of India could increase these requirements still more.

Refrigerators and Other Appliances

Electricity-using appliances--refrigerators, televisions, washing machines, etc.—are rapidly penetrating the residential sector of developing countries. Factors contributing to this explosive growth include urbanization, increasing electrification in rural areas, economic growth, improved access to appliances, and decreasing real costs of appliances—which make them affordable to a broader segment of the population than ever before. Factors limiting appliance penetration include the lack of electric service, particularly in rural areas. In Brazil, for example, 90 percent of urban households but only 24 percent of rural households have electric service.[57]

The rapidly increasing use of household appliances in the developing countries places additional demand on electric power infrastructures that are typically already short of capacity. Further, much of the residential demand comes at peak times. A review of 13 of the largest developing countries for the period 1970-86 found that the growth rate of electricity consumption was highest in the residential sector—averaging 9.9 percent annually, compared to 8.3 percent annual growth in the industrial sector.[58] Table 3-6 shows electricity intensity for the residential sector in selected developing and industrialized countries. Even the most advanced developing countries use, on average, just a small fraction of the electricity consumed by Americans. Electricity consumption by the economically well off in developing countries, however, differs little from that found in the United States or Europe.

Lights are usually the first appliance installed when a household gets electric service. Acquisition of other appliances varies by household income and region (see figures 3-10 and 3-1 1). In India, fans are typically among the first appliances acquired, followed by televisions and refrigerators. In Brazil, even relatively poorer, newly electrified households often have televisions and refrigerators, as these appliances are comparatively inexpensive and are available secondhand.[59]

Refrigerator ownership is at present quite low in most developing countries. In China, for example, less than 1 percent of households have refrigerators, although refrigerator ownership has been growing rapidly in Beijing (see figure 3-12). In Brazil, 63 percent of households have refrigerators.[a] In contrast, in the United States, 99.7 percent of households have refrigerators.[61]

55Gas Research Institute, Strategic Analysis and Energy Forecasting Division, *Baseline Projection Data Book* (Washington, DC: Gas Research Institute, 1988), pp. 37, 120.

56Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook (TEDDY) 1988* (New Delhi, India: 1989), p. 73.

57Gilberto De Martino Jannuzzi, ''Residential Energy Demand in Brazil by Income Classes,'' *Energy Policy, vol. 17, No. 3,* p. 256.

58Stephen Meyers and Jayant Sathaye, ''Electricity Use in the Developing Countries: Changes Since *1970, ''Energy,* vol. 14, *No. 8,1989,* pp. 435-441.

59A. Gadgil and G. De Martino Jannuzzi, *Conservation Potential of Compact Fluorescent Lumps in India andBrazil,* LBL-27210 (Berkeley, CA: Lawrence Berkeley Laboratory, July 1989), p. 5.

60Howard S. Geller, "Electricity Conservation in Brazil: Status Report and Analysis," contractor report prepared for the Office of Technology Assessment, March 1990, p. 17.

61Energy Information Administration *Housing Characteristics 1984*, Op. Cit., footnote 54, p. 13.

The refrigerators used in developing countries are typically half the size of American refrigerators, or smaller. They are also much less efficient than the best refrigerators now commercially available (the average refrigerator used in the United States is similarly much less efficient than the best available). In Indonesia, most refrigerators are assembled locally from imported components and, in general, do not take advantage of proven energy efficiency features such as rotary compressors and increased insulation.[62] The efficiency of Brazilian refrigerators is being improved--electricity consumption by the average new model was reduced by 13 percent between 1986 and 1989--but they are unable to make use of the very efficient motor-compressors (which Brazil manufactures and exports), as these units cannot tolerate the voltage fluctuations found in Brazil.[63]

Advances in materials and manufacturing techniques, coupled with a growing secondhand market, are forcing down the first cost of refrigerators and other appliances. The real cost of new refrigerators in the United States, for example, has plummeted by a factor of nearly 5 over the past 40 years (see figure 3-13). This trend should make many household appliances affordable to a much larger share of developing country populations than was the case for today's industrialized countries at a comparable level of development—a generation or more ago. As a result, energy use could increase significantly above the historical record in the near to mid-term. For example, the average new refrigerator in the United States uses about 1,000 kWh of electricity per year.[64] If every household in China had a U.S.-style refrigerator, an additional 200,000 gigawatthours (GWh) of electricity per year-or the output of about 50 full-size coal-burning power plants—would be required, at a cost for the power plants alone of about $100 billion.[65]

The Industrial Sector

The industrial sector typically consumes 40 to 60 percent of total commercial fossil energy in developing countries (see table 3-l);[66] it also makes heavy use of traditional biomass fuels-often traded in commercial markets. The primary energy services required by industry are process heat and mechanical drive. These services will be treated generically here; in a later report of this OTA study, they will be examined as specific parts of integrated industrial processes.

Firms in the industrial sector of developing countries today vary widely in size and sophistication. Atone end of the spectrum are small traditional firms that use relatively energy-inefficient and low-productivity manufacturing technologies.[67] At the other end are large, modern firms, often with multinational parent companies, that have world-class manufacturing capabilities.

Manufacturing operations typically fall into three broad size categories-household or cottage, small workshops and factories, and large-scale industry. Over time, a few smaller companies tend to grow into large ones as the transport infrastructure improves and incomes rise, increasing the size of markets and providing economies of scale that turn the advantage to larger firms.[68]

In many developing countries, one-half to three-quarters of manufacturing employment is in household-scale establishments, with the remainder divided between medium and large operations. Much of the employment in the small traditional (and largely rural) household industries is seasonal labor available during the nonagriculturally active times of year. Typically one-fourth to one-third of rural

62Lee Schipper, "Efficient Household Electricity Use in Indonesia," Lawrence Berkeley Laboratory, draft report, January 1989, p. 3, section on "Conservation Potential."

63Howard S. Geller, *Electricity* Conservation *in Brazil: Status Report and Analysis,* Op. Cit., footnote 60, p. 29.

64Howard S. Geller, "Residential Equipment Efficiency," contractor report prepared for the Office of Technology Assessment, May 1988.1990, NAECA standard.

65Assuming: 5 people per household, 45 percent load factor, no transmission and distribution losses, and a capital cost of $2,000 per kW of installed capacity.

66J. Sathaye, A. Ghirardi, L. Schipper, "Energy Demand in Developing Countries: A Sectoral Analysis of Recent Trends," op. cit., footnote *52,* table 5.

67Although they are small and often use little modern technology or methods, these manufacturing enterprises are not inefficient in some respects. High transport and marketing costs and small market size might greatly raise the cost to larger, modern firms if they should try to enter these small village markets, making them the higher cost producers.

68Dennis Anderson, World Bank, "Small Industry in Developing Countries: Some Issues," Staff Working Paper No. 518, 1982.

Table 3-7-Kenyan National Energy Use by Fuel, 1980 (percent of total)[a]

Energy service	Commercial fuels	Biomass fuels			
		Wood	Charcoal	Other	Total
Household	2.9	46.3	6.6	2.7	58.5
Cooking/heating	1.0	46.3	6.1	2.7	.
Lighting	1.7	—	—	.	—
Other	0.2	—	0.5	—	—
Industry	8.6	14.5	1.0	—	24.1
Large	8.6	5.3	0.3	—	—
Informal urban	—	0.1	0.6	—	—
Informal rural	—	9.1	0.1	.	—
Commerce	0.6	0.5	0.1	—	1.2
Transportation	13.7	—	—	—	13.7
Agriculture	2.5	—	—	—	2.5
Total	28.4	61.3	7.6	2.7	100.0

—Not available or not applicable.

a Total national energy consumption .332 million gigajoules; per capita power consumption=658 watts.

SOURCE: Phil O'Keefe, Paul Raskin, and Steve Bernow (eds.), *Energy and Development in Kenya: Opportunities* and Constraints (Uddevalla. Sweden: Beijer Institute and Scandinavian Institute of African Studies, 19&).

nonfarm employment is in manufacturing.@ This is an important source of income and employment for the rural and poor urban sectors.[70]

Process Heat

Many commercial and industrial processes require heat—ranging from the low-temperature heat used to dry food by cottage industry to the high-temperature processes used by large industries to produce steel and cement. The efficiencies of these processes are typically much lower than those found in industrialized countries.

Traditional Process Heat Technologies

Biomass is used extensively in both traditional rural and more modern industry in developing countries. In Kenya, for example, large industry accounts for about 8.6 percent of national energy use in the form of commercial fuels, and 5.6 percent of total national energy consumption in the form of biomass (wood and charcoal). Informal rural and urban industries use little or no commercial fuel, but they account for about 10 percent of total national energy use in the form of biomass (see table 3-7). Rural applications include beer brewing, blacksmithing, crop drying, and pottery firing (see table 3-8).

Estimates of the use of biomass energy for industrial processes are similarly high elsewhere. Tobacco curing uses 11 percent of all fuelwood in Ilocos Norte, Philippines, and represents 17 percent of the national energy budget in Malawi.[71] In Indonesia, the brick, tile, and lime industry consumes roughly 2.5 percent of national energy use.[72] Beer brewing uses 14 percent of the total fuelwood consumed in Ouagadougou, Burkina Faso.[73] Overall, biomass fuels supply up to 40 percent of the industrial energy used in Indonesia, 28 percent in Thailand, 17 percent in Brazil, and similarly large fractions in many other countries.[74]

69Dennis Anderson and Mark Leiserson, "Rural Nonfarm Employment in Developing Countries," *Economic Development and Cultural Change*, vol. *28, No. 2, 1980,* p. 245, table A2, cited in Donald W. Jones, *Energy Requirements for Rural Development (Oak* Ridge, TN: Oak Ridge National Laboratory, June 1988).

70Enyinna Chuta and S.V. Sethuraman (eds.), *Rural Small-Scale Industries and Employment in Africa and Asia* (Geneva: International Labor Office, 19s4).

71E.L. Hyman, "The Demand for Woodfuels by Cottage Industries in the Province of Ilocos Norte, Philippines,"*Energy, vol. 9,* pp. 1-13, 1984; E.M. Mnzava, "Village Industries vs. Savannah Forests," *UNASYLVA*, vol. 33, No. 131,1981, pp. 24-29; E.M. Mnzava, "Fuelwood and Charcoal in Africa," W. Paley, P. Chartier and D.O. Hall (eds.), *Energy from Biomass* (London: Applied Science Publishers, Ltd., 1980); M.J. Mwandosyasnd M.L. Luhanga, *Energy DemandStructures in Rural Tanzania* (Princeton, NJ: Center for Energy and Environmental Studies, Princeton University, and Dar-Es-S_ Tanzania: Department of Electrical Engineering, University of Dar-Es-Salaam, 1984).

72World Bank, Energy Sector Management Assistance Program, "Indonesia, Energy Efficiency Improvement in the Brick, Tile and Lime Industries on Java," March 1987.

73Henri Chauvin, "When an African City Runs Out of Fuel," *UNASYLVA*, vol. 33, No. 133, 1981, pp. 11-20.

74Joy Dunkerley et al., Energy *Strategies for Developing Countries* (Baltimore, MD: Johns Hopkins University Press, 1981), P. 265.

Table 3-8-Annual Consumption of Fuelwood and Charcoal in Kenya by Rural Cottage Industries, GJ/Capita

Industry	Fuelwood	Charcoal[a]
Brewing	1.07	—
Construction wood	0.50	.
Butchery	0.24	0.06
Restaurants	0.17	0.04
Baking	0.13	—
Brick firing	0.06	—
Blacksmithing	—	0.06
Crop drying	0.04	
Tobacco curing	0.04	
Fish curing	0.02	—
Total	2.27	0.16

—Not available or not applicable.
a This does not include the losses in converting wood to charcoal.

SOURCE: Phil O'Keefe, Paul Raskin, and Steve Bernow (eds.) *Energy and Development in Kenya: Opportunities and Constraints* (Uddevalla, Sweden: Beijer Institute and Scandinavian Institute of African Studies, 19S4).

The efficiency with which these tasks axe done can be quite low (see table 3-9). On close examination, however, the performance of traditional biomass-fueled technologies is often found to be carefully optimized in terms of efficiency, capital, and labor, given existing materials and technological constraints. An example of this is the traditional brick kiln in Sudan, which holds as many as 100,000 bricks at a time and gains economies through size and other design factors. To improve the performance of these technologies usually requires the input of modem materials and technologies, including modern means of measuring efficiencies.

Modern Large-Scale Industry

Modern large-scale industries in developing countries are modeled after their counterparts in industrialized countries, but they are often operated at significantly lower efficiencies. A few energy-intensive materials-steel, cement, chemicals (especially fertilizer), and paper-account for much of the energy used by industry (see table 3-10). The total energy used to produce these materials will increase rapidly as developing countries build their national infrastructures.

Steel—In the OECD countries, the steel industry typically consumes about one-fifth of the energy used in the industrial sector.[75] Developing countries such as China, India, and Brazil devote a similar share-18 percent, 23 percent, and 20 percent, respectively [76]--of industrial commercial energy consumption to steel production. The top 10 producers account for about 90 percent of the crude steel made in the developing world; many other developing countries produce little or no steel.

Per-capita steel consumption increases rapidly as national infrastructures are built, and then tends to saturate the market and level off at higher income levels[77] (see figure 3-14). A similar trend has been found for a wide variety of materials.[78] Simply put, there is a limit to the number of steel-intensive cars, refrigerators, washing machines, buildings, bridges, pipelines, etc., a person needs. Eventually, consumption levels tend to plateau at replacement levels. When these wants for basic materials are fulfilled, people tend to spend incremental income on higher value-added materials-such as those with a high-quality finish--or on less material-intensive but higher value-added consumer goods.

