Appendixes

Appendix A
Capital and Life Cycle Costs for Electricity Services

This appendix calculates the capital and life cycle costs of providing electricity services to users. This is done in three stages. First, a general framework for calculating costs is presented. Second, the capital cost of providing electricity supplies is determined. Third, the total systemwide—including both electricity supply and end-use equipment-capital costs and life-cycle operating costs are determined for standard and energy efficient equipment.

General Framework for Calculating Costs

All costs are in constant 1990 U.S.$. Where necessary, other currencies are converted to U.S.$ in the year cited and then the U.S.$ are deflated to 1990 values using GNP deflators. The factors used to convert foreign currencies to U.S.$ are generally market exchange rates as these are capital goods.

Capital costs are calculated using a simple capital recovery factor (CRF) method.[1] This method divides the capital cost into an equal payment series—an annualized capital cost-over the lifetime of the equipment. For example, the CRF for a 30-year lifetime and a discount rate of 7 percent is 0.080586. A $1,000 widget then has an annualized capital cost of $80.586, including interest payments and in constant dollars, each year of its 30-year expected lifetime.

In the base case, a uniform real discount rate of 7 percent is used for both the supply and end-use sectors. The discount rate used is intended to be the equivalent of a societal discount rate. In comparison, the real cost of capital in the United States averaged about 3 percent between 1950 and 1980, rising briefly to nearly 10 percent in 1983, before dropping back to about 6 percent and below from 1987 onward.[2] Capital costs in developing countries vary widely. Sensitivity analyses, discussed below, examine the effect of varying the discount rates and other parameters for both the supply and end-use sectors,[3]

The total systemwide capital cost of each energy service and each choice of equipment to deliver that service is determined by adding: 1) the annualized capital costs of the end-use equipment, and 2) the corresponding annualized capital costs for the electricity supply system needed to power the end-use equipment. This latter value, (2), is determined by averaging the number of kWh used over the year by the equipment to get an equivalent average kW demand and then multiplying by the corresponding annualized cost of electricity supply per kW of delivered power (as determined in detail below).

Note, however, that the capital cost of delivering a kW of power is substantially greater than the cost of a kW of supply capacity. This is due to the additional capital costs of, e.g., coal mining equipment, transmission and distribution equipment, etc. that are needed on the supply side; because supply equipment can deliver only a fraction of its rated capacity due to maintenance needs, breakdowns, imperfect matching of the demand to the available capacity, the need to maintain reserve capacity, etc.; and because of losses in the system before the power is delivered to the consumer.

More sophisticated analyses of capital and operating costs are possible.[4] These include, for example, taking into account the higher cost of delivering electricity during the peak of the system load. Such refinements are avoided here in order to make the presentation as simple and transparent as possible, while still presenting reasonable estimates of the relative costs of different means of delivering desired energy services.

Finally, the following estimates of capital and lifecycle operating costs have a number of highly conservative factors built in. The cost of electricity supply is estimated on the low side. In particular, factors that lower the estimated cost of electricity supply include low assumed values for the capital costs of coal mining, utility generation plants, transmission and distribution equipment, and other capital investments; high assumed values for the capacity utilization levels of generation equipment and Transmission and Distribution (T&D) equipment; and low assumed losses in T&D systems; among others. These are detailed in the following section.

In contrast, the cost of end-use efficiency is intentionally estimated to be higher than it is likely to be in practice, specifically:

[1] The CRF = $\{i(1+i)^n\}/\{(1+i)^n-1\}$ where i is the discount rate and n is the lifetime or period of capital recovery of the system.

[2] Margaret Mendenhall Blair, "A Surprising Culprit Behind the Rush to Leverage," *The Brookings Review*, Winter 1989/90, pp. 21.

[3] Additional factors—such as levelizing increasing real costs of inputs like labor, energy, etc.; shadow pricing/opportunity costs; economies of scale and learning; byproduct credits; environmental costs; etc.—are not included in order to keep the model calculations as simple as possible so as to clearly show the overall driving financial forces in the system.

[4] Electric Power Research Institute, "Technical Assessment Guide: Electricity Supply," and "End-Use Technical Assessment Guide," various volumes, Palo Alto, CA various years; Jonathan Koomey, Arthur H. Rosenfeld, and Ashok Gadgil, "Conservation Screening Curves to Compare Efficiency Investments to Power Plants," *Energy Policy*, October 1990, pp. 774-782.

- Direct Substitutions Only. Only direct substitutions of more efficient for less efficient end-use equipment are considered. This excludes many highly capital-conserving and life-cycle cost-effective investments, such as insulating buildings, using improved windows, daylighting, improved industrial processes, and many others.
- No Synergisms. Synergisms between efficient equip ment are excluded. For example, high efficiency lights, refrigerators, and other equipment reduce heat loads in buildings that must otherwise be removed by ventilation and air conditioning systems. For each kW of internal heat load that is avoided, roughly one-third kW of electricity required by an air conditioner to remove this heat is saved.
- No Downsizing Credits. With more efficient lights and refrigerators, etc. lowering internal heat gains, the size of the needed air conditioner to cool the space can be reduced. Similarly, with more efficient pumps/fans, ASDs, etc. the size of the motor needed could be reduced. Such downsizing is not considered here.
- No Credit for Manufacturing Volume. Margins for efficient equipment are sometimes larger than those for standard equipment. Manufacturing costs for efficient equipment may also be higher than for standard equipment due to the smaller production volumes. The impact of such learning can be substantial. As shown in chs. 2 and 3, the real cost of refrigerators in the United States declined by a factor of 5 between 1950 and 1990 due to improved materials and manufacturing methods. No credits were given for expected cost reductions at higher volume production or for reduced manufacturer margins.[5]
- Capacity Increments. Capacity increments are assumed to be added as needed rather than in large lumps as is the case in reality. This reduces the effective cost of supply.

Together, these low-side supply costs and high-side end-use costs are intended to bias the case against efficient equipment in order to be as conservative as possible. Even under these circumstances, energy efficient equipment shows systemwide capital savings, life-cycle operating savings, and energy savings as illustrated in various figures in chs. 1,2, and 3.

Capital Costs of Electricity Supplies

This section calculates the cost of delivering a kW of electric power to the end-user. Capital costs for electric power systems are usually cited in terms of $/kW of electricity generation capacity. Such figures are substantial understatements of the full capital costs of delivering electricity supplies.

Typical capital costs for generation capacity range from $500/kW for a conventional gas turbine used for providing peak power to over $2000/kW for current nuclear power plants and even higher for current photovoltaic systems. The World Bank estimates that developing countries, under current power expansion plans, will invest $775 billion (1990 U.S.$) during the 1990s for 384 GW of additional capacity, including generation, T&D and other capital expenditures or $2,018/kW total. This cost is divided into 60-percent generation, 31-percent T&D, and 9-percent general.[6]

This overall figure of $2,018/kW total assumes that existing plant and equipment can be used more intensively than at present,[7] a highly desirable opportunity. Without this credit, the World Bank estimates the capital cost of new capacity at $2,618, including generation, T&D, and other capital expenditures, or $1,568/kW for generation equipment alone (assuming the same percentage breakdown as above). Corresponding estimates of the capital cost of new generation equipment from the World Energy Conference are $2,310-$2,770 (1990 U.S.$), shown in table A-l,[8] and costs for the United States are shown in table A-2. It should be noted that the capital costs of fossil steam and gas turbine plants listed in table A-2 are "recommended best practice" estimates and do not include any contingency for unexpected costs (or savings) incurred in actual field construction. The costs of capacity for various generation technologies are examined in more detail in chapter 6 and appendix B.

