Title

Making the Market Right for Environmentally Sound Energy-Efficient Technologies: U.S. Buildings Sector Successes That Might Work in Developing Countries and Eastern Europe

Authors

Gadgil, A
Rosenfeld, A H
Price, L

Publication Date

1991-12-01

LBL-31701

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

Presented at the ESETT '91: International Symposium on Environmentally Sound Energy Technologies and their Transfer to Developing Countries and European Economies in Transition, Milan, Italy, October 21–25, 1991, and to be published in the Proceedings

Making the Market Right for Environmentally Sound Energy-Efficient Technologies: U.S. Buildings Sector Successes That Might Work in Developing Countries and Eastern Europe

A. Gadgil, A.H. Rosenfeld, and L. Price

December 1991

ENERGY & ENVIRONMENT DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

DISCLAIMER

Presented at (and to be published in proceedings of):
ESETT '91: International Symposium on Environmentally Sound Energy Technologies and their Transfer to Developing Countries and European Economies in Transition, Milan, Italy, October 21-25, 1991.

LBL-31701

MAKING THE MARKET RIGHT FOR ENVIRONMENTALLY SOUND ENERGY-EFFICIENT TECHNOLOGIES: U.S. BUILDINGS SECTOR SUCCESSES THAT MIGHT WORK IN DEVELOPING COUNTRIES AND EASTERN EUROPE

Ashok Gadgil
Indoor Environmental Program
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

Arthur H. Rosenfeld
Department of Physics
University of California, Berkeley
and
Center for Building Science
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

Lynn Price
Center for Building Science
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

December 1991

This work was supported in part by the Pew Scholars Program in Conservation and the Environment and by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Technologies, Buildings Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

MAKING THE MARKET RIGHT FOR ENVIRONMENTALLY SOUND ENERGY-EFFICIENT TECHNOLOGIES: U.S. BUILDINGS SECTOR SUCCESSES THAT MIGHT WORK IN DEVELOPING COUNTRIES AND EASTERN EUROPE

Ashok Gadgil, Arthur H. Rosenfeld, Lynn Price

LIST OF FIGURES AND TABLES

TABLES

FIGURES

MAKING THE MARKET RIGHT FOR ENVIRONMENTALLY SOUND ENERGY-EFFICIENT TECHNOLOGIES: U.S. BUILDINGS SECTOR SUCCESSES THAT MIGHT WORK IN DEVELOPING COUNTRIES AND EASTERN EUROPE

Ashok Gadgil, Arthur H. Rosenfeld, Lynn Price

ABSTRACT

Between 1973 and 1985, when energy prices were high, all Organization for Economic Cooperation and Development (OECD) countries improved their E/GNP by about 2.5% annually. Increased energy efficiency accounted for 2/3rds of this improvement; the remaining portion was due to structural changes in the economy. In the U.S., analytic and policy tools that have successfully promoted energy efficiency include integrated resource planning, energy use labels, energy use standards, "Golden Carrot" incentive programs, and revenue-neutral "feebates." In addition, a number of low cost, environmentally sound, energy-efficient technologies, such as electronic ballasts, compact fluorescent lamps, and low-emissivity windows, have recently been developed. We discuss how many of these policies and technologies are probably exportable to developing countries and Eastern Europe,[1] giving examples of successful starts in India, the ASEAN countries, and Brazil.

1 INTRODUCTION

Developing countries and Eastern Europe are faced with escalating demands for energy to support the economic and social development of their growing populations and changing economies. Although the per capita Gross Domestic Product (GDP) and energy consumption of these countries are far lower than that of the industrial countries, their energy efficiency is lower and their rate of growth in energy consumption is far higher. Between 1973 and 1988, annual growth in energy consumption averaged 5.4% in developing countries and 2.3% in Eastern Europe compared to an average of 0.9% in OECD countries.[2]

Experience to date has shown that even with impressive expansion of installed generation capacity, energy demand in developing countries and Eastern Europe continues to exceed power system capacity. Rapidly escalating demand, coupled with deteriorating utility performance, has led to persistent unscheduled power outages which result in measurable economic losses to a country's economy.[3] The present power system expansion plans of developing countries and Eastern

---

1 For this paper, developing countries are the non-OECD and non-Eastern European countries excluding the following "newly industrialized" countries: Hong Kong, Singapore, Taiwan, South Korea, Israel, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates.

2 M. Levine, A. Gadgil, S. Meyers, J. Sathaye, J. Stafurik, and T. Wilbanks, *Energy Efficiency, Developing Nations, and Eastern Europe: A Report to the U.S. Working Group on Global Energy Efficiency*, International Institute for Energy Conservation, June 1991. Note: these authors included Turkey and South Africa as developing countries based on their per capita GNP.

3 U.S. Agency for International Development, *Power Shortages in Developing Countries: Magnitude, Impacts, Solutions and The Role of the Private Sector*. Report to Congress, 1988.

Europe will require annual investments of nearly $70 billion until 2000, and about $145 billion for the first quarter of the next century. In comparison, the current annual World Bank lending for the power sector is less than $4 billion; even including the lending from all multilateral and bilateral sources, total lending is less than $10 billion.[4]

To complicate the situation, much of the energy sold worldwide is subsidized, leading to consumer expectations for inexpensive energy and fostering inefficient use of energy. Furthermore, entrenched and powerful bureaucracies in utility companies have historically been exclusively concerned with expanding supply.

Improving end use efficiency offers a way out of this dilemma. The capital requirements for production of many efficient end use technologies are so much smaller than those of equivalent new supply sources that even importing a plant to manufacture energy-efficient technology requires far less foreign exchange than the necessary fractional import of capital machinery for new power generation.[5]

In this paper we focus on creating market conditions to promote the adoption of environmentally sound energy efficiency technologies in developing countries and Eastern Europe.[6] We will first concentrate on the U.S., describing the magnitude of energy savings that can be realized there and discussing methods used to promote improved energy efficiency. We will then describe four energy-efficient technologies that are now penetrating the U.S. market and will discuss their application in developing countries and Eastern Europe. The experience with promotion of energy efficiency in these countries, including adoption of building standards and integration of energy-efficient technologies will also be presented. Finally, barriers to the full realization of potential savings available from improved energy efficiency will be identified.

2 POTENTIAL ENERGY, ECONOMIC, AND GREENHOUSE-GAS EMISSIONS SAVINGS

2.1 Cost of Conserved Energy and Conservation Supply Curves

Energy savings achieved by implementing a given efficiency measure are compared to the annualized cost of the measure using the "cost of conserved energy" (CCE).[7] The CCE can be a useful guide in two cases: 1) when faced with a choice of technologies which satisfy the same end use but have different efficiencies, lifespans and first costs, and 2) when older inefficient equipment is already in place and is not due for replacement, but a new efficient technology exists

---

4 E. Moore and G. Smith, *Capital Expenditures for Electric Power in the Developing Countries in the 1990s*, World Bank, Industry and Energy Department, Energy Series Paper No. 21, 1990.

5 A. Gadgil, A. Rosenfeld, D. Arasteh, and E. Ward, *Advanced Lighting and Window Technologies for Reducing Electricity Consumption and Peak Demand: Overseas Manufacturing and Marketing Opportunities*, presented at the International Energy Agency/ENEL Conference on Advanced Technologies for Electric Demand-side Management, April 4-5, 1991, Sorrento, Italy. Proceeding to be published by IAEE, Paris. Also appears as Lawrence Berkeley Laboratory Report LBL-30389 (Rev.)

6 We note that these policies and technologies are equally relevant for application in Russia and the former republics.

7 For a detailed discussion of CCE calculations see: A. Meier, J. Wright, and A. Rosenfeld, *Supplying Energy Through Greater Efficiency: The Potential for Conservation in California's Residential Sector* (University of California Press, Berkeley, 1983).

that can be used in its place. In the latter case, the scrap value of existing equipment can be incorporated into the CCE calculation.

CCEs of various efficiency measures can be plotted on a *conservation supply curve* where each measure or step (such as "efficiency improvements to residential refrigerators") is defined as follows:

Height = CCE (cents/saved kWh)
Width = annual kWh saved
Area under the step = total annualized cost of investment ($)

The steps are ranked in order of ascending CCE, with the cheapest options plotted first, causing the curve to be upward-sloping. All of the measures on the conservation supply curve below the levelized price of electricity provide energy savings at a net negative cost.

There are a number of underlying assumptions that must be made before a conservation supply curve can be constructed. These choices can make a given application appear more or less attractive. The choices include the level of technology saturation assumed ("technical potential" or "achievable"), the baseline and analysis period chosen, the number of new buildings, appliances, etc. included, whether existing efficiency is frozen or increases naturally, economic considerations such as retail vs. wholesale prices and discount rates, and whether fuel switching is included.

The Center for Building Science at Lawrence Berkeley Laboratory (LBL) has recently compiled and adjusted nine conservation supply curves that depict the technical potential for electricity savings for both U.S. residential and commercial buildings (which consumed 1627 BkWh or 64% of all 2630 BkWh sold in 1989) by about the year 2000.[8] LBL adjusted all curves to a real discount rate of 6%, to frozen efficiency, and to technical potential energy savings. All of these studies were based on available technologies; technologies that only exist as prototypes were excluded. Cumulative electricity savings of the conservation supply curves range between 35% and 55% of the baseline electricity consumption in these buildings. Other conservation supply curves that include technologies that are now only prototypes will undoubtedly result in larger technical potential savings.

Figure 1 presents a slightly modified 12-step Electric Power Research Institute (EPRI) curve which represents the approximate mid-range of the compiled supply curves.[9] The EPRI curve indicates a cumulative savings potential of 734 BkWh, which is 45% of 1989 U.S. building sector electricity use.

The Energy Analysis Program at LBL has also recently completed a comprehensive electricity conservation supply curve for U.S. residential buildings.[10] This curve evaluated the technical (versus achievable) potential for electricity efficiency improvements and assumed a 7% real

---

8 A. Rosenfeld, C. Atkinson, J. Koomey, A. Meier, R. Mowris, and L. Price, *A Compilation of Supply Curves of Conserved Energy*, Center For Building Science, Lawrence Berkeley Laboratory, 1991.