The level of per-capita steel consumption needed to provide a given service has also been reduced over time through a variety of technological improvements, including higher weight-to-strength steel alloys, more efficient motors and engines, better design, and the substitution of alternative products such as high-performance plastics. For example, the tensile strength of steel increased fourfold between 1910 and 1980.[79]

Overall steel production has been increasing by a little over 7 percent per year in the developing countries, while remaining relatively constant in the industrialized countries. At current rates, steel production by developing countries will overtake that in the industrialized countries early in the next century.

The energy efficiency of steel production in the developing countries varies widely. In some cases, it has significantly lagged that of the industrialized

[75] Maurice Y. Meunier and Oscar de Bruyn Kops, "Energy Efficiency in the Steel Industry With Emphasis on Developing Countries," World Bank technical paper, No. 22, 1984.

[76] Ibid.

‘Per-capita steel consumption increases approximately linearly with per-capita income up to several thousand dollars.

[78] Robert H. Williams, Eric D. Larson, and Marc H. Ross, "Materials, Affluence, and Industrial Energy Use," *Annual Review of Energy*, vol. 12,1987, pp. 99-144.

[79] Economic Commission for Europe, *Evolution of the Specific Consumption of Steel* (New York, NY: United Nations, 1984).

Table 3-9-Efficiency of Fuel Use In Traditional (Developing Countries) and Modern (Industrial Countries) Commercial and Industrial Operations

Activity	Location	Estimated efficiency of traditional technology (percent)	Estimated efficiency of modern technology in U.S. (percent)
Cooking	West Africa	15-19	50-60
Beer brewing	Burkina Faso	15-17	79
	Burkina Faso	0.3-0.7	0.6
Tobacco drying	Tanzania	0.5	—
Tea drying	Tanzania	2.9	—
Baking	Sudan	12-19	43
	India	16	—
	Guatemala	3	
Fish smoking	Tanzania	2-3	—
Brick firing	Sudan	8-16	6-11
	India	6.4	—
	Uganda	5-10	—
Foundry work	Indonesia	3	40

NOTE: — Not applicable or not available.

SOURCE: For complete list of sources, see app. 3-B.

Table 3-10-Energy Consumption by Chinese industry, 1980

Sector	Final energy use	
	Exajoules	Percent
Basic metals (iron and steel)	2.38	25.7
Chemicals (fertilizer)	2.23	24.1
Building materials (cement, brick tile)	1.44	15.6
Machine building	0.82	8.8
Textiles	0.64	6.9
Food, beverages, tobacco	0.38	4.1
Pulp and paper	0.25	2.7
Other	1.12	12.1
Total	9.26	100.0

SOURCE: World Bank, *China: The* Energy Sector(Washington, DC: 1985).

countries. Integrated steel plants in India and China currently use, on average, 45 to 53 gigajoules (GJ) per ton of crude steel produced; integrated steel plants in the United States and Japan use half as much energy.[80] Some developing countries have made significant strides to reduce energy use in steel production. The Brazilians, for example, cut energy consumption from 34 GJ to 27 GJ per ton of crude steel between 1975 and 1979,[81] and the South Korean steel industry is among the most efficient in the world.

Cement—The cement industry typically consumes 2 to 6 percent, and sometimes more, of the commercial energy used in developing countries. The use of cement is expected to increase rapidly as national infrastructures of roads, bridges, buildings, etc., are built. In general, per-capita consumption of cement increases approximately linearly with income up to several thousand dollars, and then saturates and levels off at higher incomes (see figure 3-15). Despite the energy intensity of cement production, it is one of the least energy-intensive construction materials when in its final form of concrete/aggregate (see tables 3-11 and 3-12).

The value of cement is quite low compared to its weight. Because of this and because the raw materials for cement—limestone, various clay minerals, and silica sand-are widely available, cement is usually produced relatively near its point of use. In the United States, the maximum range for truck shipments of cement is about 300 km. In developing countries, where the transport infrastructure is less well developed, economical transport distances are often less. In China, for example, 150 to 200 km is the typical limit of transport; if transport over longer distance is needed, the construction of a new cement plant in the local area will be considered.[82] Thus, as a result of inadequate transport infrastructures, cement plants are often small and relatively inefficient.

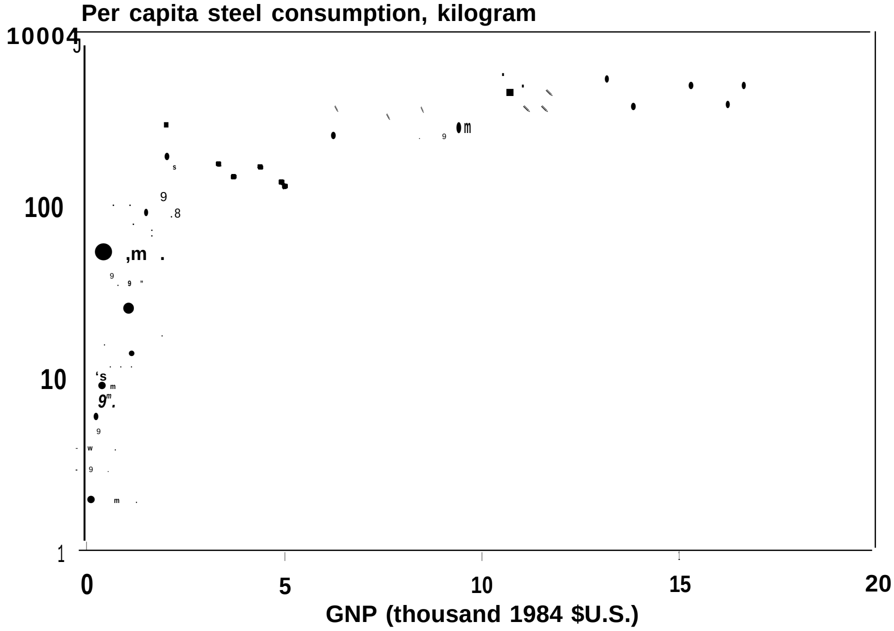
The energy required to produce cement varies widely with the type of production process, quality

[80] Maurice Y. Meunier and Oscar de Bruyn Kops, op. cit., footnote 75; Sven Eketorp, "Energy Considerations of Classical and New Iron- and Steel-Making Technology," Energy, vol. 12, No. 10/11, 1987, pp. 1153-1168.

[81] Maurice Y. Meunier and Oscar de Bruyn Kops, op. cit., footnote 75.

[82] Li Taoping, "Cement Industry in China," *Rock Products,* February 1985, p. 32.

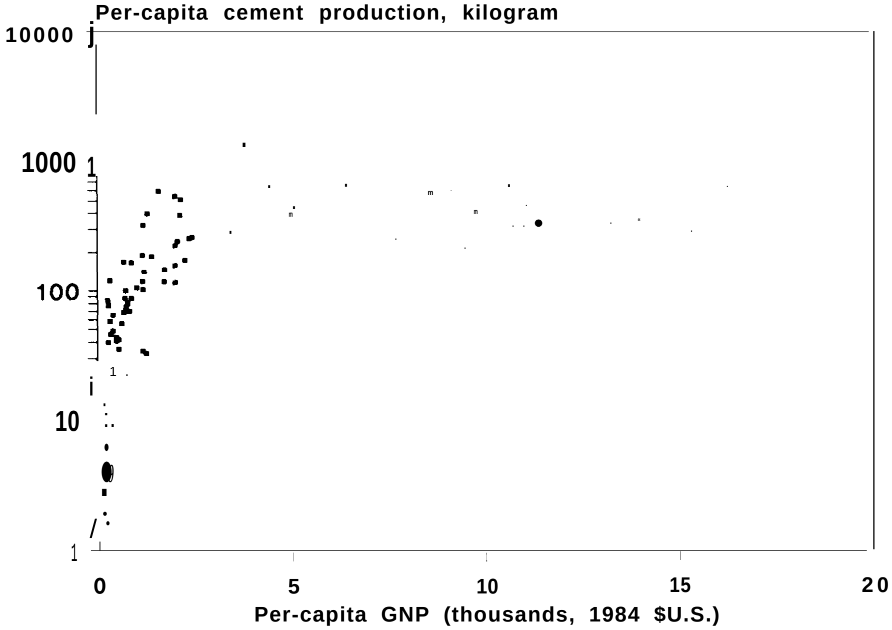
Figure 3-14-Per-Capita Steel Consumption v. GNP for Various Countries



The saturation of the steel market at higher income levels is readily seen in linear or logarithmic plots. It is shown herein a semi-log plot so as to better display both low-end and high-end data. Each data point represents a country,

SOURCE: United Nations, *Statistical Yearbook 1985/86 (New York, NY: 1988),* pp. 550-552, table 130.

Figure 3-15-Per-Capita Cement Production v. GNP for Various Countries



The saturation of the cement market at higher income levels is readily seen in linear or logarithmic plots. It is shown herein a semi-log plot so as to better display both low-end and high-end data Each data point represents a country.

SOURCE: United Nations, *Statistical Yearbook 1985/86,* (New York, NY: 1988), pp. 524-526, table 116.

Table 3-1 l—Average Energy Intensities of Building Materials (megajoules per kilogram)

Material	Energy intensity
Concrete aggregate	0.18
Concrete	0.80
Brick and tile	3.7
Cement	5.9
Plate glass	25.0
Steel	28.0

SOURCE: Mogens H. Fog and Kishore L. Nadkarni, World Bank, "Energy Efficiency and Fuel Substitution in the Cement Industry With Emphasis on Developing Countries," technical paper No. 17, 1983.

Table 3-12—Energy Intensities of End Products Using Alternative Building Materials (megajoules per square meter)

Structure	Concrete	Steel	Asphalt	Brick
Building wall	400	—	—	600
Bridge (per m_2)	4,000	8,000	—	—
Roadway (per m^2)	800	—	3,000	—

— Not applicable or not available.

SOURCE: Mogens H. Fog and Kishore L. Nadkarni, World Bank, "Energy Efficiency and Fuel Substitution in the Cement Industry With Emphasis on Developing Countries," Technical Paper No. 17, 1988.

of raw materials, plant management and operating conditions, and other factors. The performance of cement plants in developing countries also varies widely and is difficult to characterize simply. Many plants approach the efficiency of those in the industrialized countries, depending on when they were built and the conditions under which they are operated. Others show significant inefficiencies-using 25 to 50 percent more energy than efficient plants of the same type and with the same quality of raw materials input.[83]

Mechanical Drive

Traditional Drive Power

The productivity of people in many rural and poor urban areas of developing countries is now limited by their reliance on human and animal muscle power for water pumping, grain grinding, agricultural activities, transportation, and small industry. When only muscle power is available, many hours can be spent simply on "enabling" activities, such as hauling water or grinding grain, rather than on directly economically productive activities. Productive activities themselves are sharply limited by the efficiency and total output of muscle power. If the productivity of people in rural areas of developing countries is to be increased, modem motor drive technologies and supporting infrastructures must be made available at affordable costs. As these technologies are adopted, energy use-especially electricity—will increase rapidly.

A person's power output and energy efficiency are low. The basal metabolism of a person is about 100 watts; for each unit of work output, an additional 4 to 5 units of food energy must be consumed.[84] Working 8 hours a day at a rate of 50 watts of output, a person consumes about 15 megajoules (MJ) of energy and produces 1.5 MJ of work output, for a daily (24-hour) average efficiency of 10 percent.[85]

Much of the labor expended in developing countries is not directly productive, but is instead for "enabling' activities-that is, domestic chores. Hauling water from the village well can take 0.5 to 3 hours per household each day, with a corresponding energy input in the form of food of 0.3 to 3.0 MJ.[86] The poorest households must often go further and thus have less available time to haul water, resulting in much lower water usage even with greater effort (see table 3-13). Water could instead be pumped by a motor and piped to the home using just 3 to 5 percent as much energy .87 For electricity priced at $0.10 per kWh, the direct energy cost for

[83] Mogens H. Fog and Kishore L. Nadkarni, *Energy Efficiency and Fuel Substitution in the Cement Industry With Emphasis on Developing Countries* (Washington, DC: World Bank, 1983), see figure 5-1, p. 39.

[84] W. Edmundson, Energy Research Group, International Development Research Center, Ottawa, Canada, "1S There a Vicious Cycle Of Low Food Energy Intake and Low Human Output?" July 1984(Mimeo); Christopher Hurst, Energy Research Group, International Development Research Center, Ottawa, Canada, "Human and Animal Energy in Transition: The Changing Role of Metabolized Energy in Economic Development" June 19S4 (Mimeo); Roger Revelle, "EnergyUseInRural India," *Science*, vol. 192, June 4, 1976, pp. %9-975.

[85] For a countercase, see G.M.O. Maloiy et al., "Energetic Cost of CarryingLoads: Have African Women Discovered an Economic Way?" Nature, vol. 319, Feb. 20, 1986, pp. 668-669.

[86] In a study of Gujurat, India, the time required to fetch water was found to vary from 0.5 hour to more than 3 hours per day, with an energy use of 100 to 800 kcal/day. Household washing takes 4.5 to 6.3 hours per week and isas strenuous as hauling water. GirjaSharan (etI.), *Energy Use in Rural Gujurat*, op. cit., footnote 37.