Estimates of generating capacity alone do not, however, reflect the full capital cost of delivering electricity supplies to users. First, the capacity to produce electricity is not the same as actually producing it. Typical baseload coal-fired plants, for example, might be available for operation 70 percent of the time. The remaining 30 percent of the time they are shut down for routine maintenance or due to breakdowns. Additional generating capacity is needed to make up this shortfall.

In operation, electric power systems normally maintain a "spinning reserve' of perhaps 5 to 7 percent of the

[5] Note, however, that a constant retail markup of 100 percent over estimated manufacturing cost was assumed for refrigerators.

[6] Edwin A. Moore and George Smith, "c~i~ Expenditures for Electric Power in the Developing Countries in the 1990s,'' Washington, DC World Bank, February 1990, Industry and Energy Department Working Paper, Energy Series Paper No. 21 (Washington, DC: World Bank, February 1990).

[7] Specifically, it assumes that reserve capacities can be reduced from the 1989 level of 42.5 percent to a 1999 level of 36.3 percent. See Moore and Smith, op. cit., annex tables 2.1 and 2.2.

[8] World Energy Conference, "Investment Requirements of the World Energy Industries, 1980-2000," London, 1987.

Table A-l—Capital Costs of Delivered Electricity Supply

	World Bank parameters		World Energy Conference		
	Low[a]	High[b]	Low	High	OTA base case
Coal mining and transport[c]	$55/kW	$126/kW	$55/kW	$126/kW	$55/kW
Generation	$1,211/kW	$1,568	$2,310/kW	$2,770	$1,536[d]
Capacity factor	50%	50%	50%	50%	60%
T&D loss	15%	15%	15%	15%	10%
Capacity needed	2.36 kW	2.36 kW	2.36 kW	2.36 kW	1.85 kW
Firm kW	$2,858	$3,700	$5,451	$6,537	$2,844
T&D	$625/kW	$812	$1,897/kW	$2,770/kW	$625
T&D loss	15%	15%	15%	15%	10%
Capacity factor	75%	75%	75%	75%	75%
Capacity needed	1.57 kW	1.57 kW	1.57 kW	1.57 kW	1.48 kW
T&D Capacity.	$981	$1,275	$2,978	$4,349	$926
Othercapital[e]	$363	$471	NA	NA	$337
Total cost ($/delivered kW)	$4,257	$5,572	$8,484	$11,012	$4,162

NOTE: Optimistic values are used throughout this table for the generation capacity factor (50%) and for the T&D capacity factor (75%), among others. The assumed values for these and other key parameter—generation capacity factor (60%), T&D capacity factor (75%), and T&D losses (10%)—are substantially more optimistic in the OTA base case than those observed in practice.

[a]The $ values from the World Bank include a credit for improving the utilization of existing capacity and so are not strictly comparable to the capital cost of new electricity supply capacity.

[b]These $ values simply do not include a credit for better utilization of existing capacity as in the "low" case and use high values for coal mining. In other respects, these $ values are the World Bank baseline case.

[c]Based on World Energy Conference estimates cited in text.

[d]Electric Power Research Institute. See table A-2.

[e]This assumes that the other capital requirements—buildings, other equipment, administrative support, etc.—increase directly with the generation capacity, as indicated by the World Bank.

SOURCE: Edwin A. Moore and George Smith, "Capital Expenditures for Electric Power in the Developing Countries in the 1990s," Washington, DC World Bank, February 1990, Industry and Energy Department Working Paper, Energy Series Paper No. 21; World Energy Conference, "Investment Requirements of the World Energy Industries, 1980-2000," London, 1987.

Table A-2—Typical Capital Costs and Capacity Factors for Existing U.S. Electricity Generating Plants, 1990 U.S.$

Prime mover	Capital cost, $/kW capacity	Capacity factor, percent	T&D loss[a] percent
Fossil steam	$1,536[b]	50	6
Gas turbine	$ 500'	7	6
Nuclear	$2,580[d]	62[e]	6
Hydroelectric		33	6

[a]T&D loss is the U.S. average of about 6 percent.

[b]Average cost of 300 MW coal-fired steam plants in the United States under EPRI recommended practice, table 7-4, EPRI.

[c]Average cost of conventional simple and combined cycle gas turbines operating on distillate or natural gas, exhibits 15-19, EPRI.

[d]Note that this is the average cost for the 63 nuclear power plants put into operation in the United States since 1975. Dollars are mixed current dollars over the construction period and then discounted from the date of operation to 1990 U.S.$. Consequently, the costs are somewhat underestimated. The comparable average cost for all 108 U.S. nuclear power plants in operation is $1,834. The estimated cost for an advanced reactor design has been estimated by EPRI at approximately $1,667.

[e]Note that a 10-year unweighed average, 1980-1990, capacity factor for nuclear plants is 58.8%. The figure shown is for 1989. Energy Information Administration, "Monthly Energy Review," May 1991, U.S. Department of Energy, DOE/EIA-0035(91/05)

[f]Too variable to be readily quantified here.

SOURCE: Steam and gas turbine capital costs are from the Electric Power Research Institute, "Technical Assessment Guide: Electricity Supply, 1989," EPRI P-6587-L, vol. 1, Rev.6, September 1989, Palo Alto, CA.; Nuclear power costs are from Energy Information Administration, "Nuclear Power Plant Construction Activity, 1988," DOE/EIA-0473(88); capacity factors are from: Energy Information Administration, "Annual Energy Review, 1989," U.S. Department of Energy, 1989, tables 89, 93.

system load in order to handle normal short-term fluctuations in demand.

Excess generation capacity is also built into the overall system in order to handle peak loads—for example, on exceptionally hot summer days when everyone with an air conditioner turns it on. Typical reserve margins on well-run systems might be 20 to 30 percent greater than the maximum peak load including the spinning reserve. That reserve margins aren't larger than this--corresponding to the plant availability cited above, or 43 percent (1/0.7)--is because some of the routine maintenance of the plants can be scheduled during nonpeak times and because some of the peak is met by using additional equipment specifically designed just for peak loads, such as low capital cost—but high fuel cost—gas turbines.

Finally, because generation equipment comes in large units, there is typically a stairstep increase in system capacity above overall demand.

As a consequence of these considerations, the typical power system produces electricity at only a fraction of the capacities of its individual plants. For example, the average (weighted by country) generation capacity factor—measured as the ratio of actual gross generated kWhs divided by the potential kWhs generated by the power plant if it ran at full capacity all the time-across 98 developing countries is 36 percent. (This very low generation capacity factor reflects serious institutional and operational problems in many of these power systems. These issues are discussed in ch. 6.) In comparison, the generation capacity factor of the United States[9] was 46 percent in 1989. Only 10 of the developing countries reviewed by the World Bank had generation capacity factors of greater than 50 percent. For example, Brazil had 50 percent, China 55 percent, Colombia 57 percent, Egypt 59 percent, and Kenya 52 percent.[10]

This average generation capacity factor includes both peaking and baseload power plants. Actual operating experience for different types of prime movers is shown in table A-2 for the United States. Generation capacity factors ranged from 7 percent for gas turbines, to 50 percent for fossil steam, to 62 percent for nuclear plants. Corresponding generation capacity factors for prime movers in India are shown in table A-3. Low generation capacity factors increase the capital cost of delivering electricity to users.