9 The EPRI curve actually includes only 11 steps; an additional first step for white surfaces and urban trees has been added by LBL. A. Faruqui, *Efficient Electricity Use: Estimates of Maximum Energy Savings*, prepared by Barakat & Chamberlin, Inc. for the Electric Power Research Institute, CU-6746, 1990.

10 J. Koomey, C. Atkinson, A. Meier, J. McMahon, S. Boghosian, B. Atkinson, I. Turiel, M. Levine, B. Nordman, and P. Chan, *The Potential for Electricity Efficiency Improvements in the U.S. Residential Sector*, LBL-30477, 1991.

discount rate, an analysis period of 1990 to 2010, and frozen efficiency. For those measures costing less than the price of electric power to residential customers, or 7.6¢/kWh in 1989, the technical potential for residential electricity savings in all buildings in 2010 is about 40%, or 404 BkWh of 2010 baseline use of 1028 BkWh.

Thus, these curves, prepared for the U.S. buildings sector, show that large energy savings are possible at no net cost. Similar, or even larger, savings can be expected in developing countries and Eastern Europe where existing technologies and practices are usually highly inefficient.

2.2 Cost of Conserved Carbon Dioxide (CO_2)

Reducing energy consumption has the added benefit of also reducing emissions of greenhouse gases, such as carbon dioxide (CO_2), that are produced during combustion of fossil fuels and that contribute to global warming. Potential energy savings can also be translated into savings of CO_2 emissions. For electricity this conversion is made using the CO_2 produced by the mix of fuels burned by U.S. power plants,[11] which produce 500 million tonnes (Mt) of carbon (C) for 1990 electric sales of 2610 BkWh, or 0.19 Mt C/BkWh. One kilogram (kg) of carbon is equivalent to 3.667 kg of CO_2, so 0.19 Mt C = 0.7 Mt CO_2. Thus, for U.S. electricity production:

$$1 \text{ kWh} = 0.7 \text{ kg } CO_2 \qquad (1)$$

Using (1), the cost of electricity is then converted as follows:

$$\frac{1¢}{\text{kWh}} \times \frac{1 \text{ kWh}}{0.7\text{kg } CO_2} = \frac{\$14.3}{\text{t } CO_2} \qquad (2)$$

Using (2), net CCE can be converted to the net "cost of conserved CO_2", or "CC CO_2."

Figure 2 shows the EPRI conservation supply curve presented in Figure 1 with the savings converted to units of CO_2. The full x-axis in this figure corresponds to 569 megatonnes of CO_2, which is half of the 1989 U.S. CO_2 emissions from electric generation for the buildings sector. As with energy, there are large potential CO_2 savings at net economic benefit.

2.3 U.S. National Academy of Sciences Study on Energy Efficiency Potential

In early 1991, the U.S. National Academy of Sciences reported potential savings of 1.75 billion tons of CO_2 equivalent per year for the U.S. from various energy efficiency measures.[12] As shown in **Table 1**, this amount is 36% of the total U.S. annual emissions of 4.8 billion tons from fossil fuel identified in the report. All of the efficiency measures used to realize this reduction can be called *"no regrets"* measures because they result in either *net benefit* or *very low cost*. In other words, they either completely or nearly pay for themselves out of energy savings alone, and hence the carbon reduction is either free or inexpensive. Thus, progress can be made toward reducing

---

11 J. Edmonds, W. Ashton, H. Cheng, M. Steinberg, *A Preliminary Analysis of U.S. CO_2 Emissions Reduction Potential from Energy Conservation and the Substitution of Natural Gas for Coal in the Period to 2010*, (DOE/NBB-0085), U.S. DOE Office of Energy Research, Washington, DC, 1989.

12 National Academy of Sciences, *Policy Implications of Greenhouse Warming: Report of the Synthesis Panel*, Washington, D.C., 1991.

emissions of greenhouse gases that contribute to global warming without imposing additional costs on our economy. In fact, all of these measures should provide net economic savings.

The NAS study did not produce a conventional *scenario* (of 20 or 40 years) that includes GNP growth. Instead, NAS simply assumed that all "hardware" (appliance, cars, manufacturing plants) is replaced with today's optimally efficient model as it wears out, and that building shells are retrofit to efficient technologies over the next decade. Since cars and most household appliances are replaced in 10-20 years, and industrial processes and plants are replaced over a 10 to 20 year period, the potential improvements are completed between 2000 and 2010.

Thus, on can project U.S. CO2 emissions for a future date by assuming no substantial structural change and a certain GNP growth rate. For example, using 2005 (when most of the potential improvements in Table 1 could be implemented) and assuming a U.S. GNP annual growth rate of 3%[13], we calculate that the demand for energy services will grow by 50% during this 14-year period. The efficiency gains estimated by the NAS study (shown in Table 1) can save 36%, resulting in energy demand growth of 14% by 2005, or 1% per year. We note that the NAS study was conservative in its assumptions; it did not include any prototype products or the very large savings in *new* buildings. Thus, the NAS study assumed that new U.S. Corporate Average Fuel Economy (CAFE) cars will increase a mere 5 miles per gallon (mpg) with no downsizing of vehicles.[14] However, some automobile manufacturers have already introduced smaller, high-mileage vehicles such as the 1991 Geo Metro and the 1992 Honda Civic VX which both get 55 mpg on the highway. So, the potential energy savings are most likely higher than estimated by NAS, and growth in energy demand and CO_2 could be flat or negative instead of 1% per year.

3 U.S. EXPERIENCE: WHAT WORKS?

Since the Organization of Petroleum Exporting Countries (OPEC) oil embargo, the U.S. has been faced with the need to use energy more efficiently to reduce its reliance on imported sources of energy. Additional concerns over the environmental effects of energy production and consumption have reinforced this need for increased energy efficiency. Thus, we will review the U.S. experience of the past 18 years, highlighting programs that have been successful in reducing energy consumption.

3.1 Recent and Projected Energy Use Trends in the U.S.

Figure 3 shows U.S. energy and electricity consumption (E) and gross national product (GNP) trends since 1960. For the U.S., we define energy intensity as Energy (primary) consumed per dollar of GNP[15, 16], i.e.:

$$\text{energy intensity} = E/GNP. \qquad (3)$$

---

13 U.S. Department of Energy, *National Energy Strategy,* Washington, D.C.: Office of Science and Technical Information, 1991.

14 National Academy of Sciences, *Policy Implications of Greenhouse Warming: Report of the Mitigation Panel,* Washington, D.C., 1991.

15 We recognize that GNP is not the ideal measure of aggregate standard of living for the population (e.g., making obsolescent appliances increases GNP, but hardly improves the quality of life).

16 For this discussion, "E" excludes biofuels since they are renewable, but includes fossil and nuclear fuels.

As a nation industrializes, E/GNP first rises as energy intensive technology is used to build an infrastructure, then falls as more of a service economy prevails and as energy intensities decline with time.[17] This pattern was especially prevalent for the U.S. and other OECD countries; countries that are now industrializing can use more efficient products and methods for both infrastructure building and energy services.

Between 1960 and 1973, energy was inexpensive and no distinction was made between providing *energy* and providing the *energy services* of space heating, lighting, motor shaft power, etc. Accordingly, little explicit attention was paid to improving energy efficiency, which remained "frozen." Primary energy use and U.S. GNP were thus linked, and each climbed about 4% per year. In 1973, the OPEC oil embargo introduced a powerful incentive to conserve energy. During the 13 years of high oil prices and more progressive energy policies from 1973 to 1986, national energy use stayed constant, while U.S. GNP grew by a total of 35%, i.e. 2.4% per year. Of the total savings of 28 exajoules (the difference between GNP-projected and actual consumption during this period), 1/3rd is attributed to structural changes in the economy and the remaining 2/3rds is attributed to improved energy efficiency.[18] Efficiency measures implemented during this period avoided a sharp increase in coal use and hence avoided a rise of 50% in U.S. greenhouse gas emissions.

Even more impressive than the past reductions in primary energy is the electricity conservation also shown in Figure 3. Until 1973, total electricity use was growing at a rate of 7.3% per year (3.2% faster than GNP). Between 1973 and 1986, electricity use grew only as fast as GNP, for an annual savings of 3.2% or 50% in the 13-year period. This 50% savings, 1160 billion kilowatt-hours (BkWh) per year, is equivalent to the annual output of 230 baseload (1000 megawatt) power plants.

In late 1985, when OPEC's oil prices collapsed, gains in energy efficiency nearly stopped. Since 1986, primary energy consumption has climbed again at a rate of about 2.5% per year versus 3% per year for GNP, directly contributing to increased emissions of CO_2. **Figure 4** shows three projections of future energy use: constant energy intensity of the economy (where efficiency is frozen at 1990 E/GNP), the U.S. Department of Energy/Energy Information Administration's "reference case," and a "high efficiency" forecast based on a recent analysis of savings potential following adoption of 14 policy proposals.[19]

3.2 U.S. Utilities: Responsibility and Profit Regulation

Typical U.S. investor-owned utilities generate about 2/3rds of the nation's electricity and sell most of the natural gas. These utilities are regarded as natural monopolies with a responsibility to serve their customers and with their profits regulated by state commissions. Investor-owned utilities raise capital by selling both stock and bonds. The "real" (corrected for inflation) cost of capital for these utilities is about 6% per year, far lower than the cost of capital for consumers that might want to purchase more efficient buildings or appliances.

---

[17] A. K. N. Reddy and J. Goldemberg, "Energy for the Developing World," Scientific American, 263:3, September 1990.

[18] L. Schipper, R.B. Howarth, and H. Geller, Annual Review of Energy, Vol. 15, 1990, and U.S. Office of Technology Assessment, Energy Use and the U.S. Economy, June 1990.