[87] It is often argued tithe social interaction provided by activities such as foraging for fuelwood, hauling water, grain @.id@, and others is an important element of village life and should not be tampered with naively. One notes, however, that village women spend 10 to 12 hours per day in such activities. Surely they would not object to such social interaction while having a leisurely eup of tea instead.

Table 3-13-Average Daily Household Consumption of Water, Gujurat, India

class	Consumption (liters per day)
Landless	60
Less than 2 ha.	126
Less than 2-4 ha.	134
Less than 4-10 ha.	161
More than 10 ha.	256

SOURCE: Girja Sharan (cd.), *Energy Use in Rural Gujurat* (New Delhi: Oxford and BH Publishing Co., 1987).

the typical 1.5 hours spent hauling water would be just one-fifth of a penny ($0.002). Thus, lack of access to capital has significant impacts on labor and energy use.

Similarly, in Africa, to pound maize or millet by hand can take 1 to 2 person-hours per day per household.[88] This requires perhaps 1 MJ of energy (at 300 watts of input). A typical motor-driven mill can do the same job in a minute or less, with an energy expenditure of less than 0.2 MJ--or 0.05 kWh. This is less than one-half of a penny ($0.005) worth of direct energy (at $0.10 per kWh) for 1 to 2 hours' worth of hard labor. The capital costs in these cases, of course, are a serious barrier to investment; but with the time saved, the person might have done something more productive, such as make handicrafts for market.

The advantages of mechanical processing of grains has led to a rapid transition in many parts of the world. In Java, Indonesia, for example, the fraction of rice processed by hand dropped from perhaps 80 percent to less than 40 percent between 1971 and 1973.[89] This freed many women from the chore of grinding grain; it also cost many of the poorest households an important source of income earned by hand pounding rice for wealthier households.[90] The introduction of mechanical rice milling in Bangladesh in the early 1980's was estimated to displace an additional 100,000 or more poor women per year from their traditional part-time employment at hand pounding rice. For the poorest, landless women, this represented roughly half of their annual income and 15 percent of family income.[91]

The power output and efficiency of draft animals are similarly limited in performing typical farm tasks. A typical 500-kg ox or buffalo has a basal metabolic rate of about 1,000 watts.[92] Average net output over a 6-hour working day is typically 250 watts, and the net efficiency while working is 29 to 39 percent, which drops to about 10 percent over the 24-hour working day. A typical draft animal might work just 40 days per year as many of the jobs formerly done by draft animals-pumping water, crushing sugar cane, hauling goods to market-have already been taken over by modern motor-driven equipment. At such a low rate of usage, the efficiency of a draft animal is 2 percent or less on an annual basis. These efficiencies are raised somewhat when the value of the animal's dung, milk, meat, and leather is included.[93]

The low power output and efficiency of a draft animal severely restricts the potential work that can

[88] Prabhu Pingali, Yves Bigot, and Hans P. Binswanger, *Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa (Baltimore* and London: Johns Hopkins University Press for the WorldBank, 1987); Mead T. Cain, "The Economic Activities of Children in a Village in Bangladesh," *Population andDevelopmentReview, vol. 3, No. 3,* September 1977, pp. 201-227; A.S. Bhalla, "ChoosingTeehniques: Handpounding V. Machine-Milling of Rice: An Indian Case," *Oxford Economic Papers,* vol. 17, No. 1, March 1965, pp. 147-157; Margaret Haswell, *Energy for Subsistence* (London: MacMillan Press, Ltd., 1981).

[89] C. Peter Timmer, "Choice of Technique in Rice Milling on Java," Carl K. Eicher and John M. Staatz (eds.), *Agricultural Development in the Third World* (Baltimore, MD: Johns Hopkins University Press, 1984), pp. 278-288. See also A.S. Bhalla, "Choosing Techniques: Handpounding V. Machine-Miliing of Rice: An Indian Case," op. cit., footnote 88.

[90] William L. Collier et al., "A Comment," in Carl K. Eicher and John M. Staatz (eds.), *Agricultural Development in the Third World (Baltimore, MD:* Johns Hopkins University Press, 1984).

[91] Gloria L. Scott and Marilyn Carr, World Bank, "The Impact of Technology Choice on Rural Women in Bangladesh: Problems and Opportunities," Staff Working Paper No. 731, 1985.

[92] Peter Lawrence and Anthony Smith, "A Better Beast of Burden," *New Scientist,* Apr. 21, 1988, pp. 49-53. Oxen and buffaloes use 2 joules per meter traveled per kg of body weight (2 J/m/kg). Aanimal weighing 500 kg and walking at 1 m/s will use an extra kW, approximately doubling its resting metabolic rate. Most agricultural animals move at 0.6 to 1.1 mAnimals use more energy for carrying loads than they do for carrying their *own* weight, ranging from 2.6 to 4.2 J/m/kg. See alacA.R. Rae, "Bioenergetics of Bullock Power,"Energy, vol. 9, No. 6, 1984; N.H. Ravindranath et al., "AnIndian Village Agricultural Ecosystem—Case Study of Ungra Village. Part I. Main Observations," op. cit., footnote 5; Amulya Kumar N. Reddy, "AnIndian Village Agricultural Ecosystem—Case Study ofUngraVillage. PartII. Discussion" op. cit., footnote 5. They estimate the efficiency of an Indian bullock as 8.7 percent when working full time, or if working just 20 days per year as observed, the bullock would have an overall efficiency of 0.5 percent.

[93] N.H. Ravindranath and H.N. Chanakya, "Biomass Based Energy System fora South Indian Village," *Biomass, vol. 9, No. 3, 1986,* pp. 215-233. Draft animal efficiency is 3.5 percent, including nitrogen in manure for fertilizer. Without nitrogen, the efficiency is 2.0 percent.

Table 3-14-industrial Electricity End Use in Brazil, 1984

Industry	Percent of total industrial electricity consumption	Fraction of subsector total for each end use (percent)					
		Motor	Process heat	Direct heat	Electro-chemical	Light	Other
Nonferrous metals	20.9	32	1	35	32	1	
Iron and steel	12.4	1	—	98	—	1	—
Chemicals	11.9	79	5	4	9	3	—
Food and beverage	9.0	6	78	16	—	1	3
Paper and pulp	6.5	87	8	2		3	
Mining/pelletization	5.6	50	.	49	—	1	
Textiles	5.3	89	4	1	.	5	1
Steel alloys	4.8	7	—	92	—	1	—
Ceramics	3.9	65	—	34		1	.
Cement	2.7	91	—	6		3	1
Other	17.0	76	2	16	.	5	1
Total[a]	100.0	49	10	32	.	2	—

—Not available or not applicable.

a Total industrial electricity use was 105 terawatthours.

SOURCE: Howard S. Geller, "Electricity Conservation in Brazil: Status Report and Analysis," contractor report prepared for the Office of Technology Assessment, March 1990.

be done. To irrigate a l-hectare rice crop, for example, requires the work output of two bullocks, which in turn require the fodder produced from 2 hectares of crop.[94] By himself, the individual farmer could not, however, pump this much water by hand in an entire year.

Modern Drive Technologies

Electric motor drive consumes an estimated 58 to 68 percent of the electricity used in the United States, and an even higher percentage in the industrial sector alone.[95] Motor drive is similarly important in developing countries (see tables 3-14 and 3-15). Electric motors are the workhorses of modern industrial society. They run home refrigerators; drive office air conditioners; power industrial pumps, fans, and compressors; and keep city water supplies flowing.

The efficiency, convenience, and high degree of control of electric motors provide dramatic efficiency and productivity improvements in industry.[96] This led to a rapid transition in the industrialized countries from water- and steam-powered drive to electric drive in the early 1900's;[97] and the electricity intensity of industry continues to increase today in industrialized as well as developing countries.

The efficiency of electric motors is generally fairly high in the industrialized countries, but can be significantly lower in developing countries due to the use of lower quality materials for construction and improper techniques for maintenance, repair, and rewind.[98] Figure 3-16 compares the efficiency of electric motors in Brazil, India, and the United States.

Higher efficiency motors are sometimes readily available in developing countries but cannot be used because of the poor quality of the electric power available. In Brazil, for example, the largest manufacturer of small motors exports more efficient models than those sold at home. These high-efficiency motors[99] cannot be used in Brazil due to the excessive variation in the power line voltage.

[94] Geoffrey Barnard and Lars Kristofferson, *Agricultural Residues as Fuel in the Third World* (London: Earthscan, 1985).

[95] Samuel F. Baldwin, "Energy-Efficient Electric Motor Drive Systems," in *Electricity: Efficient End-Use and New Generation Technologies and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989).

[96] Samuel F. Baldwin, "The Materials Revolution and Energy-Efficient Electric Motor Drive Systems," *Annual Review ofEnergy,* vol. 13,1988, pp. 67-94; W.D. Devine, Jr., "Historical Perspective on Electrification in Manufacturing," S. Schurr and S. Sonenblum (eds.), *Electricity Use: Productive Efficiency and Economic Growth* (Palo Alto, CA: Electric Power Research Institute, 1986).

[97] Samuel F. Baldwin, "The Materials Revolution and Energy Efficient Motor Drive Systems," *Annual Review of Energy,* vol. 13, 1988, p. 67-94.

[98] Samuel F. Baldwin and Emile Finlay, Princeton University, Center for Energy and Environmental Studies, "Energy-Efficient Electric Motor Drive Systems: A Field Study of the Jamaican Sugar Industry," working paper, No. 94, February 1988. In particular, when motors are rewound they are sometimes simply put on an open fire to burn the insulation off the windings rather than in temperature-controlled ovens, This can damage the insulation between the core laminations and lead to greater losses.

[99] The efficiency of these motors is equivalent to the standardefficiency in the industrialized countries.

Table 3-15-Projected Electricity Consumption in India by Sector and End Use, 1990
(percent of total national electricity use)

		Industrial process				Space conditioning		Appliances		
Sector	Total[a]	Motor drive	Electrolysis	Process heat	Lighting	Cooling/ ventilation	Heating	Refrigeration	Other	Miscellaneous
Residential	13.0	—	—	—	4.2	3.5	—	1.5	1.0	2.9
Urban	10.4	—	—	—	2.9	2.9	—	1.2	1.0	2.4
Rural	2.6	—	—	—	1.3	0.5	—	0.3	—	0.5
Commercial	11.2	—	—	—	4.8	1.6	1.5	0.4	0.8	2.1
Agriculture	18.4	18.4	—	—	—	—	—	—	—	—
Industrial	54.8	33.4	10.8	5.5	5.1	—	—	—	—	—
Primary metals[b]	17.2	6.4	6.9	3.0	0.9	—	—	—	—	—
Chemicals	13.8	8.8	3.6	0.1	1.3	—	—	—	—	—
Textiles	10.2	7.8	—	0.4	2.1	—	—	—	—	—
Coal, cement	6.8	5.8	—	0.5	0.4	—	—	—	—	—
Secondary metals[c]	3.4	1.5	0.2	1.4	0.2	—	—	—	—	—
Paper	3.4	3.0	—	0.1	0.3	—	—	—	—	—
Railway traction	2.6	2.6	—	—	—	—	—	—	—	—
Total	100.0	54.4	10.8	5.5	14.5	5.1	1.5	1.9	1.8	5.0
Motor drive	61.4	54.4	—	—	—	5.1	—	1.9	—	

—Not available or nonapplicable.

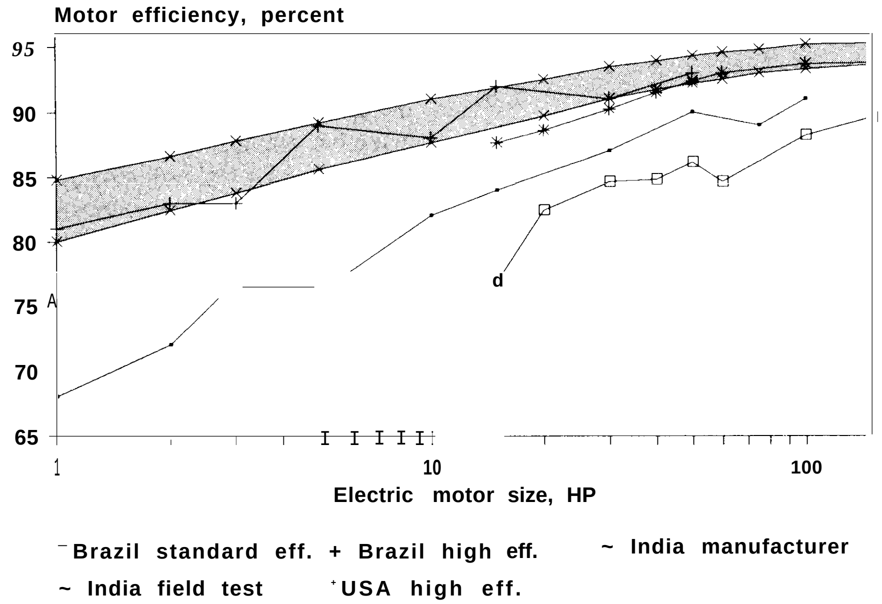
a Total national consumption is projected to be 249.1 terawatthours in 1990.

b Aluminum, nonferrous, iron, and steel.

C Iron andsteel.

SOURCE: Ahmad Faruqui, Greg Wilder, and Susan Shaffer, “Application of Demand-Side Management (DSM) To Relieve Electricity Shortages in India,” contractor report prepared for the Office of Technology Assessment, April 1990.

Figure 3-16-Efficiency of Electric Motors in the United States, Brazil, and India



This figure shows the efficiency for motors in Brazil, India, and (high-efficiency only) the United States. Note the large difference in motor efficiency as measured in field tests and as cited by manufacturers in India.