Table A-3-Capacity Factors for Electricity y Generating Plants in India

Prime mover	Capacity factor
Coal-steam	42.2%
Nuclear	44.8%
Oil and gas	28.5°/0
Hydro	37.5%

SOURCE: Ashok V. Desai, "Energy, Technology and Environment in India," contractor report for the Office of Technology Assessment, December 1990.

Second, to determine the capital cost of supplying electricity to users, the large losses of electricity between the plant and the customer must be considered. Transmission and distribution losses in developing countries include both technical losses and nontechnical losses due to billing errors, unmetered use (theft), and other factors. Technical losses of 15 percent are typical. This relatively high level of loss is due to poor system power factors, long low voltage lines to dispersed consumers, inefficient equipment, and other factors. System improvements can reduce this high level of loss, but it will probably remain higher than the 6 percent typical for the United States due to the large dispersed rural demand likely in the future. Nontechnical losses are not considered here.[11] To deliver 1 kW of power to a consumer, then, requires 1.18 kW of power to be generated at the utility when 15-percent transmission and distribution losses are included. Assuming an optimistic 50-percent generation capacity factor and with 15-percent T&D losses, to deliver 1 kW of power on average to consumers, a generation capacity of 2.36 kW would be needed.

Third, estimates of the capital cost of generation capacity alone ignore the cost of transmission and distribution equipment to deliver it to customers. The World Bank estimates the cost of T&D capacity in current developing country expansion plans at $625 to $812/kW. The World Energy Conference estimates the cost of new T&D capacity at $l,900-2,770/kW. Costs in developing countries are likely to be particularly high because of the extension of electric power grids into rural areas, an expensive undertaking. This capacity, too, must be augmented by the T&D losses of 15 percent. In addition, utilization capacity factors for T&D systems are often quite low. Lines to residential areas are used primarily in the evenings and on hot summer afternoons and the T&D capacity is substantially underused the rest of the time. Lines to commercial areas are used primarily during weekdays, but carry little load during evenings and

[9]Note that the generation capacity factor for the United States is net generation-not including the electricity consumed in operating the power plant—rather than gross generation.

[10]Jose R. Escay, World Bank, Industry and Energy Department, "S~ Data Sheets of 1987 Power and Commercial Energy Statistics for 100 Developing Countries," Industry and Energy Department working paper, energy series paper No. 23 (Washington, DC: World Bank, March 1990).

[11]Mohan Munasinghe, Joseph Gilling, Melody Mason, "A Review of World Bank Lending for Electric Power" (Industry and Energy Department working paper energy series paper No. 2 (Washington, DC: World Bank, March 1988), p. 33.

weekends, etc. This results in an increased capital investment per kW of electricity supply delivered to the user.

Fourth, there are other capital costs associated with electricity supplies, such as investment in buildings, administrative support offices, etc. The World Bank estimates these capital costs at 9 percent of the total required investment, or $182 to $236/kW of capacity.

Fifth, the capital costs of producing the fuels to run thermal power plants must also be included if the capital costs of supply expansion is to be accurately depicted. The World Energy Conference estimates the capital investment in coal mining at $0.38 to $1.00/GJ (1990 U.S.$)[12] plus $0.20 to $0.33 per GJ[13] for transportation equipment. For thermal power plants with conversion efficiencies of 33 percent, 1 GJ produces 92,6 kWh or 0.01057 kW-yr. This is equivalent to $55 to 126/kW of annual electric power output,

The corresponding capital costs for oil production are $0.80 to $1.10/GJ[14] for exploration and production, and $0.18/GJ[15] for downstream investment in storage tanks, refineries, and transportation equipment, This is equivalent to $93 to $121/kW of annual electric power output.

For gas, the corresponding capital costs are $0.04 to $0.16/GJ[16] for exploration and production, and $0.58 to $1.12/GJ[17] for natural gas transport and distribution infrastructure. For a thermal power plant with a conversion efficiency of 33 percent, this gives a capital cost of $59 to $121/kW of annual electric power output. Obviously, for coal, oil, and gas there can be wide variations from these estimates based on local conditions.

These capital costs and capacity factors can now be used to estimate the approximate total capital cost of supplying electricity, as shown in table A-1. Estimated costs of a firm kW of power range from $4200 to over $11,000. These values are comparable to those found in more detailed analyses of electricity supply options in India[18] and in Brazil.[19]

To be as conservative as possible, OTA uses more optimistic values for its base case than those found in or estimated for developing countries or, indeed, the United States (table A-l). The extent of this conservatism should be noted.

First, OTA assumes a low capital cost for coal production, This value is in part based on the World Energy Conference assumption that intensive energy efficiency improvements will reduce the elasticity of energy use with economic growth in developing countries to just 0.7—that is, that energy use will increase at just 70 percent of the rate at which developing country economies grow. In turn, this results in greater availability of low cost coal supplies, according to the World Energy Conference.

Second, OTA optimistically assumes that generation capacity factors can be raised from the current average of 36 percent (by country) to 60 percent—a level higher than those found in all but two of the 98 developing countries reviewed by the World Bank.[20] This is also better, for example, than the 56-percent capacity factor projected for Brazil by Eletrobras—the federal utility holding company—for the year 2010.[21] The cost of new capacity was chosen to be $1,536 corresponding to the estimates by the U.S. Electric Power Research Institute for new coal-fired steam plants constructed under "good' practice conditions.[22]

A more comprehensive analysis would examine the capacity factors and costs for each component of the electricity supply system, including base load and peak load generation capacity.

[12]Table 5.4 World Energy conference, 1987, op. cit., footnote 8. Excludes South Africa.

[13]Table 5.7 divided by Table 5.2 World Energy Conference, 1987, ibid.

[14]Table 3.2 of World Energy Conference, 1987, ibid.

[15]Table 3.5 of World Energy Conference, 1987, ibid.

[16]Table 4.3 World Energy Conference, 1987, ibid.

[17]Table 4.7, World Energy Conference, 1987, ibid.

[18]Amulya Kumar N. Reddy et al., "Comparative Costs of Electricity Conservation: Centralized and Decentralized Electricity Generation, ' *Economic and Political Weekly* (India), June 2, 1990, pp. 1201-1216.

[19]Jose Goldemberg and Robert H. Williams, "The Economics of Energy Conservation in Developing Countries: A Case Study for the Electrical Sector in Brazil, " in David Hafemeister, Henry Kelly, and Barbara Levi, "Energy Sources: Conservation and Renewable," American Institute of Physics, New York, NY, 1985.

[20]Note that Cape Verde achieved a generation capacity factor of 76 percent and Madagascar achieved a level of 64 percent. These high capacity factors, if correctly reported, are probably unique to these very small systems and may be due to the lack of reserve margins, not meeting peak loads, having little or no backup capacity, or other unusual features. See Jose R. Escay, op. cit., footnote 10.

[21]Howard S, Geller, ' 'Electricity Conservation in Brazil: Status Report and Analysis,' Contractor Report for the Office of Technology Assessment, November, 1990.