[19] H. Geller, E. Hirst, E. Mills, A. Rosenfeld, and M. Ross, *Getting America Back on the Energy-Efficiency Track: No-Regrets Policies for Slowing Climate Change,* American Council for an Energy-Efficient Economy, 1991.

Until the 1980s, U.S. utilities paid little attention to the difference between *raw energy* and *energy services*. It was believed that the role of utilities was only to sell raw energy. This belief was changed with the introduction of concepts such as "Least Cost Energy Services" and "Integrated Resource Planning." Integrated resource planning includes environmental costs of various energy options. Least cost planning ranks all energy sources, including improvements in energy efficiency, by cost. Under this scheme, if an energy efficiency improvement costs less than a newly constructed power plant and supplies the same amount of energy, then the energy-efficient option should be implemented first.[20]

As individual states in the U.S. address integrated resource planning, they must each determine how to internalize previously ignored environmental costs ("externalities") of energy sources into the resource planning process. Since these decisions are made on a state-by-state basis, there are now various methods of accounting for these environmental externalities. **Table 2** shows four calculations of the cost of specific air emissions resulting from combustion of fossil fuels. By adding these costs to the traditional energy production costs, the societal cost of these energy sources can be more fairly compared to the cost of energy efficiency measures.

3.3 Energy Use Labels for Appliances, Equipment, and Buildings

U.S. experience has shown that consumers are seldom knowledgeable about the energy efficiency of products they purchase. In most cases, the lifetime energy cost of a major appliance is more than the original cost of the product. Consumers can be greatly assisted in making informed decisions through labeling programs that provide clear information about lifetime energy costs.

The largest financial decision most consumers make is buying a home. After mortgage costs, energy is the next largest cost of home ownership. Home energy labeling programs allow consumers to compare the relative energy cost implications of their home-buying decisions and have been successfully introduced in some areas of the U.S.[21] These programs can also be linked to energy-efficient home mortgage programs.

The U.S. has established a mandatory energy efficiency labeling program for domestic refrigerators and freezers, water heaters, and other appliances. These large and highly visible labels inform the consumers of the annual energy costs of operating these appliances. Of course, testing protocols for appliance energy use under standardized "typical" conditions have also had to be developed and applied.

3.4 Energy Standards for Appliances, Equipment, and Buildings

In many cases, it has proven to be far easier and more effective to overcome consumer emphasis on minimizing first cost by removing or discouraging inefficient products from the market, rather than trying to educate consumers on how to make individual energy purchase decisions. A recent study compared various policy options and found that energy standards result in more savings than other methods, including tax credits, rebates, and consumer education.[22]

---

20 F. Krause and J. Eto, eds., *Least-Cost Planning Handbook for Public Utility Commissioners, Volume 2: The Demand Side: Conceptual and Methodological Issues*, NARUC, 1988.

21 E. Vine, B.K. Barnes, R. Ritschard, "Implementing Home Energy Rating Systems," Energy 13 (5), 1988.

22 U.S. Congress, Office of Technology Assessment, *Changing By Degrees: Steps to Reduce Greenhouse Gases*, Washington, D.C.: U.S. GPO, 1991.

Currently, the U.S. government has set energy efficiency standards for 13 major home appliances and fluorescent ballasts. (See section 4.4 of this paper for a discussion of the savings attributable to refrigerator standards enacted in California.) Significant additional energy and CO_2 savings may be achieved by setting standards for other products such as motors, lamps and lighting fixtures, office equipment, windows, and commercial HVAC and refrigeration equipment.

3.5 Golden Carrots: Motivating New Products that Beat the Standards

It would be beneficial to society, and to those utilities whose profits are linked to efficiency, to promote further efficiency improvements, i.e. to "beat the standards." This is the motivation behind the "Golden Carrot" program championed by David Goldstein of the Natural Resources Defense Council. The name "Golden Carrot" is based on the saying that to manage your donkey you need a combination of a stick (standards) and a carrot (reward for beating the standard).

The Golden Carrot program recognizes that products that beat the standard by a substantial margin (say 20%-40%) can be brought into the market successfully only if the volume of sales is large enough that economies of scale lower the incremental manufacturing cost (including the cost of the new production line) to a market-bearable amount. The Golden Carrot program seeks to meet these conditions by offering cash rebates to a large (but fixed) number of first purchasers of the product (e.g. $200 rebate per refrigerator to the first 250,000 refrigerator purchasers) and large cash incentives (e.g. $50 million) to a manufacturer to set up a new production line.

The U.S. Environmental Protection Agency (EPA) and about 20 utilities have joined together to promote such a Golden Carrot program and are pooling funds to create an incentive pool of between $20 and $50 million for the production of a large refrigerator-freezer (18 cu. ft.) with annual electricity usage reduced to 350-500 kWh. This program lead to the formation of the Consortium for Energy Efficiency that has the goal of expanding the Golden Carrot program to include more appliances and other existing and emerging energy-efficient technologies.

The Golden Carrot program has swept the U.S. and Canada and is also underway in Sweden. In 1990, the Swedish Energy Administration (STEV) held a competition for refrigerator-freezer manufacturers to design and supply a specified number of units that would consume at least 30% less electricity than used by the best model currently on the market. The competition was won by Electrolux, and the Swedish government has arranged to purchase a specified number of units of Electrolux model TR 1060 LE, a 370 liter refrigerator-freezers at 314 kWh/year (35% lower consumption than the best available model worldwide), and of model TR 1060 SLE, of the same volume, that uses only 212 kWh/year (55% better than the best available model worldwide).

3.6 Revenue-Neutral "Feebates" for Whole Buildings, Appliances, and Automobiles

Revenue-neutral fee/rebate incentives for new appliances, whole buildings, and automobiles are a good way to strengthen the market for energy-efficient technologies. A "variable hookup fee" involves setting target energy consumption and peak demand values for each category of new building. Buildings exceeding the average electricity intensity (watts per square foot) would pay a fee of $1000/kW which would be rebated to those buildings with energy use below the target.[23] The target would be adjusted annually to keep the account revenue-neutral and a portion of the fees

[23] The value of $1000 per kW could be used because it is roughly equivalent to the cost of an avoided kW of peak capacity.

would be allocated to cover administrative costs for running the program. Bills proposing this policy have been introduced in both the Massachusetts and California legislatures.[24]

Fee-bates for appliances and variable hook-up fees have not yet attracted much international interest, but a California fee-bate bill for automobiles has received broad attention. In 1990, the California House and Senate enacted a sliding scale fee-rebate system, called "Drive-Plus," which finances rebates for relatively efficient and non-polluting motor vehicles by taxing the poorer performers in the same vehicle classes. Drive-Plus addresses emissions of hydrocarbons, oxides of nitrogen, carbon dioxide, carbon monoxide, and particulates. [25]

3.7 U.S. Weaknesses

Despite the remarkable success in promoting increased energy efficiency in the U.S. during the past 18 years, problems remain that hinder the realization of the energy savings to the level approaching the full technical potential. Market barriers are one reason for this problem and these barriers are discussed in section 6 of this paper. Other reasons for the failure to use energy as efficiently as technically possible include inadequate monitoring and program evaluation, a shortage of trained building designers and tools, a shortage of trained auditors and retrofitters, and inadequate research and development funding to keep the pipeline full of more efficient products.

4 ENVIRONMENTALLY SOUND ENERGY-EFFICIENT TECHNOLOGIES

During the past decade, significant strides have been made in the development of low cost, environmentally sound energy-efficient technologies. **Table 3** provides a summary of the characteristics and economics of three technologies that will be described in this section: high frequency electronic ballasts, compact fluorescent lamps, and low-emissivity windows. These technologies illustrate that there are remarkable benefits-to-costs ratios realized with research and development funding of energy-efficient technologies. We finish this section with a discussion of the value of energy efficiency standards for refrigerators.

Low-emissivity (low-E) windows, high-frequency electronic ballasts, and compact fluorescent lamps (CFLs) are three energy-efficient technologies that have been recently developed to reduce energy consumption in space conditioning and lighting of buildings. **Figure 5** shows recent and projected sales for electronic ballasts and CFLs, illustrating their rapid market adoption. Almost all sales of these technologies are in commercial buildings and are concentrated on the West Coast and in New England where utilities have promotion programs.

These technologies are rapidly gaining acceptance in the U.S. and should now be attractive for use in developing countries because they can be manufactured indigenously, require relatively small capital investments, and save both energy and money for the local economy.

---

24 Massachusetts House Bill 5277 "An Act Reducing the Greenhouse Effect by Promoting Clean and Efficient Energy Resources" was defeated in 1990. The 1991 version of the bill is being introduced by Representative Cohen and currently has 60 cosponsors. The Massachusetts Public Interest Research Group is also sponsoring the bill. In California, Senate Bill 1210 introduced by Senator Calderon, "Pilot-Project Variable Utility Hook-Up for Energy-Efficient Buildings" has passed the Senate.

25 Drive-Plus was introduced by Senator Gary Hart as CA Senate Bill No. 1905, 1990.

4.1 High Frequency Ballasts

Fluorescent lamps cannot be wired directly across 110 or 220 volt lines; they must be protected with "ballasts" which were originally inductors with steel cores and copper windings that got hot and wasted about 16 watts for every pair of 40 watt (120 cm) lamps. Modern efficient core-coil ballasts still dissipate 10 watts. But today one can make a solid-state power supply which dissipates only 4 watts. Further, if this ballast-substitute supplies power at 50,000 Hertz (cycles per second -Hz) instead of 50 or 60 Hz, the fluorescent lamp itself turns out to be 10% more efficient, for a total gain of 22%. A further benefit of electronic ballasts is that they are easier to control electronically, permitting "daylighting" by automatically dimming lights to save electricity when daylight is available. This raises the system efficacy of fluorescent lamps powered through such electronic ballasts, averaged over an entire floor of an office building, easily 30 to 40% above fluorescent lamps powered with undimmed "standard" ballasts.