SOURCES: *United States*: John C. Andreas, *Energy-Efficient Electric Motors (New York, NY: Marcel* Dekker, 1982). *Brazil*: Howard S. Geller, "Electricity Conservation in Brazil: Status Report and Analysis," contractor report prepared for the Office of Technology Assessment, March 1990; *India*: S. Anand, and V.S. Kothari, *Characterization of Electric Motors in Industry and Energy* Conservation *Potential in India (New* Delhi, India: Tata Energy Research Institute, no date).

This firm has also developed motors with efficiencies comparable to the highest performance motors in industrialized countries.[100]

Although the efficiency of electric motors themselves can be quite high, the efficiency of the overall system is generally low. For example, the conversion of coal to electricity typically results in the loss of two-thirds of the input coal energy. There are additional losses throughout the system, with the resulting net output as low as 5 percent of the input energy (see figure 3-17). Significant energy savings are possible through the use of better technologies and better control strategies throughout the system.

Barriers to Efficiency Improvements

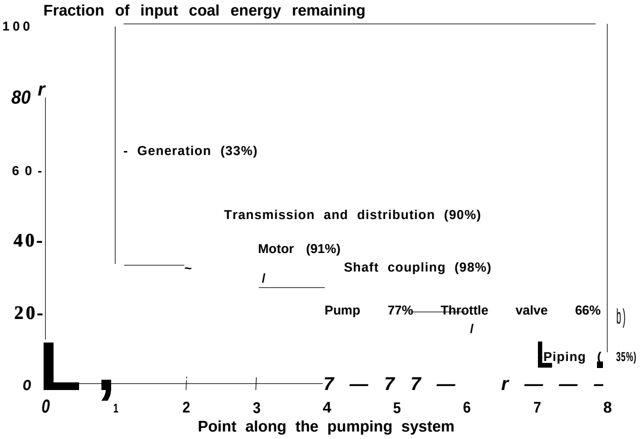
A number of factors limit the efficiency, productivity, and performance of industrial operations in developing countries: plants that are too small to be efficient; technologies that are of low quality and often obsolete; raw materials that are of low quality; inadequate national infrastructures; lack of foreign exchange to purchase critical components not available locally; and a lack of skilled technicians, engineers, and managers.

The average U.S. paper mill, for example, has an annual capacity of 100,000 tons, whereas in Latin America, Africa, and Asia (except Japan), the average capacities are 18,000,9,000, and 5,000 tons, respectively. These smaller scales can lead to significant inefficiencies. Studies indicate that a paper mill with an annual capacity of 30,000 tons can consume from 30 percent to as much as 100 percent more energy/steam respectively per unit output than a mill with a capacity of 150,000 tons.[101] In addition, a variety of energy-conserving technologies, such as waste heat recovery systems and

[100] Howard S. Geller, "Electricity Conservation in Brazil: Status Report and Analysis,'' contractor report prepared for the Office of Technology Assessment, March 1990.

[101] Andrew J, Ewing, "Energy Efficiency in the Pulp and Paper Industry with Emphasis on Developing Countries," World Bank technical paper, No. 34, Washington, DC, 1985, p. 45.

Figure 3-17—Energy Losses in an Example Electric Motor-Driven Pumping System in the United States



This figure shows the useful energy remaining at each stage of a pumping system. The values in parentheses are the efficiencies of the particular device at each stage.

SOURCE: Samuel F. Baldwin, *Energy-Efficient Electric Motor Drive Systems*, in Electricity: *Efficient* End-Use and New *Generation Technologies and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989).

cogeneration systems, become financially less attractive or even uneconomical at smaller scales.

The raw materials available to industries in developing countries are often of low quality. For example, coal resources in India are poor, providing blast-furnace coke with an ash content that typically ranges from 21 to 27 percent. This lowers the energy efficiency of the steelmaking process as well as potentially interfering with steel production.[102]

Inadequate national infrastructures also reduce efficiency and productivity. Frequent electric power brownouts or blackouts are particularly damaging. In Ghana, for example, the GIHOC Brick and Tile Co. had 152 hours of electricity outages in 1986. When an outage occurs, the fuel oil feed to the kiln burners is cut off and the fire must be stoked with wood. This is a haphazard process and significantly reduces the quality of the fried bricks.[103]

The lack of foreign exchange to buy spare parts can also be a serious handicap. This has been an important factor in the decline of the Tanzanian cement industry, which operated at just 22 percent of rated capacity in 1984.[104]

Assistance may be useful at several levels. The efficiency and productivity of traditional rural industries might be significantly increased in a cost-effective reamer with the introduction of a limited set of modern technologies and management tools. To do this, however, is extremely difficult due to the small and scattered nature of traditional rural industries and the large extension effort needed to reach it. Large industry in developing countries has many of the same needs-technical, managerial, and financial assistance--but can be reached more readily. International aid agencies and a few nongovernmental organizations are providing such assistance to the extent that their funds allow.

Dramatic improvements in the energy efficiency and productivity of basic materials processing technologies are also still possible-even beyond the levels currently achieved in the industrialized countries. Research is going on in this area, but much more could be done. Much of the current research is focused on higher value-added specialty materials and high-grade finishing rather than on primary processing.[105] Developing countries, however, have little capital to undertake the research needed to improve their industrial processes, and few international agencies support research of this kind.

The Traction (Agricultural) and Transportation Sectors

Traction and Agriculture

Agriculture entails a series of operations: soil preparation, sowing, weeding, harvesting, and post-harvest storage. In traditional agriculture, these operations are performed by manual labor with, in some cases, assistance from animals. As agriculture increases in scale and is commercialized, many of these operations are done by machines.

Agriculture is by far the largest employer and goods-producing economic sector in the poorer developing countries. In sub-Saharan Africa, for example, 75 percent of the work force is engaged in

[102] Energy and Environmental Analysis, Inc., "Conserving Process Heat in Primary Industries of India and China," contractor report prepared for the Office of Technology Assessment, April 1990.

[103] UNDP/World Bank Energy Sector Management Assistance Program, "Ghana: Energy Rationalization in the Industrial Sector," June 1988.

[104] D.F. Stewart, and B. Muhegi, "Strategies for Meeting Tanzania's Future Cement Needs," *Natural Resources Forum*, November 1989, pp. 294-302.

[105] Robert H. Williams, Princeton *University, personal communication* Feb. 1, 1989.

agriculture, compared to just 2 percent in the United States. Agriculture also provides a significant fraction of GDP in developing countries--one-third of GDP for the nearly 3 billion people in low-income countries[106] (see table 3-16).

Agriculture in the lowest income countries is largely by small, family farms using human and animal power and organic fertilizer with little access to or knowledge of modern inputs such as chemical fertilizers, hybrid seeds, or mechanical drive. Ethiopians, for example, use on average just 4 kg of chemical fertilizer per hectare of cropland, while the English use 368 (see table 3-16). Low soil fertility and inadequate or irregular rainfall sharply limit the productivity of low-input farms in developing countries.

There is a general trend toward larger farms, greater mechanization, and greater use of commercial inputs in many developing countries, resulting in greater productivity but at the cost of greater direct and indirect energy inputs. India, for example, nearly doubled its irrigated area between 1950 and 1984 in order to reduce its vulnerability to poor monsoons.[107] Increased irrigation and use of high-yield variety crops have contributed to increases in both absolute and per-capita agricultural production.[108]

China has similarly moved toward greater mechanization and use of modern inputs. Agriculture in China is sharply constrained by land availability—only about 10 percent of the land can support crops-yet per-capita production increased by 18 percent from 1979 to 1983 with little increase in cultivated area.[109] Improved water control and distribution, increased use of tractors and fertilizers, and the adoption of new crop varieties contributed to this achievement.[110]

Traditional Shifting Agriculture

Traditional shifting agriculture begins with forest-fallow systems, in which plots of forest land are cleared and cultivated for a few years and then left fallow for 20 years or more. Clearing by fire requires little labor, and stumps are left for rapid regrowth during fallow. Because the ground underneath tree cover is soft, no further labor is required before sowing, and because the forest cover has long suppressed weeds, few seeds remain and little weeding is needed. Such burning does, however, effectively lead to very large agricultural energy intensities due to the large amount of forest cover that is burned off.[111]

With increasing population density, the fallow period becomes shorter. As a result, regrowth during the fallow period is reduced to bush, and finally to grass. Since fire does not kill roots, extensive hoeing and weeding become necessary. Inputs of organic fertilizer are needed to maintain soil fertility, and there is a shift from simple addition of organic material to more complex comporting and manuring techniques. Further increases in population lead to annual cultivation and eventually multiple cropping. (In the humid tropics, however, soils tend to be poor and easily eroded and leached, and the potential for continuous cultivation is limited.[112]) As the need for hoeing and weeding increases it becomes advantageous to go to the extra effort of destumping the land and obtaining, training, and maintaining animals or mechanical agricultural technology.[113]

There are a number of potential advantages associated with the use of animal or mechanical traction for agriculture. Properly done, tillage improves the condition of the soil for crop growth—increasing porosity, aeration, root penetration, and water infiltration while reducing evaporation. Ex-

[106] World Bank, *World Development Report 1990* (New York, NY: Oxford University Press, 1990).

[107] Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook (TEDDY) 1988*, *Op. Cit.*, footnote 56, P. 128.

[108] Food and Agriculture Organization of the United Nations, "The State of Food and Agriculture, 1984," Rome, Italy, 1985, p. 137.

[109] Ibid.

[110] C. Howe, China's *Economy (New York, NY:* Basic Books, Inc., 1978).

[111] A. Terry Rambo, "Why *Shifting* Cultivators Keep Shifting: Understanding Farmer Decision-Making in Traditional Agroforestry Systems," Community *Forestry: Some Aspects,* UNDP THA/81/004 (Bangkok, Thailand: Environment and Policy Institute, East-West Center, Honolulu, and UNFAO Regional Office for Asia and the Pacific, 1984).

[112] Prabhu Pingali, Yves Bigot and Hans P. Binswanger, *Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa,* op. cit., footnote 88.

[113] Prabhu Pingali et& ibid. The exact transition point from hand to animal and then tractor technology will, of course, depend on numero us factors, including how difficult the soil is to work; the value of milk, me@ hides, and other services provided by cattle; the use of manure; the cost of training and maintaining animals; the cost of destumping and otherwise preparing fields and weeding; the length of time that animals can be used; the risk of disease such as trypanosomiasis (transmitted by the tsetse fly); and many others.

Table 3-16--Agricultural Indicators for Selected Countries

Country	GNP/Cap (1987)	Agricultural GDP as percent of total GDP	Agricultural employment as percent of total employment	Percent of farms larger than 5 ha	Fertilizer (kg/ha)	Crop yields (kg/ha)	
						Cereal	Roots/tubers
Ethiopia	130	45	—	4	4	1,081	2,827
Zambia	250	13	—	—	14	1,747	3,687
India	300	30	61	9	43	1,590	14,268
China	290	26	57	—	176	3,891	15,614
Brazil	2,020	10	36	63	35	1,719	12,072
UK ...0	10,420	2	2	83	368	6,081	36,072
U.S.A.	18,530	2	2	90	101	4,618	31,215

— Not available or not applicable.

SOURCES: World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 19S9).
Food and *Agriculture* Organization of the United Nations, *The State of Food and Agriculture 1984* (Rome: FAO, 1965), pp. 163-165, 17S-160.
Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook 1988* (New Delhi, India: Tata Energy Research Institute, 1969), p. 123.
World Resources Institute, *World Resources 1988-89* (New York, *NY: Oxford* University Press, 19S6), pp. 272-277.

Box 3-A—The One-Ox Plow[1]

Many farmers in developing countries are unable to support the two draft animals needed to pull a traditional plow. Although half of the households in Bangladesh keep cattle, only a quarter have two or more. In Ethiopia, only a third of the farmers own two draft animals-and many of these are lost in the periodic droughts. At peak cultivation times, these farmers must then rent or borrow a second animal and maybe delayed in planting their crops, which depend critically on catching the sparse and irregular rains in a timely manner-both for making maximum use of the nitrogen released with the first rains (see ch. 2) and for reaching maturity with the last rains.

Researchers at the International Livestock Center for Africa (ILCA) in Addis Ababa, Ethiopia, responded to this situation by redesigning the traditional double yoke for a single ox: experiments showed that one ox could pull with 70 percent of the force of two.

In the field, however, Ethiopian farmers quickly converted the one-ox plows back into the traditional two-ox form. On examination, researchers found that the traditional two-ox form had a number of advantages. Farm oxen were not as well fed nor as strong as those which had been tested at the ILCA headquarters and could not pull as hard; and two oxen were able to steady each other when one stumbled. The rigid coupling of the traditional two-ox plow also enabled the farmer to steer the oxen and to shift some of the weight of the plow to the oxen during a turn. In contrast, the single ox yoke used a flexible rope harness which reduced the farmer's ability to steer the animals and forced him to carry the full weight of the plow when turning. The one ox plow also had a skid to regulate the depth of the cut: it broke easily but could not be repaired by the farmers themselves.