[22]For conceptual clarity and again t. be as conservative as possible in estimating costs, this analysis assumes a high generation capacity 'actor 'or a baseload coal plant operating under near ideal conditions of almost constant load. This should be contrasted with a typical electric power system which includes a variety of different baseload and peaking plants with differing capital, operating and maintenance, and fuel costs; availabilities and effective capacity factors; and efficiencies.

Third, OTA assumes that nontechnical losses can be ignored and that even with extensive rural electrification T&D losses can be lowered by one-third, from the current 15 percent to 10. In the much longer term, increasing urbanization and various technical improvements may make further reductions possible.

Fourth, OTA assumes that T&D capacity is used at 75 percent of its limit and ignores the frequently low level of utilization in many parts of a typical T&D system, as noted above.

Together, these considerations indicate that the OTA base case is likely to be substantially conservative in its estimate of the capital costs of electricity supply systems.

Calculating Operating Costs for Electric Power Systems and End Use

To determine life-cycle operating costs, it is necessary to know the full cost of electricity, including capital, operations and maintenance, fuel costs, and other factors. Electricity costs for new supplies are estimated at $0.09/kWh for the residential and commercial sectors (1990 U.S.$) and $0.07/kWh for the industrial sector. The lower cost for industry reflects the greater concentration of use-allowing the purchase of bulk supplies, reduced T&D costs, lower administrative overheads, and other benefits.

These values correspond to the 1987 OECD weighted average electricity price of $0.087/kWh (1990 U.S.$). Electricity prices charged in developing countries, however, have a weighted (by electricity sales) average price of $0.048/kWh (1990 U.S.$) but have a marginal cost of production of $0.094/kWh assuming a high 60 percent average system capacity factor.[23] Expected costs of $0.09 to $0.13/kWh (1990 U.S.$) are listed by Jhirad for some 18 commercially available technologies running at a high capacity factor of 75 percent corresponding to baseload applications. Gadgil and Januzzi give marginal costs of production of $0.09/kWh and $0.12/kWh for India and Brazil respectively.[24] OTA has thus chosen the current average cost of electricity or lower in order to be conservative. A more detailed examination of electricity costs are given in ch. 6.

Systemwide Capital and Operating Costs

To complete the analysis, systemwide capital and life-cycle operating costs can now be calculated for standard and energy efficient equipment. A level of services corresponding to a U.S. or Western European standard of living is assumed, as described below and summarized in table A-4. Parameters for each energy service are shown in tables A-5 through A-14 together with notes providing context. The corresponding summary values of systemwide capital, life-cycle operating costs, and electricity use are shown in tables A-15 and A-16.

Residential households are assumed to have five persons; capital costs of end-use equipment are allocated equally among them to get per capita capital and life-cycle costs.

The following discussion of costs is not inclusive. There are many related costs that are not included as they are assumed to be the same for both the standard and the energy-efficient cases. Examples include the wiring, switches, and related capital components within the home, business, or industry-note, particularly, that for industry these related components such as switchgear, pipes and ducts, and related process equipment are a very substantial part of the total systemwide costs; labor and other costs associated with actually putting equipment into service; and many other costs. There are also many other cases where energy efficient equipment is not considered or where it is left out due to it not being cost effective. Several examples are listed below.

Cooking[25]

Cooking levels are scaled by efficiency factors from those currently observed in developing countries-6 GJ per person per year when using wood with a stove thermal efficiency of 17 percent. This corresponds to an electricity consumption in the all electric household of about 2250 kWh/household-year. This is slightly lower than the 2500 kWh/yr observed in, for example, Guatemala (see ch. 2), but is substantially higher than the 700 kWh/household-year observed in the United States. The dramatically lower residential household energy consumption for cooking in the United States is due to a number of factors, including: 1) smaller households--e.g. two people--than assumed here; 2) extensive dining out or purchase of

[23] Calculated from Annex 9 of A. Mashayekhi, "Review of Electricity Tariffs in Developing Countries During the 1980s," Industry and Energy Department working paper, energy series paper No. 32, World Bank, Washington, DC November 1990.

[24] A. Mashayekhi, Ibid. David J. Jhirad, "Innovative Approaches to Power Sector Problems: A Mandate for Decision Makers," (New Delhi, India: PACER Conference, Apr. 24-26, 1990, U.S. Agency for International Development, Washington, DC) A more general discussion of electric power pricing issues can be found in Mohan Munasinghe, "Electric Power Economics" (London, England: Butterworth & Co, 1990). Ashok Gadgil and Gilberto De Martino Januzzi, "Conservation Potential of Compact Fluorescent Lamps in India and Brazil," Lawrence Berkeley Laboratory, report No. LBL-27210, July 1989.

[25] Additional detail on cooking can be found in, Samuel F. Baldwin, "Cooking Technologies," Office of Technology Assessment, staff working paper, 1991.

Table A-4-Assumed Levels of Electricity y Services and Other Parameters

Energy service	Level of service provided
Residential/commercial	Five people per household.
Cooking	Comparable to cooking energy requirements in developing countries today, scaled by efficiency. This results in per capita consumption levels somewhat above those observed in the United States (see text for details). Cooking energy is allocated 75 percent to electric resistance/gas stoves in the standard/high-efficiency cases, respectively, and 25 percent to microwave ovens in both cases.
Water heating	50 liters of water heated 30 °C per day, corresponding to the U.S. level of hot water usage.
Lighting	Lighting levels at the midrange of industrial countries. Residential lighting is the equivalent of six hours of lighting by 60 W incandescent bulbs (four hours with one bulb and two hours with a second) per capita per day. Commercial and industrial lighting is equivalent to 10 hours, 260 days per year by 4 standard 40 W fluorescent per capita.
Refrigeration	One 510-liter top-mount freezer, automatic defrost refrigerator, corresponding to the most popular type in use in the United States.
Air conditioning	1,200 kWh of electricity for cooling (SEER=8) annually per capita. This is slightly lower than the 1,400 kWh/year used per capita in the United States.
Electronic information services	One color TV used about 5 hours per day.
Industrial motor drive	Industrial motor drive power consumption of 300 W/capita in the base case, comparable to the 308 W used in the United States.

NOTE: This does not cover all energy services, nor all costs associated with a particular energy service.

SOURCE: Office of Technology Assessment, 1992.

Table A-5-Cooking, OTA Base Case Parameters

	Stove parameters			Fuel parameters	
Stove/fuel	Lifetime	Capital cost	Efficiency	Capital cost	Total cost
Standard case:					
Electric resistance	15	$75	63%	$335/kW[a] ($10.6/GJ)	$0.09/kWh ($25/GJ)
Microwave	15	$250	580/0	same	same
High efficiency case:					
LPG	20	$50	58%	$1/GJ/yr	$7/GJ
Microwave	15	$250	580/o	above	above

SOURCE: Note that the same discount rate of 7 percent real is used to calculate a capital recovery factor for the given stove lifetime. The CRF is then used to annualize all capital costs. Energy consumption is scaled by the relative efficiencies of the stoves from a baseline value of 6 GJ/capita (30 GJ/household) with a 17 percent efficient wood stove. The electric resistance stove then uses the kW equivalent of 1.6 GJ.

[a]This is the annualized cost per kW over the 30-year lifetime of the utility power plant, using a total cost per delivered kW of $4,162 as in table A-1 .