The electronic ballast was developed through U.S. Department of Energy (DOE)-sponsored research at Lawrence Berkeley Laboratory (LBL) in the late 1970s. Electronic ballasts are now commercially available in the U.S. for about $15 each wholesale ($8 more than standard ballasts), saving 1330 kWh (worth about $100 each) over its 10 year lifetime (See Table 3). Between 1985 and 1990, 8 million electronic ballasts were sold in the U.S. Based on the net lifetime savings of $92 per ballast, cumulative net lifetime savings for these 8 million ballasts is about $750 million. As shown in Table 3, there are 600 million ballasts in place today, and when replaced with high-frequency ballasts annual savings will be 80 BkWh, emissions of 55 Mt CO_2, and expenditures of $5.5 billion annually. The initial DOE project to develop electronic ballasts cost $3 million and is estimated to have advanced commercialization by 5 years, for a net project savings of over $25 billion. This represents over an 9000:1 return on DOE's investment.

4.2 Compact Fluorescent Lamps

Fluorescent lamps are about four times more efficient than their 100-year old incandescent ancestors. However, before the advent of high-frequency ballasts in the late 1970s, inefficiency at each end of these lamps made it impractical to make the lamp shorter than about two feet. Development of the high-frequency ballast eliminated these end-losses and ushered in the CFL which can be screwed into sockets now occupied by incandescents. The first CFL, produced in the 1980s, was the Philips SL-18 with a high-frequency ballasts. Since that time, CFL technology, especially the phosphors, has improved so much that CFLs are now cost-effective even with 60 Hz core-coil ballasts.

Incandescent lighting consumes about 8% of all U.S. electricity, or the equivalent output of nearly 40 baseload power plants. CFLs will only require half of this power, allowing the power from about 20 baseload power plants for other uses.

An individual CFL rapidly pays for itself through reduced energy bills. For example, in the U.S. one 16-watt CFL replaces a series of about one dozen 60-watt incandescents since it burns 12 times longer than the incandescents. As shown in Table 3, this CFL would save 440 kWh (worth about $33 in electricity costs) over its 40-month life in a commercial building. A modern, automated CFL plant costs $7.5 million and can produce 6 million lamps annually. These six million lamps will save over 2.5 BkWh annually, equivalent to the annual electricity sales of a 500 megawatt intermediate or baseload power plant that costs $1 billion to construct.

Many developing and Eastern European countries face a situation of explosive electricity demands and large end-use inefficiencies. For such countries, construction of CFL production plants and installation of energy-saving CFLs represents a painless way to conserve scarce electricity.

For example, demand for electricity in India is so great that 70% of the residences are not electrified and many industries suffer power shortages. Instead of meeting all the increasing electricity demand with capital-intensive, environmentally destructive generating plants, India could reduce the gap between supply and demand with CFL plants for a fraction of the cost. In India and most of the developing world, incandescent lamps drive peak demand, so the alternative lamps produced in five years by a CFL plant would save the equivalent of 3700 megawatts of installed peak capacity. Providing such capacity from traditional energy sources would cost between $2.8 billion for gas turbines and $5.6 billion for coal-fired thermal power stations, substantially more that the $7.5 million needed for the CFL production plant.[26]

India is an example of the *twice* tilted playing field in the competition between energy efficiency and supply. First, import taxes on components for power generation plants are only 30%; CFLs are charged a customs duty of over 250%. Second, residential electricity is subsidized by commercial and industrial customers. Because of this, there is no residential market for CFLs. To overcome these barriers, an experimental program promoting installation of CFLs in residences in Bombay, India is about to be launched. This program, the Bombay Efficient-Lighting Large-Scale Experiment (BELLE), is described in detail in section 5.3 of this paper.

4.3 Low-Emissivity Windows

Heat losses and gains through windows are responsible for 25% of all heating and cooling requirements in U.S. buildings. The Alaskan pipeline, pumping 1.8 million barrels of oil per day (Mbod), just makes up for the natural gas burned every winter to replace the heat lost through U.S. windows.

In the late 1970s, research at Lawrence Berkeley Laboratory (LBL), combined with private industry efforts, resulted in the development of double-glazed windows with low-emissivity (low-E) coatings filled with low-conductivity gas such as argon. These low-E windows resemble the familiar double-glazed ("thermopane") windows but have thin film coatings applied to at least one of the inner surfaces. These films are transparent to light but reflect 85% of room-temperature heat, significantly reducing winter heating needs. This cost-effective film is slowly saturating the market, and has doubled the thermal resistance (R)[27] of old-fashioned "thermopane" windows (from R-2 to R-4).

Significant energy savings can be garnered by using low-E windows in the construction of new buildings. For example, as shown in Table 3, a small (one square meter) low-E window costs about $20 more than a conventional double-glazed window but, in a winter application, saves ten gigajoules (ten million Btu) of natural gas worth about $70 over its 20 year lifetime.

Many major U.S. window manufacturers such as Andersen, Pella, and Marvin, now offer low-E windows exclusively. During the past five years, 50 million of these windows were sold in the U.S. When market saturation is reached and 70 million low-E windows are sold annually, the yearly net savings from these windows will be $4 billion. This savings will displace 300,000 equivalent barrels of oil per day, also equivalent to the production of 30 offshore oil platforms.

Although low-E windows were originally designed to reduce thermal losses in winter, they can be equally effective in hot summer applications. As developing countries become urbanized and industrialized, afternoon peak electrical demands occur because of air-conditioning and industrial

---

26 A. Gadgil, et al., op. cit., footnote 5.

27 In these "R-" units, a single-glazed window is R-1, double-glazed is R-2, and a wall insulated with 10 millimeters (4 inches) of fiberglass is typically R-11.

requirements. If new buildings are constructed with low-E windows in these countries, air conditioning demands can be significantly reduced.

In the Association of South East Asian Nations (ASEAN) countries of Indonesia, Malaysia, the Philippines, Singapore, and Thailand, urban areas are growing rapidly. In these countries, over 30% of the electricity generated is used by commercial buildings and it is estimated that this percentage will continue to increase.[28] In Bangkok, Thailand, about half of the total electricity consumed in commercial buildings is for air conditioning. For a centrally air-conditioned office building in Bangkok, it has been calculated that one square meter of low-E window reduces the building's heat gain such that over 60 kilowatt hours (kWh) of electricity worth $5 can be avoided annually. Because of the reduced air conditioning needs, the building's chiller and auxiliary can be down-sized, saving more than the initial cost of the low-E windows and resulting in a *negative* cost to conserve energy.[29]

For an investment of $10 million, a low-E window coating plant can be constructed in countries with high air-conditioning demands. In a year, one plant will produce about two million square meters of low-E windows, which, *over their 30 year service life,* will save almost four terawatt hours. This savings is equivalent to the annual sales from an 800 megawatt power plant that would cost $1.5 billion to construct. For a much smaller investment (about $1 million) a plant can be set up to manufacture windows locally incorporating rolls of coated plastic film that can be imported to match the demand.

4.4 Efficiency Standards

An example of the benefits of standards in improving energy efficiency is provided in the last column of Table 3. This column illustrates the energy and economic savings attributable to the 1985 California refrigerator and freezer appliance standards when compared to 1976 base case appliances.

The efficiency of refrigerators has varied greatly over the last 40 years. In 1950, refrigerators used about 650 kWh per year. This increased to about 1,800 kWh per year by 1975 because motor efficiency and wall thickness was reduced and defrost cycles and various convenience items were added. Since refrigerators use 15% of electricity in homes, such efficiency loss was significant. The U.S. enacted national refrigerator/freezer standards effective in 1990, estimated to save 0.6 quads per year between 1990 and 2015 and new standards on these and other appliances effective in 1993 that will save another 0.3 quads per year.[30]

---

28 M. Levine, "ASEAN Building Energy Conservation Program," *Proceedings of the Conference on Energy Efficiency Strategies for Thailand*, March 4-6, 198, Pattaya, Thailand. Also LBL-26759.

29 A. Gadgil, et al., op. cit., footnote 5.

30 J.E. McMahon, et al., Impacts of U.S. Appliance Energy Performance Standards on Consumers, Manufacturers, Electric Utilities, and the Environment, *ACEEE 1990 Summer Study on Energy Efficiency in Buildings Proceedings.*

5 EXPERIENCE OF DEVELOPING COUNTRIES

5.1 Utilities in Developing Countries

Several major characteristics are common to utilities in developing countries. First, because availability of electricity has been seen by developing country governments as a key aspect of the development process, historically the governments have taken a lead (and often legislated an exclusive) role in investments and operation of the electricity sector. In most developing countries, the government (or a government owned and financed corporation) is the sole owner and operator of electricity services. The electricity sector owns and controls very large amount of capital stock; sometimes it is the financially most powerful sector of the government. Large and powerful bureaucracies operate this sector; owing to their past dedication to the increase in power supply, their thinking and operations are supply dominated (often exclusively so). Like all large and mature bureaucracies, they are resistant to challenges to their traditional ways. In practical terms, this means that most do not have a strong commitment to identify and implement least cost solutions to supplying energy services. Often there is only an understaffed and powerless ("without teeth") office that is "responsible for conservation."

Another major common characteristic of the developing country utilities is the subsidized electricity tariffs, particularly for domestic sectors (and sometimes also for small commercial and small-scale industrial sectors, because these are operated in conjunction with the residence of the sole proprietor). The justification for subsidy is societal; access to affordable electricity is considered (and probably is) essential to improved standard of living, literacy, and "modern civilization." If the electricity tariff were its true marginal cost it would not be affordable to a large majority of the population in the poorer developing countries. This logic is also extended to subsidize electricity supply to agricultural pumping, for example, in India. The agricultural sector is seen as essential for national self-sufficiency in food supply (or what is called "food security" in modern analyses). As a result, the tariffs for the agricultural sector in India can be as low as US$ 0.01/kWh; in some parts of the country there is a small flat monthly charge, and no meter and no tariff.