Further, where the quality of the feed is very poor-a common situation in many tropical areas-working animals are unable to compensate for their energy expenditure by eating more and consequently lose weight. A working animal also has a 10 percent higher basal metabolic rate than a nonworking animal-requiring more food just for maintenance. In this case, it may be better to use two oxen to do "what little they can without losing too much weight rather than to have one ox which soon becomes exhausted beyond recovery. "

As one researcher at the ILCA noted, "It might have occurred to us that if Ethiopian farmers hadn't invented something as simple as the one-ox plow in 3,000 years of agriculture, they probably had reasons. "

Some have similarly thought that the same animal might be used to provide both labor and milk. Experiments in Costa Rica showed that cows could, in fact, provide both—if fed adequately. Tropical pastures, however, are not adequate. To provide the animal a sufficient diet for such a high rate of energy expenditure required concentrated feed supplements such as grain. This could create a direct conflict over food between draft cows and people in many parts of the world.

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[1]Debora MacKenzie, ''Ethiopia's Hand to the Plough,'' New Scientist, Oct. 1, 1987, pp. 52-55; Peter Lawrence and Anthony Smith, "A Better Beast of Burden,'' New Scientist, Apr. 21,1988, pp. 49-53; A.K.M.Abdul Quader and K. Ikhtyar Omar, Commonwealth Science Council, "Resources and Energy Potentials in Rural Bangladesh,'' technical publication series No. 191, London, 1986.

periments show that yields can be increased by plowing.[114] In practice, however, little increase is observed as farmers tend instead to focus on increasing cultivated area[115] or on saving labor, rather than improving the quality of their tillage. In West Africa, the soils are so hard they often cannot be plowed (without damage to equipment) until the rains begin, but then any delay reduces the available growing time and risks a shortage of water when plants reach maturity.[116]

Peasant farmers have responded to their often difficult circumstances in varied ways—both logical (see box 3-A) and frequently ingenious. For example, around 1925-1930, animal traction began to be used in northwestern and central Senegal and northern Nigeria for peanut cultivation. The light, sandy soils of Senegal do not require plowing, and as the growing season is so short, rapid planting of peanuts while the soil is moist is essential. Consequently, seeders are used by the peasants so that larger areas can be cultivated within the available

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[114]Prabhu Pingali, Yves *Bigot,* and Hans P. Binswanger, *Agricultural Mechanization and the Evolution of Farming systems in Sub-Saharan Africa,* op. cit., footnote 88; Peter Munzinger, *Animal Traction in Africa* (Eschborn, West Germany: GTZ, 1987), p. 279.

[115]In Senegal the average expansion of agricultural area by the introduction of draft animals to smallholders is 100 to 160 percent; in Mali the average expansion is 150 to 200 percent. Peter Munzinger, *Animal Traction in Africa,* op. cit, footnote 114, p. 287.

[116]Prabhu Pingali et al., op. Cit., footnote 88.

time. Horses are used instead of oxen, since the greater power of oxen is not needed (there is no plowing) and horses are faster, further increasing the planted area. In Nigeria, where peanuts are grown in mid-slope regions on soils highly susceptible to erosion, ox-drawn ridgers are used to control the erosion.[117]

Modern Commercial Agriculture

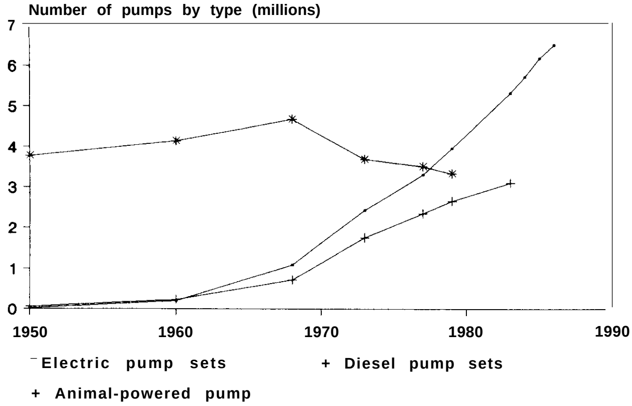
As population grows agricultural productivities must be raised. Modern inputs are needed to achieve this. Commercial fuel inputs to agriculture include mechanized land preparation, mechanized irrigation, and synthetic fertilizers.[118]

The degree of mechanization varies widely, but generally increases with per-capita income. Mechanization reduces the time and labor needed for preparing, planting, and harvesting crops. In favorable areas, it also aids double cropping. The tractors themselves come in many forms—in China the most popular is probably the "Worker-Peasant," a 7-hp garden tractor. In India, where the number of tractors almost doubled from 1972 to 1977,[119] the most popular is a 30-hp diesel.

Irrigation is most commonly done with either electric motor or diesel driven pumps. Electric pumps are quite reliable (although subject to interruptions in the electric power grid) and convenient, and are often the lowest cost alternative. Diesel-electric pumping systems, in which diesel generators produce electricity that is then used to drive electric pumps, and direct diesel and gasoline-powered pumps are more often used where no electric grid is available. These are much less mechanically dependable than electric pumps.

In China, irrigation is a significant consumer of electricity. It is estimated that 70 percent of the electricity consumed in rural areas is for irrigation, with the remainder used for food processing, various rural industries, and lighting.[120] In India, the number of electric pump sets for irrigation has grown rapidly (see figure 3-18), and the electricity consumption for these pump sets has gone from 4,470 GWh in 1970-71 to 23,420 GWh in 1985-86. The number of diesel pump sets has also grown, but they still are fewer in number than the electric units.[121]

Figure 3-18-Use of Agricultural Pumpsets in India, 1950-1990



SOURCE: Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook (TE/2DYjl 7988 (New* Delhi, India: 1989), footnote 56.

Transportation

The transportation sector accounts for a quarter or more of total commercial energy use in most developing countries-India and China being the most notable exceptions (see table 3-l). Most of this transport energy is from oil. Energy use for transportation in the developing world is expected to grow rapidly in the future, as increasing urbanization and incomes (see figure 3-19) lead to increased demand for transportation services. This will increase the outflow of scarce foreign exchange for the oil-importing countries, and will also require considerable investment in roads and related infrastructure.

Transportation can be provided by air, rail, road, or water. Inmost of the developing world, as well as in the industrialized world, road technologies provide most transport services. Notable exceptions are India and China, which have large rail networks.

In rural and poor areas of the developing world, walking is the principal transport "technology." The advantages of walking are many-it requires no capital investment, it is not restricted to roads, and

[117] Ibid.

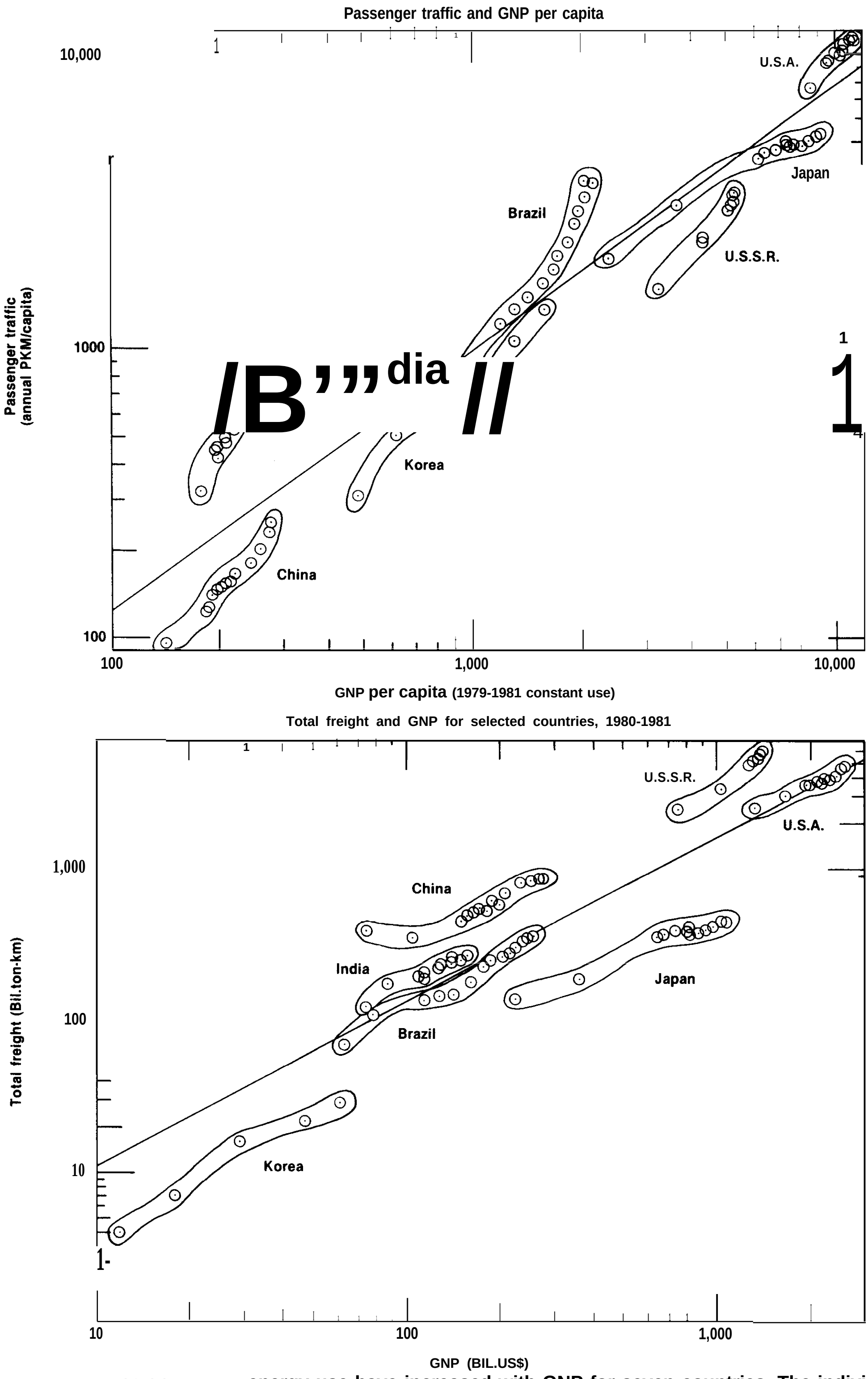
[118] This excludes energy used for fertilizer production and that used for crop preparation both of which we include under industrial energy use.

[119] Tata Energy Research Institute, *TEDDY 1988,* op. cit., footnote 56, p. 137.

[120] C. Howe, *China's Economy,* op. cit., footnote 110, p. 88.

[121] In 1983/84, for example, there were about 5.3 million electric pump sets and 3.1 million diesel pump sets in India. Some Of these diesel units were used as backups for the electric units. Tata Energy Research Institute, *TEDDY 1988*, op. cit., footnote 56, p. 135.

Figure 3-19-Passenger and Freight Transport v. GNP for Selected Countries, 1960-81



This figure shows how passenger and freight transport energy use have increased with GNP for seven countries. The individual data points are for specific years.

SOURCE: J. Venny and L. Uy, "Transport in China," World Bank staff working paper, No. 723, Washington, DC, 1985.

it requires no fossil fuels. On the other hand, it is slow, tiring, and requires energy in the form of food. Animal technologies, such as bullock carts, are sometimes faster, have a much greater freight capacity, and involve less work for people. Capital investment in the bullock and cart is required, however, as well as an operational cost for feed. These two technologies-walking and domesticated animals-are the principal means of transport in many poorer and rural areas, particularly in Africa and Asia.

Bicycles are a popular transport technology, especially in China, where from 50 to 90 percent of urban vehicle trips are made by this mode.[122] The frost cost of a bicycle can be a barrier-a new bike costs the equivalent of 7 to 8 months' wages in Tanzania, for example-but in some areas bicycles can be bought on credit. In India, government employees are entitled to loans for vehicle purchase, which can be used to buy a bicycle. Bicycles work well in congested urban areas, where they have some advantages over private automobiles-they are easier to park and store, less expensive to own and operate, and do not contribute to air pollution. Their range and freight capacity, however, are limited.

The technological leap to the internal combustion engine allows for much higher speeds, longer distances, larger freight capacity, and greater comfort. The disadvantages of the internal combustion engine are technological complexity, movement largely constrained to roads, high first cost and operating cost, and environmental damage due to fossil fuel burning. There are also secondary effects, such as injury and death due to accidents and land use for roads and parking. Despite its disadvantages, the internal combustion engine is the dominant transport technology in the industrialized and developing world, and its use is growing rapidly.

Passenger Road Transport Technologies

Mechanized passenger road transport in the developing world is performed by a wide range of technologies, including mopeds, private autos, and buses. Developing countries have only about 1 percent as many autos per personas does the United States (see table 3-17), but their automobile fleets are growing rapidly. Further, the scrappage rate (the fraction of vehicles retired each year) is very low in developing countries, due to the high value placed on any vehicle that runs. Therefore, choices made now as to the energy efficiency of new vehicles in developing countries are doubly important-these vehicles will soon be the majority of the fleet and they will be on the road a long time.

Table 3-17—Passenger Fleet Size and Growth in Selected Countries

Country	Automobiles per 1,000 people, 1986	Average annual growth in automobile fleet size, 1982-86
China	0.7	41.6
India	1.8	8.2
Kenya	8.9	3.2
Thailand	21.9	8.8
Brazil	87.0	8.9
Japan	234.0	3.0
West Germany	444.8	3.3
United States	673.4	2.4

SOURCES: Fleet size and growth from Energy and Environmental Analysis, Inc., "Policy Options for Improving Transportation Energy Efficiency in Developing Countries," contractor report prepared for the Office of Technology Assessment, March 1990. Population from World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989). Figures for the United States include both autos and light trucks; data are from Oak Ridge National Laboratory, *Transportation Energy Data Book*, Edition 10, ORNL-6565 (Oak Ridge, TN: Oak Ridge National Laboratory, September 1989).