[b]Note that this is the estimated thermal efficiency of a microwave; in practice, a microwave can realize overall cooking efficiencies substantially higher than conventional cooking devices, particularly for baking.

SOURCE: Office of Technology Assessment, 1992.

''take-out meals rather than cooking at home; 3) extensive use of highly processed foods such as "minute' rice or TV dinners, etc. rather than cooking unprocessed grains for long periods at home; 4) greater use of high-value foods such as meats that typically do not require as much cooking energy to prepare as unprocessed grains; and others,

In the standard efficiency case, an electric resistance stove provides 75 percent of the required cooking energy and a microwave oven provides the remaining 25 percent. In the high efficiency case, an LPG stove substitutes for the electric resistance stove—reducing upstream capital costs and cutting primary energy consumption by two-thirds, and a microwave oven again provides the remaining 25 percent. Natural gas could readily substitute for LPG, but upstream capital costs for installing and maintaining a pipeline distribution system would vary, depending on the total demand. In the industrial countries, the large winter space heating requirements help justify the high capital costs of a natural gas distribution system.

The high efficiency case summary values for electricity consumption do not include the LPG used for cooking (capital and operating costs for the LPG system are included in the totals, however). If the total systemwide

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Table A-6-Costs, Efficiencies, and Lifetimes for Alternative Cooking Technologies

Technology	Efficiency: Stove percent	Efficiency: System percent	Stove capital cost $	Lifetime years	Fuel cost $/GJ
Traditional stoves					
Dung	11-15	10-14	0.00		0.00
Agricultural residues	13-17	12-16	0.00	—	0.00
Wood	15-19	14-18	0.00	—	0.00
Wood (commercial)	15-19	14-18	0.00		1.50
Charcoal	19-23	8-12	3.00	2	4.00
Improved biomass stoves					
Wood	27-32	26-31	6.00	2	1.50
Charcoal	29-34	13-17	8.00	3	4.00
Wood II	40-44	38-42	10.00	3	1.50
Liquid stoves					
Kerosene wick	40-45	36-41	20.00	10	5.00
Kerosene pressure	45-50	41-45	40.00	10	5.00
Alcohol Wick	40-45	33-37	20.00	10	10.00
Alcohol pressure	45-50	37-42	40.00	10	10.00
Gas stoves					
Central gasifier	55-60	39-42	20.00	10	1.50
Site gasified	40-45	39-44	50.00	4	1.50
Biogas	55-60	54-59	20.00	10	0.00[a]
LPG	55-60	48-53	50.00	20	7.00
Natural gas	55-60	53-58	20.00	20	1.50
Electricity					
Resistance	60-65	17-21	75.00	15	25.00
Microwave	55-60	16-20	250.00	15	25.00
Solar					
Solar box oven	25-30	25-30	25.00	5	0.00

[a]There are substantial capital costs for the fuel system, as well as large amounts of labor involved in collecting the biomass and dung to be put into the digester. For a detailed discussion of this data, including fuel cycle capital costs, see Baldwin, below.

SOURCE: Samuel F. Baldwin, "Cooking Technologies," Office of Technology Assessment, U.S. Congress, staff working paper, 1991.

energy consumption values are converted to their primary energy equivalents, using a fuel to end-user conversion efficiency of 33 percent, then the high efficiency case primary energy consumption—including LPG—increases to 34.3 GJ. The corresponding ratio of primary energy use between the efficient and standard cases (efficient case divided by standard case) is 59.4 percent, compared to their ratio for electricity y consumption of 57.4 percent.

Water Heating

The OTA base case assumes that each household will use 250 liters of 50 'C water daily for a per capita consumption of 50 liters per day. The standard efficiency equipment is an electric resistance storage water heater; the efficient case is a solar water heater with a storage tank and electric resistance heater backup. The solar water heater is assumed to provide 85 percent of the household water heating requirements on an annual average,

Lighting

The OTA base case assumes that residential, commercial, and industrial lighting services will total about 30 million lumen hours per person per year. This is in the middle of the range of lighting levels currently provided in the industrial countries (see ch. 3). No additional use of daylighting or other such techniques is considered. This lighting is assumed to be provided by two 60 W incandescents—one burning 4 hours and one 2 hours each day-within the home for each person and by, on average, a bank of four standard 40 W fluorescent tubes with conventional core-coil ballasts in the commercial and industrial sectors for each person that are used 10 hours per day, 5 days per week, 52 weeks per year. Obviously, there will also be other lights that are used for short periods of time--such as in a hall closet, etc.—that are not included in the analysis here.

The energy efficient case assumes the use of 15 W compact fluorescent lamps to directly replace the 60 W incandescent; and the use of two 32 W high efficiency fluorescent lamps with electronic ballast and a mirrored glass reflector to directly replace the bank of four 40 W standard fluorescent lamps. Data for the efficient fluorescent lamp case is shown in table A-9. To the extent that the assumed utilization rates are relatively low—for example, using one incandescent/compact fluorescent for 2 hours per day and the commercial/industrial fluorescent just 10 hours per day (particularly in industry it might be

Table A-7—Water Heating, OTA Base Case Parameters

Water heater	Water heater parameters: Lifetime years	Capital cost $	Efficiency percent	Solar fraction percent
Standard case:				
Electric resistance	13	360	100[a]	—
Intermediate ease:				
Heat pump water heater	13	800	200[b]	—
High efficiency case:				
Solar water heater	13	1,125	100[c]	85

[a] It is assumed that 100 percent of the electric energy is converted into heat in the water. Standby losses are included in all cases.

[b] The heat pump water heater is assumed to heat water using half the electricity used by the electric resistance heater.

[c] The solar water heater obtains 85 percent of water heating needs from sunlight; the remaining 15 percent is provided by a backup electric resistance heating coil with 100 percent efficiency. The solar water heater is a thermosyphon type with a flat plate collector and a storage tank.

SOURCES: Sunpower, Ltd., Barbados, installed cost October 15, 1990; Howard S. Geller, "Residential Equipment Efficiency: A State-of-the-Art Review," American Council for an Energy-Efficient Economy, Washington, DC, Contractor Report for the Office of Technology Assessment, May 1988; and Howard S. Geller, "Efficient Electricity Use: A Development Strategy for Brazil," American Council for An Energy Efficient Economy, Washington DC, and Contractor Report for the Office of Technology Assessment, 1991.

Table A-8—Lighting, OTA Base Case Parameters

	Lamp Parameters: Lifetime hours	Capital cost $	Efficiency lumens/W	Useful output lumens
Residential:				
Standard case:				
Incandescent	1,000	0.5	12	—
Intermediate case:				
Halogen	3,500	1.50	16	—
High efficiency case:				
Compact fluorescent	10,000	15.00	48	.
Commercial:				
Standard case:				
fluorescent	10,000	43.00	56	2,260
High efficiency case:				
Advanced fluorescent	10,000	68.00	83	2,100

SOURCES: Residential lamp costs are from Gilberto De Martino Januzzi et al., "Energy-Efficient Lighting in Brazil and India: Potential and Issues of Technology Diffusion," Apr. 28, 1991, draft, and from manufacturer data. Commercial and Industrial lamp data is from table A-9, below.

used for longer periods than that)--this increases the effective capital and life-cycle operating costs of the efficient equipment relative to the standard lighting equipment.