A third common characteristic of utilities in the developing countries is that most of them are losing money as a result of low tariffs and rising costs of electricity expansion. The short fall is made up by "loans" from the government to the (government owned) utilities. It is not clear how and when these can be repaid. There is substantial political pressure on the utilities to keep the tariffs low. As a result, the utilities are fed up with subsidies and are struggling to keep themselves from going bankrupt. They are thus deaf to any suggestion that a subsidy from the utility to an energy-efficient appliance may be economically viable and a better alternative to system expansion.

Oil and gas are treated much like electricity. In oil or gas exporting countries, the problems are commonly further complicated by assigning low energy prices to the fossil fuels in the domestic markets, which undercuts any efficiency improvements.

In spite of the difficulties mentioned here, there are several examples where developing countries have made significant and substantial improvements in the efficiency of their energy use. A few examples are described below by way of illustration.

5.2 Developing Country Experiences With Energy Efficiency

Several ASEAN countries (in particular Thailand, Singapore, Malaysia) have experienced very rapid growth in office buildings, and associated electricity consumption for cooling. Commercial buildings in the ASEAN countries already consume more than 30% of the total electricity generated in the region. The growth in demand from this sector is so rapid that it is estimated to account for

40% of new electricity demand in the near future.[31] With scientific support from researchers at Lawrence Berkeley Laboratory, teams from these countries developed their own standards for new buildings based on the computer program DOE-2, aimed at limiting the rapid growth of electricity demand for cooling from new construction. Some of the standards are based on simplified methods for energy consumption, that were calibrated with the use of DOE-2.

A national electricity conservation program named PROCEL was initiated in Brazil in 1985. Until 1989, PROCEL primarily engaged in technology R&D, demonstration projects, educational and promotional campaigns, and direct installation of conservation measures. As of 1990, PROCEL had undertaken projects worth about $ 20 million, with matching contributions from utilities and research institutions. One of PROCEL's large projects has been outright replacement of incandescent street lights with mercury vapor or high-pressure sodium lamps. About 300,000 lamps were replaced by 1989, with most of the lamp cost paid directly by PROCEL. This activity has continued, with utilities bearing the cost of replacement. This is necessary because the municipalities that own and operate the lamps are financially too strapped to make the investments in efficient lamps themselves. The utilities have incentive to replace the lamps because they sell electricity for those lamps to the municipal councils at a lower tariff than the utilities' cost of generation and distribution. Although it is difficult to estimate the magnitude of total energy conservation that can be attributed to PROCEL's efforts, the officials operating the program attribute electricity savings of at least 1.1 TWh annually as of 1989 to their programs. Some estimates of savings are as high as 2.5 TWh annually.[32]

5.3 BELLE: The Bombay Efficient-Lighting Large-scale Experiment[33]

Negotiations on the BELLE project are currently underway among the Bombay Suburban Electric Supply Limited (BSES) utility, Philips India, Indira Gandhi Institute of Development Research (IGIDR), and the Program for Acceleration of Commercial Energy Research (PACER). Participation of additional lighting manufacturers is also being negotiated. The BELLE Project will demonstrate utility profits and benefits for residential and industrial customers that may lead to the construction of a CFL factory in Bombay. Replacing one household's incandescent bulbs with CFLs will allow three additional unlit households (suffering from power shortages) to receive lighting with CFLs, or will allow the additional electricity to be used elsewhere in the power short economy.

Since the long term goal of the project is to establish a market mechanism for large scale diffusion of energy-efficient end use technologies that will be indigenously produced, the project is based on economic calculations and trade-offs that do not take into account the present high customs duty on import of individual CFLs. The participating lighting manufacturers are committed to establishment of local CFL production facilities once the market can be demonstrated.

BELLE will be conducted in three stages:

1. Planning has been underway since late 1989 and will include input from consumer panels in 1991. The planning process addresses the three key areas of the technical aspects of CFL

---

31 M. Levine and J. Derringer, *Implementation Strategies for Achieving Energy-Efficient Buildings in ASEAN*, in Proceedings of the Workshop on Energy Conservation Policy and Measures for Energy Demand Management, October 12-16, 1987, Bangkok, Thailand. Also Lawrence Berkeley Laboratory Report LBL-24134, October 1987.

32 H. Geller, *Electricity Conservation in Brazil: Status Report and Analysis*, American Council for an Energy-Efficient Economy, 1990.

33 Discussion of the BELLE project is excerpted from A. Gadgil, et al., op. cit., footnote 5.

performance under Indian power conditions, the leasing scheme, and methods for promoting the replication of the successful project.

2. Phase One -- The Pilot Experiment -- includes installation and testing of 1000 CFLs over 6 months. Preliminary findings will be used to develop technical specifications for the CFLs. Three or four models of CFLs will be tested in the 1,000 CFL Pilot Test. The CFLs will be installed in targeted Bombay households, and their technical performance and consumer acceptability will be monitored and assessed over a 6 month period. The results of this trial period will determine which CFL will be used for the full-scale experiment. Preliminary advertising, educational, and promotional materials will also be developed and tested during this period. Feedback from presentations to consumer groups will guide the consortium members in designing BELLE's marketing approach.

3. Phase Two -- The Full-Scale Experiment -- includes installation of 17,000 CFLs and monitoring for four years using a three-part survey. In the Full-Scale Experiment, 19,000 CFLs will be purchased and 17,000 will be installed in targeted households that have agreed to participate in BELLE. Three detailed surveys will be carried out during the four years of Phase Two to monitor consumer response to BELLE as well as the technical performance of the CFLs.

The twenty thousand CFLs will be purchased abroad with hard currency loan monies from a supporting agency such as PACER.[34] An innovative utility-leasing program (modeled after successful programs in the U.S.), will be used to reduce the CFL purchase price from a large one-time payment to many payments over a long period. This is necessary because each CFL costs more than half the monthly income of an average Indian.

For the leasing program BSES will collect monthly lease payments for CFLs from its residential customers of Rs. 6 - 7 per month.[35] Over four years this fee will pay for the CFLs' first cost (excluding interest charges). The customer will realize savings of Rs. 8 - 9 per month from reduced electricity bills and savings of another Rs. 1 per month in avoided incandescent light bulb purchases.BSES, Philips, and PACER will share the overhead costs for planning, administering and monitoring the project in proportions that are yet to be finalized. These expenses are currently estimated at approximately Rs. 2 per CFL per month. Because of its ground-breaking nature, BELLE will incur some first-time costs (especially for multiple market surveys and technical research) that will not apply to future versions. Monthly revenue for BSES of Rs. 0.5 - 2 per CFL will result from avoided subsidies to the residential sector. This revenue will help to offset overhead costs.

The electricity conserved by BELLE will be made available to households and industrial customers on the Western grid. Because of existing regulatory and equipment constraints, it will be difficult for the consortium to receive direct revenue from these sales. However, each CFL saves India more than Rs. 1,000 over its lifetime in avoided investments in peak generating capacity. This represents societal savings from avoided investments in power plants of Rs. 16 per month per CFL, in addition to avoided impacts on India's environment. BSES customers incur almost no

[34] The loan amount will be immediately returned in local (soft) currency to PACER after the CFLs are landed in India, by refinancing the project locally. With the help of the funding agency, the consortium will request that the government charge a customs duty rate on CFLs for BELLE that is no higher than the rate charged for imported components of large power projects. This rate is currently about 30% compared to the more than 250% duty which would otherwise be charged for CFLs. Without such an adjustment in the customs duty, BELLE would be uneconomic.

[35] In 1985, U.S. $1 = Rs. 12.

risk by participating in BELLE: the CFLs are guaranteed against early failure by free replacements; and household participation in the program can be terminated at any time with no penalty.

The BELLE Project is the first utility-sponsored demand management program to be initiated in India. For this reason, careful consideration will be given to preparing materials that document BELLE's financial, technical, and managerial structure. If successful, BELLE will demonstrate that innovative institutional partnerships can overcome the "real-world" constraints that presently limit the attractiveness of CFLs to those participating in the project. BELLE should provide BSES and other utilities with the information and experience necessary to establish their own innovative, profitable, large-scale, energy efficiency end use programs. Eventually, demand management programs throughout India may succeed in slowing the rate of supply expansion, allowing capital to be diverted to other sectors of the economy.

A number of lessons have been learned from the successful development of projects such as the BELLE proposal described above. First, utilities benefit from conservation because they are losing money on subsidized tariffs and every kilowatt-hour conserved earns them an avoided subsidy. Because they are almost always power-short, they can sell the conserved kWh elsewhere (say to industrial customers) at a much higher tariff and obtain even larger benefits. Second, customers are risk averse and capital short. They benefit from BELLE-type efficiency programs because the utility fully finances their conservation investment, and guarantees its performance. After the lease charges (set to be less than the monthly savings in electricity bill) are full paid up, the consumers enjoy the full benefit of the efficient technology for the remainder of its life. Third,the producers of highly efficient (and costly) equipment, who do not see a market for their product, can now sell large quantities directly to the utility. This encourages them to produce the goods locally, driving down the unit costs in the local market owing to absence of customs duty and economies of scale.

It was also learned that there is a large need for financing for BELLE-like methods, although the financing requirement is still substantially smaller (about 6 times smaller, for the BELLE project described above) than that needed for an equivalent new power plant. Financing is required not only for setting up a factory for production of the efficient equipment, but also for financing the lease-purchase of the first several years of production from the factory (until the stock of appliances reaches a plateau). Subsequent years' production from the factory is then taken up for replenishing the stock, as appliances wear out. For example, while a factory to produce CFLs costs only $ 7.5 million, financing for the first three years' production (6 million CFLs at $12/CFL) is US$ 216 million. The large size of financing required for BELLE-type projects makes them large enough to be of interest to international lending agencies like the World Bank, who otherwise find small projects (like a US$ 10 million CFL plant) not worth the trouble to do the paperwork for.