Although their technical efficiency (vehicle kilometers traveled per liter of fuel consumed) is lower, vehicles in developing countries average a much higher load factor (persons per vehicle) than those in industrialized countries. Buses are chronically overloaded, and mopeds and motorcycles designed for one often carry two or more. Shared ride technologies, such as jitneys, are commonly filled beyond rated capacity. This increases the efficiency of the transportation system i-n terms of passenger-kilometers per liter of fuel consumed, but reduces safety and comfort.

The vehicles themselves are often less energy-efficient than those found in the industrialized world. They are often based on designs that emphasize sturdiness and dependability under adverse conditions (poor roads, chronic overloading, little maintenance) over energy efficiency.

Freight Road Transport Technologies

Road freight movement in the developing world is provided mostly by diesel trucks (with the exception of China where much of the truck fleet uses gasoline) and these trucks account for over half

122 World Bank, "Gridlock Weary, Some Turn to Pedal power," *The Urban Edge*, vol. 14, No. 2, March 1990.

Table 3-18-Energy Efficiency of Trucks in Selected Countries

Country/ region	Truck name	Capacity (metric tons)	Energy consumption (megajoules per metric ton per kilometer)
OECD	Mercedes Benz 1217 (1979)	7.0	1.0
OECD	Man-VW 9136 (1980)	5.9	1.0
India	TATA 1201 SE/42	5.0	2.1
India	Ashok Leyland Beaver	7.5	1.6
China	Jiefang CA-10B	4.0	2.3
China	Dongfeng EQ140	5.0	1.8

NOTE: OECD and Indian trucks use diesel, Chinese trucks use gasoline.

SOURCE: J. Yenny and L. Uy, World Bank, "Transport in China," staff working paper No. 723, 19S5, p. 70.

the energy used for road transport in the developing world.[123] The movement of height is required for most economic activity, and in many developing countries the prices of diesel fuel are kept lower than gasoline prices. In the United States, for example, gasoline and diesel prices at the pump are almost the same, while in India diesel is slightly less than half the price of gasoline.[124]

Trucks in the developing world are relatively inefficient, requiring 1.5 to 2.5 times as much energy to move one ton of freight one kilometer as comparable trucks in the OECD countries (see table 3-18). In developing countries, however, trucks must cope with more difficult operating conditions: the roads are typically congested and poorly maintained, aggravating technical inefficiency and accelerating wear.

Rail Technologies

Railroads are significant providers of transport services only in India and China, and in these two countries the rail share of total transport is declining rapidly due to the much faster growth of road transport. In China, for example, the share of passenger traffic using railways dropped from 69 percent in 1965 to 48 percent in 1987. Railway freight transport shows the same trend of decreasing relative use.[125] Similarly, India shows a mode shift toward roads and away from rail for both passenger and freight traffic.[126]

Despite these modal shifts, the rail systems in both countries still account for significant energy use. China and India have extensive rail networks that consume, respectively, 72 percent and 29 percent of transportation energy (see app. 3-A). The Indian rail system, although in relative decline, still carries a significant amount of freight and passengers (see table 3-19), using a mix of steam (being phased out), diesel, and electric locomotives.

Implications for Energy Demand

Road transport-private autos for passengers and trucks for freight--has become the dominant mode of transportation in developing countries. Increases in population, income, and auto ownership rates (autos per person) combine to yield a rapid increase in the number of private vehicles. Increasing urbanization leads to greater congestion, which reduces the efficiency of private vehicles. Urbanization, economic growth, and industrialization require large increases in freight movement, as producers move farther from markets. The net effect of these factors will be an increase in the energy needed to provide transportation services.

Improvements in the energy efficiency of developing world transport systems can be made in several areas. Road-going vehicles in the developing world are less energy-efficient than comparable vehicles in the industrialized world, suggesting that efficiency gains can be made in the vehicles

123 Trucks account for 50 to 75 percent of energy consumed for road transport in the developing world, compared to 30 to 35 percent for many industrialized countries. Clell G. Harrsl, "Meeting the Transportation Aspirations of Developing Countries: Energy and Environmental Effects," *Proceedings of the Energy and Environment in the 21st Century Conference* (Cambri'dge, MA: Massachusetts Institute of Technology, March 1990).

124 Energy Information Administration, *International Energy Annual 1988*, DOE/EIA-0219(88) (Washington, DC: U.S. Government Printing Office, 1989).

125 P. Kuirun and S. Guojie, "Overview of Transport Development in China," paper presented at the New Energy Technologies Transportation and Development Workshop, Ottawa, Canada, September 1989.

126 Joy Dunkerley, Irving Hoch, Charu Gadhok, Kapil Thukral, "Energy and Transport—The Indian Experience,' *Pacific and Asian Journal ofEnergy, 1987, pp. 1-12.*

Table 3-19-Comparison of Rail Systems in China, India, and the United States

	China	India	United States
Length of rail network (km)	53,000	62,000	235,000
Rail energy use (percent of total transport energy use)	51	27	3
Percent of freight traffic carried by rail	45'	47	30
Percent of passenger traffic carried by H-l	55	22	1

SOURCES: P. Kuirun and S. Guojie, "Overview of Transport Development in China," paper presented at the New Energy Technologies Transportation and Development Workshop, Ottawa, Canada, September 1989; Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook (TEDDY) 1988* (New Delhi, India: 1989); International Energy Agency, *World Energy Statistics and Balances:* 198 f-87 (Paris: OECD, 1989); Oak Ridge National Laboratory, *Transportation Energy Data Book: E&ion 10,* ORNL-6565, 1989; Association of American Railroads, *Railroad Facts 7989* (Washington, DC: American Association of Railroads, 1990).

themselves. Improvements in the transportation infrastructure, such as improved roads and reduced congestion, can also increase energy efficiency. Mode choices, such as a movement away from private autos and motorcycles to buses and bicycles, can help. Of course, all these options have benefits and costs: these will be explored later in this OTA study. The important conclusions for this section, however, are that the demand for transportation services is increasing rapidly, technologies in use today are not as efficient as they could be, and the energy impacts of technology choices made today will be felt far into the future.

Conclusion

This survey of energy services and how they are provided in developing countries reveals three common characteristics. First, each service is provided by a wide range of technologies and fuels. Cooking is provided by technologies ranging from open frees to microwave ovens, with a large number of possibilities in between. The range of passenger transport services is similarly wide, varying from foot to jet passenger airplanes. Second, there is in almost all cases a well-established transition between technologies, depending on two main factors--income and availability of fuel supplies. Third, the services are currently being provided by technologies whose efficiency could usually be significantly improved.

The following chapter will examine how the many types of energy used in developing countries—fossil fuels, electricity, and biomass fuels--are provided, including domestic production, imported supplies, the energy distribution system, and the energy conversion sector.

Appendix 3-A—Energy Balances for Selected Developing Countries

The following energy balances begin with International Energy Agency (IEA)[127] energy production, trade, and stock change totals for commercial fuels. This provides a common framework for evaluating individual countries and for comparing different countries. Biomass fuels for the traditional sector are not included in the country-specific IEA data and so are separately added based on country specific field survey data. The year chosen for each country is determined primarily by the year for which the biomass energy data is available.

In contrast to the IEA procedure, energy supply production, conversion, and transformation losses are not separately tallied in the energy balances presented here. Instead, these losses are carried forward into the sectoral breakdowns in proportion to the IEA sectoral breakdown of energy use. This more accurately indicates sectoral energy usage by showing the losses incurred in providing energy to each sector.

Electricity is initially divided into two categories in the following energy balances: nonthermal and thermal. Nonthermal electricity is given in terms of the electric power output--the joule equivalent of kWh. Thermal electricity is given in terms of thermal energy input; losses incurred in generation, transmission, and distribution are kept in the total. Nonthermal and thermal electricity quantities, therefore, can not be directly compared.

The IEA convention for electricity production divides the hydroelectric output in kWh by 0.385 in order to make hydroelectric power appear to be on the same “thermal equivalent” input basis as thermally generated electricity when listed on the basis of fossil fuel input. The IEA subsequently multiplies the sum of hydroelectric “thermal equivalent” and thermal electric inputs by 0.385 to get an electric power output in kWh. Thermal and hydroelectric “thermal equivalent” losses are lumped together as an energy production loss.

This convention of “thermal equivalents” leads to a large misrepresentation in the energy balances for hydro-rich countries such as Brazil. The procedure used here avoids the IEA convention of assigning a thermal equivalent for hydroelectric or other nonthermal power. It also carries the losses in thermal generating plants through to the end-use sectors as noted above. At the sectoral level, the thermal and nonthermal electricity are added together directly to indicate the average amount of energy, including fossil fuel, used by each sector. These figures are shown in brackets to denote that the figure is a sum of nonthermal electricity output and thermal energy input. This procedure lowers the energy supply totals compared to those usually found in the literature.

Percentage breakdowns by end-use sector are based on the IEA data; percentage breakdowns by energy service within end-use sectors are based on country-specific surveys as noted. The end service breakdowns are the best estimates that OTA could make given the poor quality and paucity of available data These breakdowns are provided here only as an indication of the relative importance of selected energy services; they should not be construed to be a precise quantitative measure of the energy consumed in delivering these services or to be a precise listing of energy services and their interrelationships. Some important energy services and fuel mixes are overlooked in many of the available energy service breakdowns. For example, lighting and the use of traditional fuels are largely left out of the industrial sector. In addition, a number of important energy services are generally left out of the breakdowns: an example might be the use of animals for traction in agriculture and the use of crop residues to feed them.

[127] International Energy Agency, *World Energy Statistics and Balances: 1971-87* (Paris: OECD, 1989).

Table 3A-l—Brazil: Energy Supplies and Services, 1987 Exajoules (10^{18} Joules= 0.9478 Quad) and Percent of National Total

	Fossil fuels			Eleotricity		Biomass			
Energy supplies	coal	Oil	Gas	Nonthermal	Thermal	Cane/ alcohol’	Wood/ Charcoal	Other	Total
Production	0.124	1.55	0.112	0.681	—	0.91	1.39	0.13	4.90
Trade/stock change	0.315	1.040	—	0.023	—	—	—	-0.01	1.37
Electric generation	-0.044	-0.073	—	—	0.117	—	—	—	0.00
Nonenergy	—	-0.167	—	—		-0.02	—	—	-0.19
Total energy	0.40	2.349	0.112	(0.821)		0.89	1.39	0.12	6.08
Percent of total	6.6%	38.6%	1.8%	.		14.6%	22.9%	2.0%	100’YO
Energy services									
Residential	—	0.202	0.007	(0.169)		—	0.48	—	0.86
Residential	—	3.3%	0.1%	2.8%		—	7.9%	—	14.1%
Cooking/heating		3.3%	O.1%	0.77%[3]		—	7.9%	—	1 2.1%
Lighting	—	—	—	0.67%		—	—	—	0.7%
Refrigeration	—	—	—	0.90%		—	—	—	0.9%
Television	—	—	—	0.1 7%		—	—	—	0.2%
Air conditioning	—	—	—	0.09%		—	—	—	0.170
Other	—	—	—	0.21 %		—	—	—	0.2%
Commercial[c]	—	0.026	0.003	(0.159)		—	0.018	—	0.21
Commercial	—	0.42%	0.05%	2.62%		—	0.3%	—	3.5%
Cooking/heating		0.42%	0.05%	0.20%		—	0.3%	—	1 .0%
Lighting	—	—	—	1.1570		—	—	—	1.270
Refrigeration	—	—	—	0.45%		—	—	.	0.5%
Air conditioning		—	—	0.52%		—	—	.	0.5%
Other		—	—	0.29%		—	—	—	0.3%
Industrial	0.40	0.56	0.10	(0.46)		0.44	0.75	—	2.71
Industrial	6.58%	9.22%	1.65%	7.57%		7.24%	12.3%	—	44.6%
Motor drive	—	—	.	3.7170		.	—	—	3.7%
Process heat	6.5%	9.22%	1.65%	3. 18%		7.24%	12.3%	—	40.2%
Lighting	—	—	—	o.15?40		—	—	—	0.2%
Electrochemical		—	—	0.53%		—	—	—	0.5%
Transport	0.00	1.417	—	(0.005)		0.44	—	.	1.86
Transport	(0*	23.3%	—	0.08%		7.24%	—	—	30.6%
Road	—	20.4%	—	—		7.24%	—	—	27.6%
Rail	°	0.43%	—	0.08%		—	—	—	0.5%
Air	—	1.74%	—	—		—	—	—	1 .7%
Other	—	0.77%	—	—		—	—	—	0.8%
Agriculture	—	0.146	—	0.026		—	0.126	—	0.30
Agriculture	—	2.4%	—	0.43%		—	2.1 %	—	4.9%

—Not available or not applicable.

() data in parentheses is sum of nonthermal energy output and thermal energy input.

a The use of bagasse for energy production(cogeneration)isdivided proportionately betweenindustrialp process heat and road transport. Electricity generation within the cane industry is not given separately.

b This is mostly for water heating(10 TWh). Only O.5 TWh were for cooking.

[c]Excludes public buildings.

SOURCES: Adapted from international Energy Agency,*World Energy Statistics and Balances:* 1971 -87 (Paris: OECD, 1989); and Brazilian Ministry of Mines and Energy, *National Energy Balance for Brazil 1988* (Brasilia, 1988), provided by Howard S. Geller, American Council for an Energy Efficient Economy, Washington, DC, and Sao Paulo, personal communication, Mar. 8,1990.