Refrigeration

The OTA base case assumes a U.S. style (18 cubic feet or, equivalently, 510 liter adjusted volume) top-mounted *freezer* with automatic defrost that consumes 955 kWh/yr. This is a much larger refrigerator and has more features (particularly automatic defrost) than those generally in use in developing countries today, but is likely to become more popular in the future as the economies of developing countries grow. It is also much more efficient (taking into account its larger size and added features) than refrigerators commonly sold in developing countries today, but is comparable in size and efficiency to new refrigerators sold in the United States. The average U.S. refrigerator, however, has much lower efficiency than this one. This biases the case against more efficient equipment relative to actual existing conditions.

The energy-efficient refrigerator chosen for comparison is technology "I" listed in ch. 3, which uses evacuated panel insulation and higher efficiency compressors, evaporators, and fans than the base case. Much larger and cost-effective improvements in refrigerator performance are possible as discussed in ch. 3.

The capital cost of these refrigerators is assumed to have a retail markup of 100 percent over the factory cost. This is somewhat lower than the 124 to 133 percent

Table A-9-Cost and Performance of Commercial Lighting Improvements, Brazil

	Standard[a]	Efficient[b]
Performance		
Power input	192 W	60W
Rated light output	10,800 lm	5,000 lm
Useful light output	2,260 lm	2,100 lm
Capital costs		
Lamps	$ 9.70	$5.80
Ballasts	$ 33.30	$28.65
Reflectors	NA	$33.95
Subtotal	$ 43.00	$68.40
Annualized capital costs	$ 12.66	$20.18
Annual energy use		
Direct electricity use	507 kWh	158 kWh
Air conditioning energy[c]	142 kWh	44 kWh
Total electricity use	649 kWh	202 kWh
Utility costs[d]		
Capital investment	$296.00	$92.00
Annualized capital cost	$23.85	$7.41
Annual electricity costs	$58.41	$18.18
System wide costs		
Total annual capital cost.	$36.50	$27.60
Total annual operating cost	$71.10	$38.40

NA = not applicable.
[a]Based on four 40 W tubes with conventional core-coil ballast in a standard fixture with completely exposed lamps.
[b]Based on two 32 w high efficiency tubes with electronic ballast and with a mirrored glass reflector. Useful output is so high because of: (1) the narrow 32 W tubes trap less light in the fixture; (2) the electronic ballast operates at high frequencies and raises nominal output of the tube; (3) the mirrored reflector increases useful light output, etc.
[c]This is the amount of air conditioning power needed to remove the heat generated by the lights. This synergism is not included in the OTA analysis.
[d]Utility costs are set at estimated marginal prices rather than prevailing average prices in Brazil which may be undervalued. Thus, capital investment is based on $4,000 per delivered kW and electricity prices are set at $0.09/kWh.

SOURCE: Adapted from Howard S. Geller, "Efficient Electricity Use: A Development Strategy for Brazil," American Council for an Energy Efficient Economy, Washington, DC 1991. Contractor report to the Office of Technology Assessment, November 1990.

markup assumed by the U.S. Department of Energy,[26] but is believed representative of the lower overheads that can be expected in a developing country.

Commercial refrigeration systems are not considered in the OTA scenarios, but information on efficiency improvements in these systems is presented inch, 3.

Table A-I O-Refrigeration, OTA Base Case Parameters

Technology[a]	Lifetime years	Retail capital cost $	Annual energy consumption kWh
	Refrigerator parameters		
Standard case:			
A	20	495.00	955
Intermediate case:			
B	20	495.20	936
c	20	498.40	878
D	20	506.00	787
E	20	514.20	763
F	20	534.00	732
G	20	550.50	706
H	20	561.20	690
Efficient case:			
I	20	635.70	577
More advanced[b]			
J	20	746.20	508
K	20	781.56	490

NOTE: A constant retail markup of 100 percent over factory prices was assumed. This is somewhat lower than the retail markups assumed forthe United States by the Department of Energy, but corresponds to lower overheads in developing countries.
[a]Specific descriptions of these technologies are listed In chapter 3, table 3-13.
[b]These *were* not considered in the OTA high efficiency scenario because, even though they appear to be cost effective on a lifecycle basis, they have substantially higher capital costs due to their projected use of two compressor systems.

SOURCE: *Technical Support Document: Energy Conservation* Standards *for Consumer Products: Refrigerators and Furnaces* (Washington, DC: U.S. Department of Energy, November 1989) publication DOE/CE-0277. See also Table 2-13.

Air Conditioning

The OTA base case averages the use of two air conditioners for both residential and commercial cooling over the five persons per household. One is smaller, at 2 tons equivalent capacity, and uses a relatively low 4000 kWh/year; the other is larger, at 3 tons, and uses a higher 8000 kWh/yr.[27] Combined, these might correspond to a household and a small office demand, respectively. Larger offices, however, would have substantially lower per occupant air conditioning costs and higher efficiencies than those assumed here due to economies of scale in the equipment and much higher capacity factors than those assumed here. The assumed base case efficiencies were, in both cases, an SEER of 8, which is comparable

[26]U.S. Department of Energy, "Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces; Including: Environmental Impacts and Regulatory Impact Analysis," report No. DE90-003491, November 1989.

[27]A ton of air conditioning is the cooling power provided by melting 1 ton-2000 pounds-of ice over a 24-hour period. This is equivalent to 200 Btu per minute or 12000 Btu/hour of heat removal, equivalent to 0.211 (MJ)/minute or 12.66 MJ/hour. The energy efficiency ratio of an air conditioning unit is its cooling capacity in Btu per hour divided by its required power input in watts. Thus, an air conditioner with an EER of 8.0 requires 426.5 watts of energy input to remove 3412 Btu/hour of heat from a building, or equivalently, to remove 1 kW of heat input. An air conditioner with a 2-ton capacity operating continuously consumes (2 tons) *(12000 Btu/hr)/8=3 kW of power, or 26,280 kWh/year. At an annual energy consumption of 4000 kWh/yr, it is then operating at an annual average capacity factor of 15 percent. A 3-ton air conditioner consuming 8,000 kWh per year has a capacity factor of 20 percent.

Table A-1 l—Air Conditioning,OTA Base Case Parameters

	Air Conditioner Parameters			Average power consumption watts
	Lifetime years	Retail capital cost $	SEER	
Low load: 2 ton				
Standard case	15	1,400	8	456
Intermediate case	15	1,700	10	365
	15	2,000	12	304
High efficiency ease.	15	2,300	14	261
High load: 3 ton				
Standard case	15	2,100	8	913
Intermediate case	15	2,400	10	730
	15	2,700	12	608
High efficiency case.	15	3,000	14	521

NOTE: Costs are based on a flat rate of $700 per ton of cooling power and $150 per SEER above an SEER of 8, corresponding roughly to U.S. retail prices installed. Power consumption is in watt--averaged over the year—and is based on the average energy use of 4000 kWh in the low-load case, scaled by SEER using an SEER of 8 for the baseline, and 8000 kWh annual energy use in the high load case, also scaled by SEER.

SOURCE: Office of Technology Assessment, 1992.