5.4. Eastern Europe

The recent political changes in Eastern Europe have caused local energy prices to rise rapidly, which has been followed by a growing interest in energy efficiency programs and technologies. In Czechoslovakia, the electricity tariff for industrial customers was raised several times in the last year, including an 80% increase in the Spring of 1991. Industrial tariffs are now about 4¢/kWh. Even residential electricity tariffs were raised by 70% in November, 1991, to about 2.5¢/kWh. Industry analysts believe that the industrial tariffs are now approximately equal to marginal costs. District heating tariffs are also rising toward subsidy-free levels. There was a 300% price increase in May of 1991 and the current price for residential customers is about $3 per gigajoule (~ MBtu). Both Czechoslovakia and Poland are interested in privatizing their utilities, but investors are hard to find. Meanwhile the utilities have been divided into smaller units, with the distribution companies transferred to the communities they serve.

Following a recent visit by a group of Western least cost utility planning (LCUP) and demand-side management (DSM) experts, utility and government representatives from these two countries expressed interest in LCUP and DSM. Officials from the Czech utility in Prague (CES) requested that one of the experts serve as an advisor on how they should proceed with LCUP and DSM. The power-hungry Slovak utility (SEP) in Bratslavia related that they were committed to completing a nuclear power station which will be expensive because they have to buy Western quality controls and instrumentation. Also, their Danube dam at Gabcikovo is financially troubled because of environmental concerns. Because of these problems, they too are interested in pursuing LCUP and DSM. Finally, similar interest was seen in Poland, with the Polish government announcing in a press conference that they plan to proceed with LCUP.

This interest on the part of Eastern European utilities and governments, coupled with the fact that there is undoubtedly a vast array of rapid payback conservation measures that can be taken in these countries, has generated interest for investing in these measures among utilities, ESCOs, and energy efficiency industries in industrialized countries. Recently established Energy Efficiency Centers in Prague, Warsaw and Budapest will be able to provide technical support and monitoring for any efforts undertaken.

6 BARRIERS[36, 37]

For a variety of reasons, households, businesses, manufacturers, and government agencies in both industrialized and developing countries fail to fully exploit cost-effective energy-conserving opportunities. The result is a significant gap between current and optimum levels of energy efficiency. The reason this occurs is that there are a number of barriers in the research and development, production, commercialization, acquisition, and use of energy-efficient systems. These barriers include a lack of international and national funding for efficiency investments, a lack of effective collaboration between industrialized and developing countries, weak national commitments to efficiency, weak national institutional capability, supply-oriented and centralized utilities, energy subsidies, the payback gap, a lack of energy-efficient products, a lack of information on energy-efficient products and practices, and capital constraints. For an excellent discussion of these barriers and proposals of ways to overcome them, see Ref. [38].

The following discussion addresses only two of these barriers, the payback gap and energy subsidies; other barriers are equally as effective in preventing investments in energy efficiency.

6.1 The Payback Gap

As evidence of these barriers, consumers in all sectors implicitly require very fast paybacks when making tradeoffs between greater initial costs and reduced operating costs. The resulting problem, often referred to as the "payback gap," is a significant difference between investment criteria for

---

36 The discussion in Section 6 and 6.1 is excerpted from H.S. Geller, et al., op. cit., footnote 19.

37 For a review of the literature on barriers to increased energy efficiency see: E. Hirst and M. Brown, *Closing the Efficiency Gap: Barriers to the Efficient Use of Energy*, Oak Ridge National Laboratory, 1989; C. Blumstein, B. Krieg, L. Schipper, C. York, Energy 5(4), 355, 1980; P.C. Stern and E. Aronson, Eds., *Energy Use: The Human Dimension*, National Research Council, 1984; and A.C. Fisher and M.H. Rothkopf, "Market Failure and Energy Policy," *Energy Policy 17*, 397, 1989.

38 A.K.N. Reddy, *Barriers to Improvements in Energy Efficiency*, Second International Workshop on Energy and Global Climate Change, Lawrence Berkeley Laboratory (LBL-31439), October 1990.

energy efficiency versus energy production investments. Four contributors to the payback gap are: 1) insufficient information, 2) limited consumer access to capital, 3) investment rules and split incentives (e.g. landlord vs. tenant, building vs. occupant), and 4) shortage of infrastructure and skilled workforce.

For example, electric utilities accept 10 to 15-year payback times on their investments, whereas studies of efficiency choices reveal implicit payback times ranging from a few years to a few months.[39] In industry a two-year payback requirement is typical. The payback gap leads to excessive energy use and less-than-optimal investment in energy efficiency from the perspective of minimizing the cost of energy services. **Figure 6** shows the results of a survey of the 660 commercial customers of Potomac Electric Power Company. This survey found that the bulk of the customers required payback periods of 3 years or less and that only 16% of the customers were willing to consider energy efficiency investments with payback periods of 4 years or longer.[40]

Some economists believe that the payback gap must be a surrogate for costs of acquiring energy efficiency which are not explicitly calculated, such as the costs of information and the costs associated with risk of failure. The literature shows instead that the payback gap is large even when such costs are accounted for. In short, market imperfections are real and substantial.

Compounding the payback gap, in many instances the life-cycle cost curve (energy costs plus efficiency investments) can have a flat minimum region that spans a significant range of efficiencies.[41] This happens where the value of energy saved is canceled out by the costs of investment required to achieve the savings. In this case, even rational consumers will only invest to the point where the curve becomes essentially flat. Further savings are not captured because -- although there is no cost -- there is no additional economic gain from doing so.

The difference in the payback requirements of utilities and of customers is even larger in the developing countries owing to large segments of population that are poorer. Requirements on rates of return on investments range from 45% to 150% annually for individuals to make the investments, naturally with the poorer individuals requiring higher rates of return before they can be induced to save from their present meager expenditures.

The large gap between discount rates of utilities and their customers (and who can save energy for the utility) present opportunities for financial energy-service companies (ESCOs) to make money by bridging the gap. The gap may be bridged, for example, by offering to supply the utility a certain amount of energy (as conserved energy) by borrowing at 6% real from the utility. So the utility invests in the ESCO, just as it would in a power plant. The ESCO makes use of this money in a creative way to finance energy efficiency by making energy service contracts with consumers, and keeps part of their savings. The customer benefits by obtaining guaranteed energy-services, at a somewhat lower bill, the ESCO makes money from the saved energy, the utility obtains conserved energy at 12% financing with very short start-up time and avoided project delays.

---

39 R.C. Cavanagh, "Least-Cost Planning Imperatives for Electric Utilities and their Regulators," *The Harvard Environmental Law Review 10* (2), 299 (1986). See also, H. Ruderman, M.D. Levine, J.E. McMahon, "The Behavior of the Market for Energy Efficiency in Residential Appliances including Heating and Cooling Equipment," *The Energy Journal 8* (1), 114, 1987.

40 B. S. Barker, et al., *Summary Report: Commercial Energy Management and Decision Making in the District of Columbia*, Potomac Electric Company, 1986.

41 For an example based on automobiles, see F. von Hippel and B.G. Levi, "Automotive Fuel Efficiency: The Opportunity and Weaknesses of Existing Market Incentives," *Resources and Conservation 103*, 1983.

6.2 Realistic Energy Pricing

All of the technologies and policies discussed above have the potential to significantly reduce energy consumption worldwide. A major obstacle to their adoption in many countries, though, is the subsidization of energy. Cheap energy is politically popular, but hampers the market for efficiency, and thus leads to overconsumption and energy bankruptcy. **Figure 7** shows the relationship between growth or decrease of energy consumption relative to gross national product (E/GNP) and energy prices in 27 countries during the high-priced decade of 1973 to 1983. The eight nations that subsidized energy all experienced *increases* in E/GNP. Restated, these countries all lost energy efficiency at an average rate of 2.5% per year, becoming 4-5% less efficient annually than nations with energy taxes.[42] How can they ever catch up?

A 1990 World Bank study of electricity prices of over 60 developing countries found that electricity subsidies grew during the 1980s. Around 1983, electricity prices fell significantly and the average prices were only 55% of the average prices in the Organization for Economic Cooperation and Development (OECD) countries. These prices need to be doubled to cover the costs associated with the expanded power supply systems that are needed in these countries. The study found that existing electricity prices were too low to encourage efficient use of electricity.[43]

Figure 8 shows a comparison of wholesale and retail prices of electricity in OECD countries, Czechoslovakia, and Bombay, India. In the industrialized European countries, retail prices are significantly higher than wholesale prices. In Czechoslovakia and Bombay, India (as well as in many other Eastern European and developing countries), retail prices are heavily subsidized, fostering inefficient use of electricity and hampering the market for energy efficiency. Although subsidized, the electric prices in Bombay are at least tiered, charging higher prices to the larger consumers.

7 CONCLUSION

In the U.S., interest in energy efficiency is now linked to interest in environmental protection. As environmental interest moved from acid rain and smog prevention to the reduction of greenhouse-gas emissions, the focus on energy efficiency as a CO_2 mitigation measure has increased.

The issues are different for developing countries and Eastern Europe, where energy efficiency represents a means of meeting developmental goals while realizing societal economic savings. Because the projected growth in energy demand is high for these countries, low-cost environmentally sound energy-efficient technologies coupled with appropriate policies to promote energy efficiency should help in meeting this demand.

8 ACKNOWLEDGEMENT

This work was supported in part by the Pew Scholars Program in Conservation and the Environment and by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Technologies, Buildings Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

---

42 M. Kosmo, *Money To Burn: The High Cost of Energy Subsidies*, World Resources Institute, Washington, D.C., 1988.

43 World Bank, Energy Development Division, Industry and Energy Department, *Review of Electricity Tariffs in Developing Countries During the 1980s*, World Bank, Washington, D.C., 1990.

Table 1. Comparison of Selected Energy and CO_2 Conservation Options in the U.S.