Table 3A-2-China: Energy Supplies and Services, 1987 Exajoules (10^{18} Joules = 0.9478 Quad) and Percent of National Total

	Fossil fuels			Electricity		Biomass fuels				
Energy supplies	coal	Oil	Gas	Nonthermal	Thermal	Crop	Wood	Dung	Biogas	Total
Production	18.15	5.32	0.46	0.33	—	3.4	3.2	0.15	0.03	31.0
Trade/stock change	-0.80	-1.40	—	—	0.00	—	—	—	—	-2.2
Electric generation	-3.15	-0.59	-0.02	—	3.76		—	—	—	
Nonenergy	—	-0.15	—	—		—	—	—	—	-0.15
Total energy	14.20	3.18	0.44	(4.10)		3.4	3.2	0.15	0.03	28.7
percent of total	49.5%	11.170	1.570	14.3%		11.870	1 1.2%	0.5%	0.1%	100%
Energy services										
Residential	5.23	0.12	0.07	(0.27)		3.3	3.2	0.15	0.03	12.4
Residential	18.2%	0.4%	0.2%	0.94%		11 .5%	1 1.2%	0.5%	0.1%	43.%
Cooking	8.7%	—	0.2%	—		11.5%	10.5%	0.4%	0.1%	31 .4%
Space heating	9.5%	—	—	—		—	0.7%	0.1%	—	10.3%
Lighting	—	0.4%		0.94%			.	—	—	1.370
Commercial/public	0.31	0.27	0.00	(0.19)			—	—	—	0.77
Commercial/public	1.1%	0.9%	—	0.66%		—	—	—	—	2.7%
Industrial	9.41	1.77	0.37	(3.06)		0.1	—	—	—	14.7
Industrial	32.8%	6.2%	1 .3%	10.7'YO		0.3%	—	—	—	51 .3%
Process heat	32.8%	3.4%	1 .3%	—		0.3%	—	—	—	37.8%
Mechanical drive	—	2.8%	—	10.7%		—	—	—	—	13.5%
Transport	0.59	0.57	0.00	(0.08)		—	—	—	—	1.24
Transport	2.1 %	2.0%	—	0.285			—	—	—	4.3%
Road	—	0.8%		—		—	—	—	—	0.8%
Rail	2.1 %	—	—	0.28%		—	—	—	—	2.4%
Air	—	—	—	—		—	—	—	—	—
Other	0.00	1 .2%	0.00	—			—	—	—	1.270
Agriculture	0.98	0.44	—	(0.50)		—	—	—	—	1.92
Agriculture	3.4%	1.570	—	1 .7%		—	—	—	—	6.7%

— Not available or not applicable.

( ) data in parentheses is sum of nonthermal energy output and thermal energy input.

SOURCE: Adapted from International Energy Agency, *World Energy Statistics and Balances: 1971-87* (Paris: OECD, 1989); and Vadav Smil, "China's Energy," contractor report prepared for the Office of Technology Assessment, 1990.

Table 3A-3-India: Energy Supplies and Services, 1985 Exajoules (10^{18} Joules = 0.9478 Quad) and Percent of National Total

	Fossil fuels			Electricity		Biomass			
Energy supplies	coal	Oil	Gas	Nonthermal	Thermal	Wood	Dung	Crop	Total
Production	3.16	1.29	0.17	0.20	—	0.87	1.2	1.6	8.5
Trade/stock change	0.03	0.48	—	—	0.00	—	—	—	0.5
Electric generation	-1.29	-0.11	-0.05	—	1.45		—	—	—
Nonenergy	—	-0.09	—	—		—	—	—	-0.09
Total energy	1.90	1.57	0.12	(1.65)/19%		0.87	1.2	1.6	8.9
percent of total	21%	18%	1.3%			10%	13%	18%	100%
Energy services									
Residential	0.06	0.39	0.007	(0.20)		0.78	1.2	1.6	4.2
Residential	o.7%	4.4%	0.0870	2.2%		8.8%	14%	18%	47%
Cooking/water heating	0.6%	1.9%	0.08%	—		8.8%	14%	18%	4370
Lighting		2.1%	—	1.8%		—	.	—	3.9%
Appliances	—	—	—	o.4%			—	—	0.4%
Commercial/pubiic	0.02	0.03		(0.09)		0.05	—	•	0.20
Commercial/pubiic	0.2%	0.3%		.		0.6%	—	*	2.2%
Cooking/heating	0.2?!	0.3%	—	1.0%		0.6%	—	*	1.1%
Lighting	—	—	—	0.4%			—	—	0.4%
Appliances	—	—		0.6%			—	—	0.6%
industrial	1.61	0.40	0.113	(0.97)		0.04	—	—	3.1
industrial	18%	4.5%	1.3%	10.9%		0.5%	—	—	35%
Process Heat	18%	3.1%	1.3%	—		0.5%	—	—	23%
Motor Drive	—	0.8%	—	10.0%		—	—	—	10.8%
Lighting		—	—	0.5%			—	—	0.5%
Appliances		—	—	0.5%			—	—	0.5%
Transport	0.23	0.77	—	(0.04)		—	—	—	1.0
Transport	2.6%	8.7%		0.5%		—	—	—	11.8940
Road		7.1%		—		—	—	—	7.1%
Rail	2.6%	0.7%	—	0.5%		—	—	.	3.8%
Air		0.8%	—	—		—	—	—	0.8%
Agriculture[a]	—	0.15	0.003	(0.28)		—	—	—	0.43
Agriculture	—	1.7%	0.03%	3.1%		—	—	—	4.8%
Motor Drive....	—	1.0%	—	3.1%		—	.	—	4.I%
Traction	—	0.7%	—	—		—	—	—	o.7%

—Not available or not a aplicable.
() data in parentheses is sum of nonthermal energy output and thermal energy input.
● Small.
a baseline data from the international Energy Agency for petroleum use in agriculture have been modified to correspond better with TERl energy data.

SOURCE: Adapted from international Energy Agency, *World Energy Statistics and Balances: 1971-87* (Paris: OECD, 1989); Tata Energy Research Institute, *TEDDY*, op. cit., footnote 58; and Ashok Desai, contractor report prepared for the Office of Technology Assessment and personai communication.

Table 3A-4-Kenya: Energy Supplies and Services, 1980, Petajoules (10^{15} Joules) and Percent of National Total

	Fossil fuels			Electricity		Biomass fuels		
Energy supplies	coal	Oil	Gas	Nonthermal	Thermal	Wood[a]	Residues	Total
Production	—	—	—	3.82	—	320	9.3	333
Trade/stock change	0.42	78	—	0.44	—	—		79
Electric generation	—	-6.1	—	—	6.1	—		0.0
Nonenergy		-2.3	—	—	—	—	—	-2.3
Total energy	0.42	70	—	(10.4)		320	9.3	410
percent of total	0.1%	17.1%	—	2.5%		78%	2.3%	100%
Energy services								
Residential	—	6.84	—	(2.19)		253	9.3	271
Residential	—	1.67%	—	0.53%		62%	2.3%	67%
Cooking	—	0.53%	—	0.32%.		62%.	2.3%.	65%
Lighting	—	1.14%	—	0.21%		—	—	2%
Commercial	—	0.75	—	(1.92)		3.5	—	6.2
Commercial	—	0.18%	—	0.47%		0.85%	—	1.5%
Cooking/heating	—	0.05%	—	—		0.85%	—	0.9%
Lighting	—	0.13%	—	0.47%		—	—	0.6%
Industrial	0.42	16.5	—	(3.23)		56	—	76
industrial	0.1%	4.0%	—	0.79%		13.6	—	18.5%
Informal	.	—		—		9.4%	—	9.4%
Formal	0.1%	4.0%	—	0.79%		4.2%	—	9.1%
Transport	—	43.3	—				—	43.1
Transport	—	10.6%	—				—	10.6%
Road	—	6.9%	—				—	6.9%
Rail	—	0.6%	—	—		—	—	0.6%
Air	.	2.8%	—	—		—	—	2.8%
Agriculture	—	6.6	—	(1.06)			—	7.7
Agriculture	—	1.6%	—	0.26%			—	1 . %

() data in parentheses is sum of nonthermal energy output and thermal energy input.

a Includes both commmercial and noncommercial uses of wood;does not include wood used as a feedstock or as a construction material..Alsoincludes charcoal that is produced from wood.This conversion takes roughly 110PJ of wood and converts it into about 27 PJ of charcoal, of which about 1.3 PJ is lost during distribution.

SOURCE: Adapted from International Energy Agency, *World Energy Statistics and Balances:* 1971 -87 (Paris: OECD, 1989); and "Energy and Development in Kenya," Eds. Phil O'Keefe, Paul Raskin, and Steve Bernow, Beijer Institute, Royal Swedish Academy of sciences, Stockholm, Sweden, 1984.

Table 3A-5-Taiwan: Energy Supplies and Services, 1987, Petajoules (101^{15} Joules) and Percent of National Total

	Fossil fuels			Electricity		Biomass	
Energy supplies	coal	Oil	Gas	Nonthermal	Thermal	wood”	Total
Production	38.9	5.4	42.3	145	—	21	253
Trade/stock change	363	758	—	—	—		1121
Electric generation	-220	-58.3	—	—	278		0
Nonenergy	·	-46.8	—	—		·	-47
Total energy	182	658	42.3	(423) -		21	1326
percent of total	13.7%	49.6%	3.2%	31.9%		1.6%	100.%
Energy services							
Residential	0.14	46.3	19.6	(87.5)/6.6%		21	175
Residential	● YO	3.5%	1.5%			1.6%	13.2%
Cooking/water heating	—	3.5%	1.5%	0.3%		1.6%	6.9%
Lighting	—	—	—	I.O%		—	1.0%
Refrigeration	—	—	—	1.9%			1.9%
Television	—	—	—	1.2%		—	1.2%
Fans/air conditioning	—	—	—	1.5%		—	1.5%
Commercial/public	0.12	31.6	4.0	(&.22		0.3	83.2
Commercial/public	●'YO	2.4%	0.3%			—	6.3%
Cooking/water heating	●VO	2.4%	0.3%	0.1%		●%	2.8%
Lighting	—	—	—	1.2%			1.2%
Air conditioning	—	—	—	1.1%			1.1%
Other Appliances	—	—	—	1.2%		—	1.2%
Industrial	180	314	18.5	(255)		—	767.5
Industrial	13.6%	23.7%	1.4%	19.2%		—	57.9%
Transport	—	222	—	(2.7)			225
Transport	—	16.7%	—	0.2%			17.O%
Road	—	15.O%	—	—		—	15.0%
Rail	—	0.1%	—	O.1%		—	0.2%
Air	—	1.0%	—	•		—	1.0%
Other	—	0.6%	—	•			0.6%
Agriculture	—	37.3	—	(13.0)/1.0%		—	50.3
Agriculture	—	2.8%	—	.		—	3.8%

—Not available or not applicable.

() data in parentheses is sum of nonthermal energy output and thermal energy input.

● Small.

aCharcoal is includedunder wood. The charcoal conversion effiency is assumed to be a relatively high level of50 percent by energy.

SOURCE: Adapted From International Energy Agency, *World* Energy *Statistics and Balances:1971-87* (Paris: OECD, 19S9); and personal communication, Dr. Gwo-Tzeng, Energy Research Group and Institute of Traffic and Transportation, NationalChiao Tung University, Taipei, Taiwan.

Table 3A-6-United States: Energy Supplies and Services, 1985,[a] Exajoules (10^{18} Joules =0.9478 Quad) and Percent of National Total

	Fossil fuels			Electricity		Biomass[b]	
Energy supplies	coal	Oil	Gas	Nonthermal	Thermal	Wood[a]	Total
Production	19.6	20.9	16.5	2.53[c]	—	2.80	62.3
Trade/stock change	-1.8	8.9	1.2	0.06[d]	—	—	8.4
Electric generation	-14.8	-1.1	-3.0	—	18.9	-0.02	—
Nonenergy	—	-1.8	—	—		—	-1.8
Total energy	3.0	26.9	14.7	(21.5)		2.8	68.9
percent of total	4.4%	39%	21.3%	31.2%		4.1%	100%
Energy services							
Residential	0.1	1.5	5.3	(7.6)		1.0	15.5
Residential	O.1%	2.2%	7.7%	11.%		1.5%	22.5%
Space conditioning	—	2.0%	5.3%	4.3%		1.5%	13.1%
Water heating	—	0.2%	1.8%	1.5%		—	3.5%
Cooking	—	—	0.5%	0.7%		—	1 .2%
Refrig/Freezers	—	—	—	1.6%		—	1.6%
Lighting/Other[e]	—	—	0.1%	2.8%		—	2.9%
Commercial/public	0.1	1.2	2.9	(6.6)		—	10.8
Commercial/public	0.2%	1 .7%	4.2%	9.6%		—	15.7%
Space conditioning	—	1.6%	2.9%	6.1%		—	10.6%
Water heating	—	0.1%	0.1%	0.1%		—	0.3%
Lighting	—	—	—	2.5%		—	2.5%
Industrial	2.6	4.3	6.5	(7.3)		1.8	22.5
Industrial	3.8%	6.2%	9.4%	10.6%		2.6%	32.7%
Heat[f]	3.8%	(11.8%)9	—	1.2%		2.6%	19.4%
Motor Drive	—	—	—	7.1%		—	7.1 %
Off-Highway transport	0.9%	—	—	—		—	0.9%
Transport	—	19.3	—	(0.03)/*%		—	19.3
Transport	—	28.%	—			—	28%
Road	—	23.1%	—	—		—	23.1 %
Rail	—	0.7%	—	●%		—	0.7%
Air	—	3.9%0	—	—		—	3.9%
Other	—	0.3%	—	—		—	0.3%
Agriculture[h]	—	0.6	—	—		—	0.6
Agriculture	—	0.9%	—	—		—	0.9%

—Not available or not applicable.
()data in parentheses is sum of nonthermal energy output and thermal energy input.
"Small.
aNote that the IEA data used as a framework for this energy balance differs slightly from official U.S. energy statistics. See, for example, Energy Information Administration, Month/yGwrgy Review, January 1990.
b split 58 percent Nuclear and 42 percent Hydroelectric and other (geothermal, solar, etc.).
d Imports of electricity into the United States are primarily hydroelectric based power from Canada.
e Includes clothes washers and dryers, dishwashers, lighting, and miscellaneous.
f Includes fuels USed for cogeneration applications.
g0il and gas applications are combined here.
h This does not include indirect inputs (fertilizer, etc.).