Table A-12—Color Television, OTA Base Case Parameters

	Color Television Parameters		
	Lifetime years	Retail capital cost $	Annual energy consumption kWh/yr
Standard Case.	10	.$316 .00	205
Intermediate case 1.	10	$320.30	184
Intermediate case 2	10	$322.90	176
High efficiency case.	10	$323.50	171

NOTE: The assumed lifetimes of 10 years are somewhat longer than the observed lifetime in the U.S. of 7 years. Efficiency improvements include reducing standby power by replacing voltage dropping resistor with a transformer; replacing the surge protection resistor and adding output taps on the power supply; and in the high efficiency case, replacing the picture tube with a slightly higher efficiency picture tube. Much larger efficiency improvements may be readily and cost-effectively achieved.

SOURCE: *Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators, Furnaces, and Television Sets* (Washington, DC: U.S. Department of Energy, November 1988) publication DE89-002738.

to the average for new room air conditioners sold in the United States in 1988, and slightly lower than the SEER of 9 for new central air conditioners (see ch. 3).

These levels of air conditioning are then divided by five (per household) to get the corresponding per capita costs and energy use; these values are then divided in half to reflect an overall average air conditioning penetration of 50 percent of households and offices. In the base case, per capita electricity consumption for air conditioning is then about 1,200 kWh/year. This is comparable to the 1,400 kWh/year used per capita in the United States for cooling residential and commercial buildings (this includes buildings with no air conditioning and cooler climates as well) and is in the same range as that observed in some developing countries for those with air conditioners (see ch. 3).

In hot, humid climates, however, air conditioning loads can be substantially higher than those assumed here. In Florida, for example, air conditioning loads on uninsulated concrete block houses were 8200 kWh/yr--twice the assumed levels here. In large buildings, there is typically a cooling demand year around in order to remove internal heat gains-from lights, people, etc.—which increases the capacity utilization of the air conditioner and improves the cost effectiveness of high efficiency units compared to the values assumed here.

Overall, air conditioning loads could easily dwarf most other electricity demands in hot, humid climates. They are intentionally kept comparable to other demands here, because there is little available data to project future air conditioning demand in developing countries, and because the case presented was intended to be as conserva-

Table A-13-industrial Motor Drive, OTA Base Case Parameters

	Industrial motor drive parameters						
	Motor lifetime years	Motor capital cost $/hp	Pump capital cost $/hp	ASD capital cost $/hp	Annual energy consumption kWh/yr-motor[a]	Weighting by motor	Power consumption by size class watts
Standard case:							
1 hp	15	218.00	75	NA	3,621	0.036283	15
10 hp	19	56.30	75	NA	30,390	0.007782	27
30 hp	22	41.03	75	NA	86,341	0.003956	39
100 hp	28	43.53	75	NA	283,116	0.002506	81
200 hp	29	37.5	75	NA	560,752	0.002155	138
Efficient case:							
1 hp	15	294.00	90	543.00	70%*	0.036283	10.5
10 hp	19	71.40	90	359.70	70%	0.007782	18.9
30 hp	22	49.70	90	203.60	70%	0.003956	27.3
100 hp	28	46.96	90	135.75	70%	0.002506	56.7
200 hp	29	41.24	90	111.07	70%	0.002155	96.6

NA = Not applicable.

SOURCES: Motor lifetimes and weighting factors are derived from table A-1 4. Motor costs are from Marbek Resource Consultants, Ltd., "Energy Efficient Motors in Canada: Technologies, Market Factors and Penetration Rates," Energy Conservation Branch, Energy, Mines and Resources, Canada, November 1987; Pump (fan) costs are very rough estimates from various manufacturers data sheets-note that these rests can vary dramatically depending on the particular type of pump and application; ASD costs are from Steven Nadel, et al., "Energy Efficient Motor Systems: A Handbook on Technology, Programs, and Policy Opportunities," (Washington, DC: American Council for an Energy Efficient Economy, 1991). System engineering and installation costs are assumed to be the same for both standard and energy efficient cases, corresponding to the situation where there is considerable practical experience with high efficiency systems and the development of effective design rules and procedures.

Table A-14-Characteristics of U.S. Motor Population, 1977

	Electric motor size, horsepower					
	<1	1-5	5.1-20	21-50	51-125	>126
Total number, millions	660.0	55.0	10.5	3.3	1.7	1.0
Average life, years	12.9	17.1	19.4	21.8	28.5	29.3
Weighted average size, hp	0.3	2.1	11.9	32.5	86.7	212.0
Average efficiency, %	65.0	77.0	82.5	87.5	91.0	94.0
Average load, %full load	70.0	50.0	60.0	70.0	85.0	90.0
Average capacity factor, %	3.5	7.0	17.4	27.7	37.5	43.2
Total annual use, 10^9 kWhr	30.5	33.9	103.4	155.2	337.7	573.3

SOURCE: Samuel F. Baldwin, "Energy Efficient Electric Motor Drive Systems", Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams, eds., *Electricity: Efficient End-Use* and New *Generation Technologies and Their Planning Implications* (Lund University Press, Lund Sweden, 1989).

tive as possible-higher air conditioning loads weight the case even more heavily in favor of more efficient air conditioning equipment. Finally, it must be noted that many techniques, such as building insulation, improved window technologies, and many others, are generally much more cost effective than even the high efficiency air conditioner case presented here (see ch, 3). Again, these alternatives were not examined, both to keep the standard and efficient cases strictly comparable and to be as conservative as possible.

Electronic Information **Services: Color Television**

The OTA Base Case assumes the use of 19-inch to 20-inch color TVs for about 5 hours per household per day. The standard TV uses about 109 W of power; the efficient TV uses about 91 W of power. As discussed in ch. 3, much greater efficiency improvements are possible using Complementary Metal Oxide Semiconductor (CMOS) electronic devices and power management techniques and, in the future, converting to flat panel displays.

Industrial Motor Drives

The OTA base case assumes the use of standard efficiency motors, pumps, fans, and other equipment. The size class of motors is weighted by U.S. data, as shown in table A-14, Motor costs and efficiencies are discussed in ch. 4.

The energy-efficient equipment case assumes that average savings of 30 percent are realized (a 30 percent reduction in energy consumption), compared to the base case through the use of energy-efficient motors, high efficiency pumps/fans, adjustable speed drives, and the elimination of throttling valves.[28] The corresponding capital costs of motors and Adjustable Speed Drives (ASDs) is listed by size; the capital costs of high efficiency pumps/fans were assumed to be 20 percent greater than standard equipment. The same weighting by size class is used as for the Base Case. No credit is given for potential reductions in the size (and cost) of efficient equipment. No consideration is given to the potential for optimizing the sizes of pipes or ducts, etc., or for improved design rules or other changes. Again, these various assumptions combine to make the case for energy efficient equipment conservative.

Summary

The results of these cases can now be summed as shown in tables A-15 and A-16, These data form the basis of the summary graphs shown in chs. 1 through 4 for the systemwide capital and life-cycle costs of electricity services.

Sensitivity Analysis

Each of the various parameters can now be varied to determine the sensitivity of the analysis to the input values. The results of such a sensitivity analysis are shown in table A-17. This sensitivity analysis shows that the above estimates of systemwide capital costs, life-cycle operating costs, and electricity consumption are fairly insensitive to the input values.