Mitigation Method	Net Implementation Cost Mid Range	Maximum Potential Emission Reduction	Reduction in 1988 CO_2 Emissions (%)		Economic Savings ($B/yr)	
	$/t$CO_2$ eq	BtCO_2 eq/yr	Per Measure	Cumulative	Per Measure	Cumulative
1. Building Energy Efficiency	-62	0.9	18	18	56	56
2. Vehicle Efficiency	-40	0.3	6	24	12	68
3. Industrial Efficiency	-25	0.5	11	35	13	81
4. Transportation System Mgmt	-22	0.05	1	36	1	82
Base Case (1988 GtCO_2)		4.8		100		$450 B

Source: National Academy of Sciences, *Policy Implications of Greenhouse Warming: Report of the Mitigation Panel*, 1991, derived from Table 11.1.

Table 2. Values for Quantifying External Costs of Air Emissions ($/tonne)

Emissions	Massachusetts Department of Public Utilities[1]	New England Electric System Proposal[2]	Pace University Study[3]	OKO-Institut[4]
CO2	22	2	15	5 to 50
SO2	1500	600	4500	2500
NOx	6500	200	2000	2000
Particulates	4000	300	2500	500

1 Massachusetts DPU Proceedings 89-239, August 1990.

2 New England Electric System proposal based on testimony of W. Nordhaus regarding CO2 values and on report of RCG/Hagler, Bailey. Nordhaus testimony and RCG report was filed May 20, 1991 as part of Massachusetts Electric Company's Integrated Resource Management filing in Massachusetts.

3 Pace University, Center for Environmental Legal Studies, *Environmental Costs of Electricity*, New York, Oceana Publications, 1990.

4 U. Fritsche, "Total Emission Model for Integrated Systems (TEMIS): Preliminary Findings for the U.S." Appendix A of Pace University, Center for Environmental Legal Studies, *Environmental Costs of Electricity*, 1990.

Table 3. Economics of Three New Energy Efficiency Technologies and Appliance Standards.

	RESEARCH & DEVELOPMENT				STANDARDS
	HIGH FREQUENCY BALLASTS VS. CORE COIL BALLASTS	COMPACT FLUORESCENT LAMPS (1) VS. INCANDESCENTS	LOW-E (R-4) WINDOWS VS. DOUBLE GLAZED WINDOWS Per small window (10 ft^2)	TOTAL (B = billions)	REFRIGER-ATORS AND FREEZERS '76 base case vs. '85 CA Stds.
1. UNIT COST PREMIUM (2)					
a. Wholesale	$8	$5	$10		
b. Retail	($12)	($10)	($20)		($100)
2. CHARACTERISTICS					
a. % Energy Saved	33%	75%	50%		66%
b. Useful Life (3)	10 years	3 years	20 years		20 years
c. Simple Payback Time (SPT) (4)	2 years	1 year	2 years		1 year
3. UNIT LIFETIME SAVINGS					
a. Gross Energy	1330 kWh	440 kWh	10 MBtu		24,000 kWh
b. Gross $ (not discounted) (5)	$100	$33	$70		$1800
c. Net $ (Gross $ - 1st cost) [3b-1a]	$92	$28	$60 (6)		$1700
d. Equivalent kg Coal (7)	500	175	350		10,000
e. km in car @ 7.5 liters/100 km	5000	1750	3500		100,000
4. SAVINGS 1985-1990 - US					
a. 1990 Sales (M = millions)	3M	20M	20M		not
b. Sales 1985 through 1990	8M	50M	50M		ramping
c. Cum. Net Savings [4b x 3c]	$750 M	$1.4B	$3B	**$5B/5yr**	up
5. SAVINGS AT SATURATION (8)					
a. U.S. Units	600M	750M	1400M		100M
b. U.S. Annual Sales	60M	250M	70M		6M
c. Annual Energy Savings [5b x 3a]	80 BkWh	110 BkWh	0.3 Mbod		144 BkWh
d. Annual Net $ Savings [5b x 3c](9)	$5.5B	$7B	$4B	**$16.5B/yr**	$10 B
e. Equivalent power plants (10)	16 "plants"	22 "plants"			29 "plants"
f. Equivalent offshore platforms(11)	45 "platforms"	60 "platforms"	30 "platforms"		78 "platforms"
g. Annual CO_2 savings(12)	55 Mt	80 Mt	18 Mt	**153 Mt**	100 Mt

From: "The Role of Federal Research and Development in Advancing Energy Efficiency," Statement of Arthur H. Rosenfeld before James H. Scheuer, Chairman, Subcommittee on Environment, Committee on Science, Space, and Technology, U.S. House of Representatives, April 1991.

---

(1) Calculations for CFLs based on one 16-watt CFL replacing thirteen 60-watt incandescents, burning about 3300 hours/year, assuming that a CFL costs $9 wholesale, or $5 more than the wholesale cost of thirteen incandescents. For retail we take $18 - $8.

(2) Unit cost premium is the difference between one unit of the more efficient product (e.g. one high frequency ballast) and one unit of the existing product (e.g. one core coil ballast).

(3) Useful life is the assumed calendar life of the product (as opposed to operating life such as burning hours for a lamp) under normal operating conditions. A commercial application is assumed for CFLs.

(4) SPT is the number of years required to recoup the initial incremental investment in an energy-efficient measure through reduction in energy bills.

(5) Assuming price of 7.5¢/kWh for commercial sector electricity and a retail natural gas price of $7/MBtu (70¢/therm).

(6) For hot weather applications where low-e windows substantially reduce cooling loads, air conditioners in new buildings can be down-sized, saving more than the initial cost of the low-e window.

(7) 1 kWh = 0.4 kg coal.

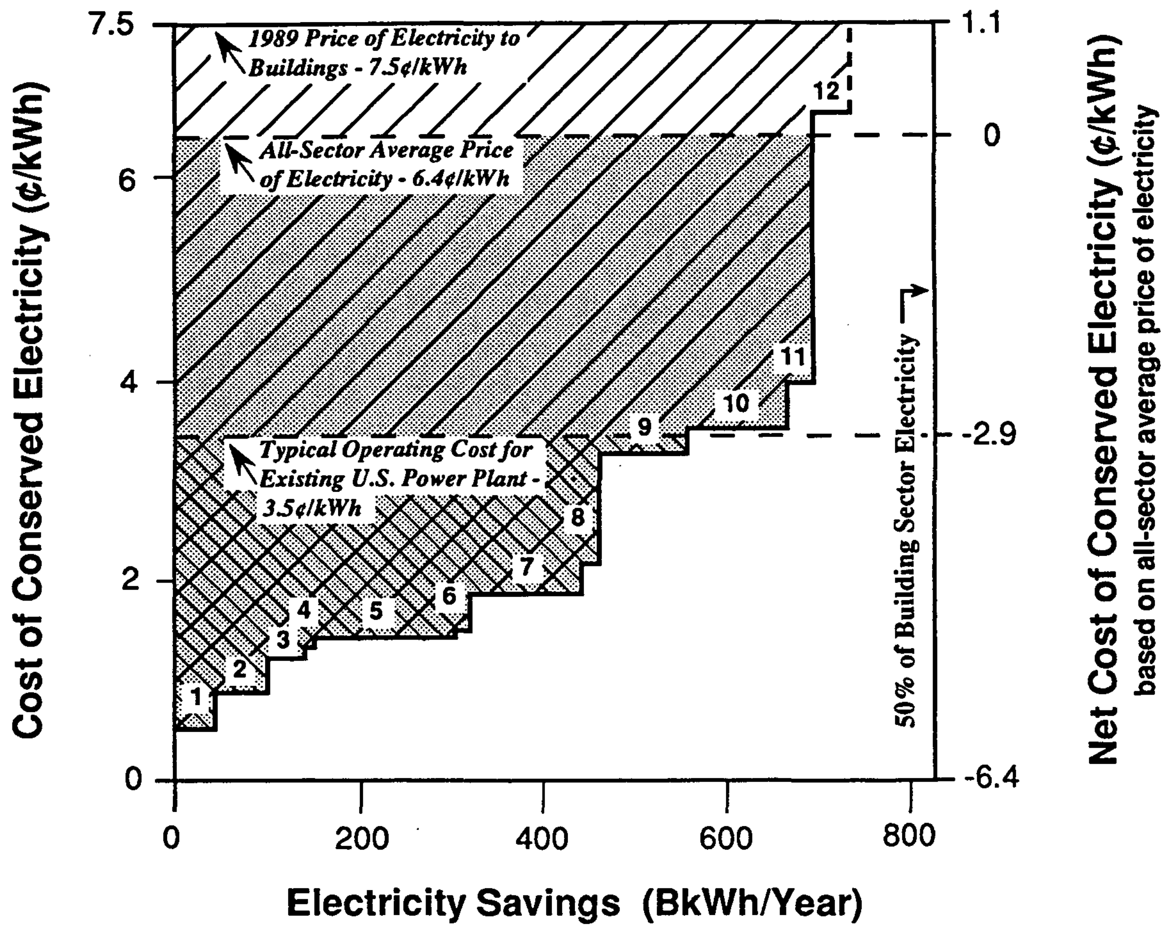
(8) Saturation is 100% of market share for all products except CFLs. It is unrealistic to assume that CFLs will replace infrequently used incandescents; thus, we have defined market saturation for CFLs as 50% of current energy used by incandescents.

(9) Net annual savings are in 1990 dollars, uncorrected for growth in building stock, changes in real energy costs, or discounted future values. See "The Role of Federal Research and Development in Advancing Energy Efficiency: A $50 Billion Contribution to the U.S. Economy," Geller et al., Annual Review of Energy 1987, Vol. 12, Table 1. Note that we attribute energy saved by the product over its useful life to the year it gets sold.

(10) One 1000 MW baseload power plant supplying about 5 BkWh/year.

(11) One offshore oil platform = 10,000 bod. To convert "plants" burning natural gas to "platforms": 1 "plant" = 27,000 bod = 2.7 "platforms." Alaska National Wildlife Refuge, at 0.3 Mbod, is equivalent to about 30 "platforms."

(12) 1989 U.S. emissions of CO_2 were 5000 megatonnes (Mt).