SOURCE: Adapted from International Energy Agency, *World Energy Statistics and Balances:* 1971 -87(Paris: OECD, 19S9); and Paui D. Holtberg, Thomas J. Woods, Marie L. Lihn and Nancy C. McCabe, *Baseline Projection Data Book: 1989 GRI Baseline Projection of U.S. Energy Supply and Demand to 2010* (Washington, DC: Gas Research institute, 1990).

Appendix 3-B—Sources for Table 3-9

As used here, efficiency is approximately the first-law efficiency; that is, the total heat transfer to the material being processed divided by the heat input to the system. This is to be contrasted with the second-law efficiency, which compares the heat transfer achieved in the process with the maximum possible heat that could be transferred for the same purpose by any system using the same energy input. For more information, see *Efficient Use of Energy, AIP* Conference Proceedings, No. 25, American Institute of Physics, New York, 1975.

Cooking: The primary source for traditional and modern cooking technologies is Samuel F. Baldwin, ***Biomass Stoves: Engineering Design, Development, and Dissemination,*** op. cit., footnote 17. An enormous range of efficiencies have been reported for the open fire, ranging from 2 to 30 percent. A list of some 45 reports on traditional cooking technology efficiencies was developed by Jas Gill in 1981 and is cited in K. Krishna Prasad, ***Woodburning Stoves: Their Technology, Economics, and Deployment*** (Geneva: 1983). International Labor Organization, World Employment Programme Research. Most of these reports, however, do not cite a source, nor any details as to how such an efficiency figure was derived.

Traditional Beer Brewing: Data are from **Frans Sulilatu,** "Improved Beer Cookers In Burkina Faso," *Boiling Point, No.* 10, pp. 10-14, August 1986. This is the thermal efficiency of heating the brew to boiling, not for the entire brewing process. In Burkina Faso, West Africa, traditional dolo (beer) cookers using 80-liter clay jars have thermal efficiencies of 17 percent with a power output of 80 kW for a cooker with four jars arranged in a square, and 15 percent at 35 kW with the jars arranged in a line with fires between adjacent jars. Simple improvements in stove design and the use of aluminum pots raised efficiencies up to as high as 53 percent.

The efficiency of the brewing process can also be determined by calculating the total amount of useful energy provided. Mnzava, cited below, has estimated that 0.12 to 0.5 m^3 of fuelwood are needed to brew 100 liters. Assuming that 1 m^3 of stacked fuelwood weighs 500 kg and has an energy content of 16 M.J/kg for a total of 8 GJ; and assuming that the energy is used to bring the water to a boil once to sterilize it and then to maintain its temperature at a low level while it ferments; the energy required to heat 100 liters of water to a boil from ambient (20 'C) is 100(80)4.186=14 MJ. This gives an efficiency range of 0.3 to 0.7 percent for the beer-brewing process. This very low efficiency compared to the thermal efficiency found for dolo cookers in Burkina Faso maybe due to the long, low temperature heating needed to concentrate the mash as well as for other operations. See: E.M. Mnzava, "Fuelwood and Charcoal In Africa," W. Palz, P. Chartier, and D.O. Hall (eds.), *Energy From Biomass,* 1st E.C. Conference on Biomass, Brighton, East Sussex (London: Applied Science Publishers, Ltd., 1980).

Modern Beer Brewing: Data are from Bernard B. Hamel et al., "Energy Analysis of 108 Industrial Processes," 1980. The figure of 79 percent is theoverallboiler efficiency for a modern brewery. This boiler provides process steam, hot water, and other heating services. The efficiency of the cooking process is somewhat reduced from this level, but no separate estimate was available.

The value of 6 percent is based on a total energy demand for a brewery found by Hamel et al., of 1,439 Btu per pound of beer produced or, equivalently, 3.35 MJ/kg compared to the energy required to heat the brew to boiling a single time to sterilize it—as in the comparison made for the traditional technology.

Tobacco Drying: The estimate of tobacco drying efficiency is from M.J. Mwandosya and M.L. Luhanga, *Energy Use Patterns In Tanzania,* Center for Energy and Environmental Studies, Princeton University, Report No. 180, February 1985; and M.J. Mwandosya and M.L. Luhanga, "Energy Demand Structures in Rural Tanzania,' Department of Electrical Engineering, University of Dar-es-Salaam, Tanzania, 1984.

Traditional Tea Drying: Tea drying is based on the data in Mwandosya and Luhanga, listed above. They estimate that 150 kg. of green tea requires 9.4 GJ of fuelwood, resulting in 30 kg. of dried tea. To evaporate 120 kg of water requires 2,260(120)kJ = 271 MJ of energy, for an efficiency of 2.9 percent.

Traditional Baking: For traditional bakeries, Ahmed and Elamgzoub found 0.5 to 0.8 kg of wood used per kg of flour. Typical ratios for bread are 720 g flour, 500 g liquid, and 50 g sugar input per kg of bread output. With specific heats of 1.8 kJ/kg 'C for flour, 4.186 kJ/kg 'C for water, and arbitrarily assuming 4.0 kJ/kg 'C for sugar; and noting that approximately half the water evaporates, the rest remaining in the bread (Geller); then the energy required to bake 1 kg of flour into bread at 190 'C is: (1.0)(1.8)(170) + (0.7)(4.186)(80) + (0.35)(2260) + (0.35)(4.186)(90) + (0.09)(4.0)(170)= 1.5 MJ, where it was assumed that the specific heat of the water remaining in the bread, 0.35 kg, remained 4.186 and the chemical reactions and heating of the vaporized steam were ignored. By comparison, 0.5 to 0.8 kg wood have an energy content of 8 to 13 MJ. Abdel Salaam Ahmed and El Sheikh Elamgzoub, Survey *of Fuelwood Consumption in Khartoum Province Industries* (Khartoum, Sudan: National Energy Administration, Ministry of Energy and Mining for the Energy Research Council, Sudan Renewable Energy Project, April 1985. Howard S. Geller and

Gautam S. Dutt, "Measuring Cooking Fuel Economy", *Wood Fuel Surveys* (Rome: 1983). Food and Agriculture Organization of the United Nations, **GCP/INT/365/SWE.**

Reddy and **Reddy** found that 0.583 kg wood were used to cook 1 kg of maida, corresponding to an efficiency of 16 percent. **Amulya Kumar** N. **Reddy** and B. **Sudhakar Reddy,** "Energy Use in a **Stratified** Society: Case Study of Firewood, in Bangalore,' ***Economic and Political Weekly (India),*** vol. 18, No. 41, Oct. 8, 1983.

Shirey and **Selker** list the efficiencies of a number of traditional and modem ovens used in a variety of countries. Ovens in **Somalia,** Sudan, Guatemala, Zimbabwe, and Sri Lanka have typical measured efficiencies of 1 to 3 kg wood per kg flour, giving efficiencies, as calculated above, of 3 to 8 percent. In contrast, an improved wood-fired Somali oven is cited as using 0.16 kg of wood to cook 1 kg of flour into bread-an efficiency of 58 percent; and modem natural gas ovens are listed as baking 360 kg of flour into bread using 1 GJ of energy -an efficiency of 54 percent. E. **Shirey** and J. **Selker,** "Bread Ovens," ***Boiling Point, No.*** 10, pp. 18-21,1986.

Modern Bakeries: Ho, **Wijeysundera,** and **Chou** found first-law efficiencies for a modem industrial bakery in Singapore to be 43 percent for the entire process, including preparation of the dough. Second-law efficiencies were also calculated and found to be 15.5 percent. **J.C.** Ho, **N.E. Wijeysundera,** and **S.K. Chou,** "Energy Analysis Applied to Food Processing," ***Energy VOL*** 11, No. 9, 1986, pp. 887-892.

Fish Smoking: **Mwalyosi** estimates that smoking 1 kg of fresh fish requires 4 to 5 kg dry wood. If 70 percent of the fish is assumed to be water, then it requires (2,260 **kJ/kg**)(0.7 kg)= 1.6 **MJ** to evaporate the water compared to (4 to 5 **kg)(16 MJ/kg)** = 64 to 80 **MJ** of wood to accomplish the **task,** for an efficiency of 2.0 to 2.5 percent. Raphael B. **Mwalyosi,** "Management of the **Mtera** Reservoir in Tanzania," ***AMBIO, vol.*** 15, No. 1, 1986, pp. 30-33.

Traditional Brick Firing: Schmitt estimates 1.36 **MJ** of energy is required per kg of brick produced in order to evaporate moisture from the raw brick (after drying in the sun) and heat it to a firing temperature of 850 'C, and an additional 0.2 to 0.4 **MJ/kg** is needed for the chemical reactions. Based on observations at six sites, an average of 2.5 **MJ** fuelwood and other organic matter were used per kg of brick produced, for an efficiency of (0.2 to 0.4)/2.5 = 8 to 16 percent. It should be noted that these results were for very large kilns, firing typically 100,000 bricks at a time. Klaus Schmitt and Werner **Siemers,** ***Energy From Agricultural Residues and Energy Utilization In Small Scale Industries In The Sudan,*** Section 5.4, "Brick Kilns" **(Gottingen,** Sweden: for the National Energy Administration of Sudan, Khartoum, September 1985).

Gandhi found an efficiency of 6.4 percent for brick kilns in India, representing the irreversible reactions that take place during firing. **The overall heat balance found** by Gandhi **for a** Bull' **s trench** was: energy in= 3.88 **MJ** +0.29 **MJ** in carbon in **brick;** energy out is 61.4 percent in dry exhaust; 16.9 percent in moisture in exhaust; 6.4 percent in irreversible reactions; 4.0 percent in heat loss of CO; 0.3 percent in carbon in ash; and other heat losses (by difference) of 11 percent-presumably, much of this loss was through the kiln walls. Other types of kilns require **from** 2 to 18 **MJ/brick** for firing. With an average brick size of 108 in3 or 108(16.387) cm3 and an average brick density of 1,800 kg/m3, this gives an energy requirement of 2 to 18 **MJ/3.18** kg or 0.637 to 5.7 **MJ/kg. Sunita** Gandhi, "The Brick Industry in India: Energy Use, **Tradition** and Development," Ph.D. Thesis, Trinity College, Cambridge, October 1986.

The brick and tile industry in Uganda uses 0.5 to 1.8 stacked cubic meters of wood per metric ton of brick **produced; with** 7,650 **MJ/m^3** for eucalyptus at **510** kg/stacked m^3 to give, at best, 3,800 **MJ** per metric ton of brick output. Potential energy savings of 35 percent may be possible simply with better fiig techniques and kiln construction, and by the introduction of small cavities and organic materials into the brick to reduce mass and improve the uniformity of firing. Using the figures for Sudan, this gives an efficiency of about 5 to 10 percent when assuming the chemical reactions need 0.2 to 0.4 **MJ/kg;** using the figures for India this gives an efficiency of about 2 percent. "Uganda: Energy Efficiency Improvement in the Brick and Tile Industry,' World **Bank/UNDP** Energy Sector Management Assistance Program, March 1989.

Modern Brick Industry: **Assumin**g the same range as for Sudan, that irreversible chemical reactions for the process are 0.2 to 0.4 **MJ/kg** of fired **brick,** a modem brick factory has an efficiency of 6-11%. The relatively high observed efficiency of the traditional process relative to modem kilns is largely due to substantial underfiring in traditional kilns and corresponding low-quality product. Calculated from Bernard B. **Hamel** et al. "Energy Analysis of 108 Industrial Processes," op. cit.

Traditional Foundry Work: In Indonesia, an estimated 1 kg of charcoal is used per kg of aluminum melted and cast into pots. From the ***CRC Handbook of Chemistry and Physics, the*** melting point of aluminum is 933 OK and its specific heat varies linearly with temperature from **C_p=0.9** kJ/kg'Cat300'K to 1.19kJ/kg'Cat933'K. The energy needed to heat it to its melting point is then given by **MC_pDT=658 kJ/kg.** To melt the aluminum requires an **additional** 398 **kJ/kg** (CRC Handbook). The total process then requires 1,056 kJ/kg. Charcoal has a calorific value of about 33 M.T/kg. The process is therefore about 3 percent efficient. World Bank, *Indonesia: Issues and Options in the Energy Sector,* UNDP/World Bank Energy Sector Assessment Program Repor& No. 3543 -IND, November 1981.

Modern Foundry work: Figure of 40 percent is from Bernard B. Hamel et al., ''Energy Analysis of 108 Industrial Processes,' op. cit. above, p. 282.