In order to erase the overall capital savings advantage of more efficient equipment: the discount rate for end-users would have to be raised to 2.3 times that for utilities; the marginal cost of efficient equipment would have to be increased by 70 percent over observed values;

28A more conservative assumption would be that two-thirds of the motor drive systems could be retrofit and achieve such 30 percent energy savings while one-third could not be usefully retrofit in terms of cost or energy efficiency (the motor systems might already operate at full constant load with high efficiency). Such an assumption obviously does not reduce the economic or energy savings for the two-thirds of the motors that could be retrofit, but does change the total economy-wide energy and lifecycle and capital cost savings realizable (the numerator is decreased by the change in motor drive systems retrofit while the denominator remains the same). The overall impact is to reduce society-wide energy savings from 47 percent in the case of all motors retrofit to 43 percent if two-thirds of the motors are retrofit; lifecycle cost from 28 percent to 25 percent; and capital savings from 13 percent to 11 percent.

Table A-15-Summary Results for Standard Equipment

Standard system	Capital costs End-user $/capita	Capital costs Utility $/capita	Capital costs System $/capita	Operating cost $/capita	Power Watts	Fuel GJ
Cooking	7.14	17.74	24.87	48.82	52.9	0.0
Water heating	6.80	25.72	32.52	67.25	76.7	NA
Lighting	14.31	24.15	38.45	71.06	72.0	NA
Refrigeration	9.34	7.31	16.66	26.53	21.8	NA
Air conditioning	38.43	45.95	84.38	146.43	137.0	NA
Information services	9.00	1.57	10.57	12.69	4.7	NA
Industrial motor drive	9.80	100.63	110.43	193.76	300.0	NA
Total	94.81	223.07	317.87	566.54	665.0	0.0

NA = not applicable.
NOTE: Many related capital costs, particularly for industrial motor drive, are not included as they are assume to be the same in both the standard and the energy efficient eases,
SOURCE: Office of Technology Assessment, 1992.

Table A-16-Summary Results for Energy Efficient Equipment

Energy efficient system	Capital costs End-user $/capita	Capital costs Utility $/capita	Capital costs System $/Capita	Operating cost $/capita	Power Watts	Fuel GJ/year
Cooking	6.43	6.05	12.48	26.83	14.1	1.3
Water heating	21.23	3.78	25.02	30.12	11.3	NA
Lighting	25.34	7.23	32.58	42.34	21.6	NA
Refrigeration	12.00	4.42	16.42	22.39	13.2	NA
Air conditioning	58.19	26.26	84.45	119.91	78.3	NA
Information services	9.21	1.31	10.52	12.29	3.9	NA
Industrial motor drive	25.44	70.44	95.88	154.21	210.0	NA
Total	157.87	119.48	277.34	408.09	352.24	1.3

NA = not applicable.
NOTE: Many related capital costs, particularly for industrial motor drive, are not included as they are assumed to be the same in the standard and energy-efficient cases.
SOURCE: Office of Technology Assessment, 1992.

the demand for a given piece of efficient equipment would have to be cut nearly in half; or the marginal efficiency gain of more efficient equipment would have to be reduced by one-third.[29]

Similarly, to erase the overall life-cycle cost savings advantage of more efficient equipment: the discount rate for end-users would have to be raised to over five times that for utilities; the cost of electricity would have to be reduced to less than one-third of its marginal cost of production; the marginal cost of efficient equipment would have to be increased by 2.5 times; or the marginal efficiency gain of more efficient equipment would have to be reduced by over two-thirds.[30]

Of particular interest in this sensitivity analysis is that real consumer discount rates must be raised to 2.3 times--or 16 percent real-that for utilities (at 7 percent) in order to erase the systemwide capital cost advantage of energy efficient equipment; and the discount rate must be raised to over five times--or 38 percent real-that for utilities to erase the life-cycle cost advantage of efficient equipment. Some will respond that observed capital costs to end-users can be that high in developing countries. This is true. Such high rates are not primarily due to the difficulty of administering large numbers of loans or other such factors, however, but rather are due to institutional mechanisms that route, often intentionally, capital from end-users to large capital users such as utilities. These mechanisms include taxes on end-users, but tax breaks for utilities; low-interest loans or special financial bonds for utilities; or other such proactive mechanisms. Unintentional impacts of these mechanisms include capital shortages in end-user markets due to the large demand for capital by utilities and other public or favored sectors. As noted in chs. 1 through 4, however, even if consumers had access to capital at rates comparable to those available to

[29] The one-third figure does not include cooking, fo, which the shift from electric resistance burners to LPG burners provides particularly large capital savings. If cooking is included, the marginal efficiency gain of energy-efficient equipment would have to be reduced by two-thirds overall in order to erase the capital saving advantage of energyefficient equipment.

[30] Again, this does not included cooking, as above.

Table A-17—Sensitivity Analysis

Parameter	Baseline	Required value to erase system capital cost advantage of efficient equipment	Required value to erase lifecycle cost advantage of efficient equipment
Discount rate for end-use sectors[a]	7%	16%	38%
Electricity cost:			
Residential/commercial	$0.09/kWh	NA	$0.028/kWh
Industrial	$0.07/kWh	NA	$o.021/kwh
Marginal cost of efficient end-use equipment	Tables A-5 to A-14	70% increase over baseline	250% increase over baseline
Load factor	Tables A-5 to A-14	55% Of baseline load	25% of baseline load
Marginal efficiency Advantage of efficient end-use equipment	Tables A-5 to A-14	66% of baseline efficiency advantage[b]	29% of baseline efficiency advantage

NA = not applicable.
[a]While keeping utility discount rate at 7 percent.
[b]This does not include cooking as the shift from electric resistance to gas burners results in efficiency gains and corresponding capital and lifecycle savings irrespective of the relative efficiency factor.
SOURCE: Office of Technology Assessment, 1992.

utilities, there are a number of market failures which would impede the purchase of efficient end-use equipment by end-users.

If real discount rates increase for both the utility and the end-user, the capital savings realized by installing efficient equipment increase. For example, increasing the real discount rate for both utility and end-user from 7 to 15 percent increases the relative capital savings of efficient equipment from 12.75 percent to 17 percent.

From a societywide perspective, failure to invest in energy efficient equipment thus results in substantially higher systemwide capital costs, life-cycle operating costs, and energy consumption—with all its related environmental impacts--than necessary. A more optimal allocation of capital to end-use efficiency would require changes in institutional mechanisms. Certainly, administrative overheads associated with oversight of large numbers of small loans will lead to higher discount rates than those for the utility sector, but they are unlikely to be twice as high, let alone the five times as high needed to erase the overall cost savings of efficient equipment found in this analysis. Such institutional mechanisms might range from channeling capital through utilities for purchase of efficient end-use equipment by end-users, to mandated efficiency standards, Combinations of these are being used in the United States and other industrial countries.

It is also useful to put the marginal cost of energy efficient equipment in the context of the overall decline in the real cost of consumer goods. As shown in chs. 1 and 2, the real cost of refrigerators in the United States declined by a factor of five between 1950 and 1990 due to improvements in materials and in manufacturing technologies. Averaged over this 40-year period, this is a 12.5 percent annual decline in real cost. In comparison, the energy-efficient equipment costs end users about 67 percent more than standard equipment, or the equivalent of about 5 years worth of manufacturing improvements.

Finally, it must be noted that these changes to erase the systemwide capital cost and life-cycle cost advantages of energy efficient equipment are on top of the highly conservative choices of parameters used in the OTA base case standard and energy efficient equipment scenarios. Based on these considerations, it appears that the overall conclusion—that energy efficient equipment can reduce systemwide capital costs and lifecycle operating costs-is robust,