Potential Net Savings:

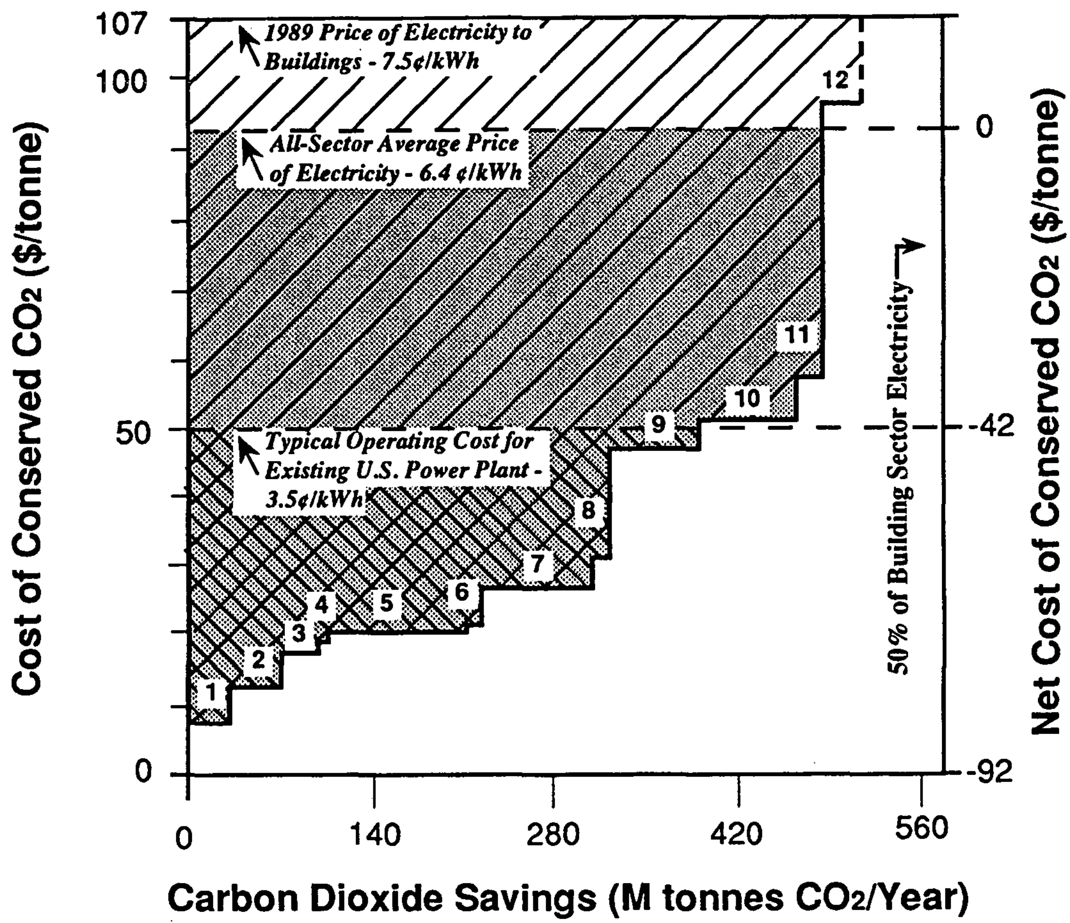
$ 37 B/yr. - CASE 1: Below 7.5¢/kWh 1989 Price of Electricity to Buildings

$ 29 B/yr. - CASE 2: Below 6.4¢/kWh All-Sector Average Price of Electricity

$ 10 B/yr. - CASE 3: Below 3.5¢/kWh Typical Operating Cost for Existing U.S. Power Plant

Figure 1. Cost of Conserved Electricity (CCE) for U.S. Buildings. The full X-axis corresponds to 813.5 BkWh, which is half of the total 1989 U.S. buildings electricity use of 1627 BkWh and which cost $140 B. The Net CCE scale is displaced by 6.4 ¢/kWh - the all-sector average price of the avoided electricity. All recommended measures that have a CCE of less than 6.4¢/kWh have a negative cost, i.e. save money.

Areas between the CCE and a price line represent annual dollar savings. Case 1 (lightly hatched area) shows this potential annual net savings of $37 B, based on the average price of the avoided electricity of 7.5¢/kWh. Case 2 (shaded area) represents the potential annual savings of $29B, based on the all-sector average price of 6.4¢/kWh (defined as Net CCE of 0 on the right hand scale). To be extremely conservative, the net CCE can be referenced to the avoided cost of merely operating an existing plant - about 3.5 ¢/kwh at the meter. Case 3 (heavily hatched area) represents this most conservative estimate of savings of $10B/year.



Potential Net Savings:

$ 37 B/yr. - CASE 1: Below 7.5¢/kWh Price of Electricity mto Buildings

$ 29 B/yr. - CASE 2: Below 6.4¢/kWh All-Sector Average Price of Electricity

$ 10 B/yr. - CASE 3: Below 3.5¢/kWh Typical Operating Cost for Existing U.S. Power Plant

Figure 2. Net Cost of Conserved Carbon Dioxide (CC CO_2) for Electric Efficiency in the U.S. Buildings Sector. This figure is the same as Figure 1, with the X-axis converted to CO_2 savings (1 TWh = 0.7 MtCO_2) and the Y-axis converted to cost of conserved CO_2 (1¢/kWh = $14.3/tonne). CC CO_2 is shown by the 11 step EPRI curve with an additional first step for white surfaces/urban trees. The full X-axis corresponds to 569 MtCO_2, which is half of the 1989 U.S. carbon dioxide emissions from buildings electricity of 1139 MtCO_2. The total potential savings are 514 Mt CO_2, which is 10% of the total 1989 U.S. carbon dioxide emissions from all sources of 5000 Mt CO_2. Cost savings are the same as for Figure 1.

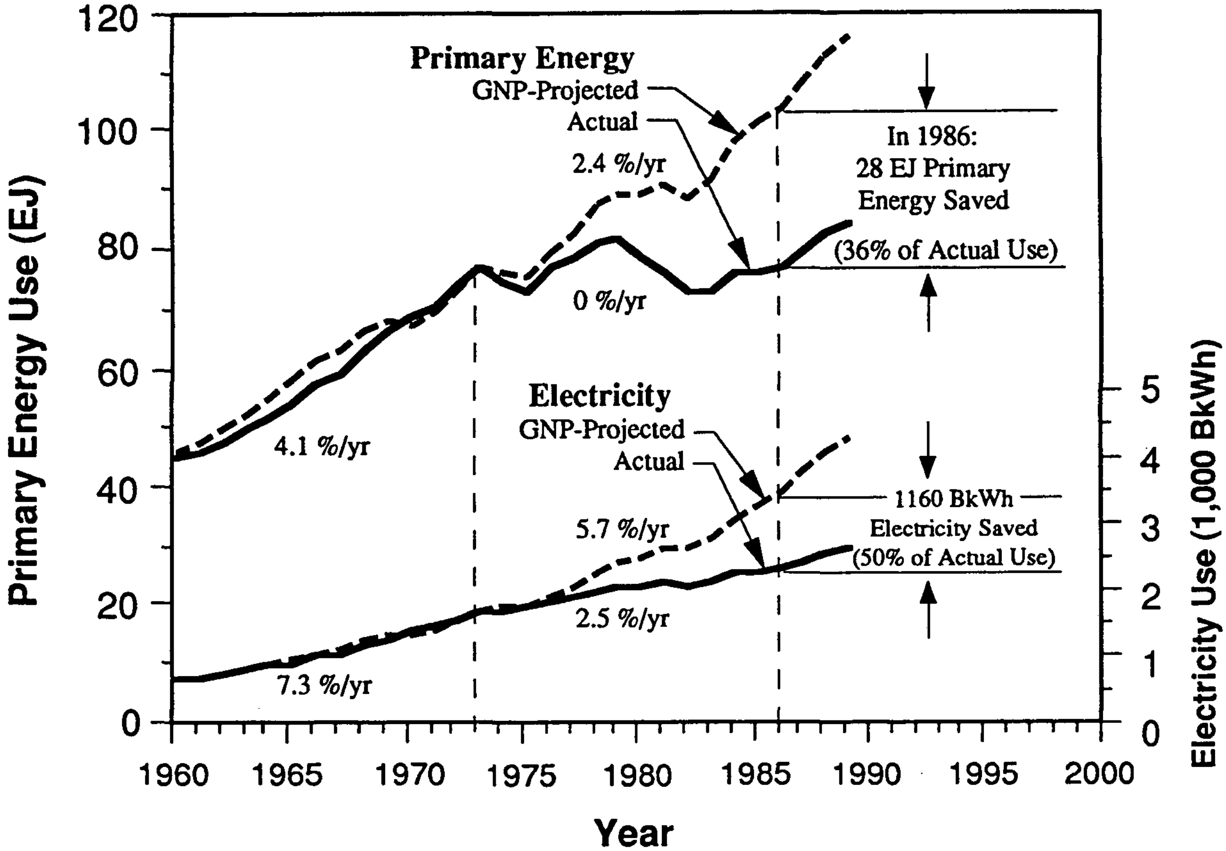


Figure 3. Total U.S. Primary Energy and Electricity Use: Actual vs. GNP Projected (1960-1989). Before the 1973 oil embargo, total primary energy use was growing at the same rate as GNP. Between 1973 and 1986, growth in energy consumption was halted by high oil prices and progressive energy policies. In 1986, projected primary energy use was 36% (28 exajoules) higher than actual use.

Electricity use followed a similar pattern. Prior to 1973, electricity use was growing roughly 3% faster than GNP. Between 1973 and 1986, growth in electricity use decreased, growing only 2.5% per year, or 3.2% per year less than projected by pre-1973 trends. (GNP-projected energy values are based on 1973 efficiency and GNP. The electricity projections include an additional 3% per year to account for increasing electrification). In 1986, projected electricity use was 50% higher than actual electricity use, indicating a savings of 1160 BkWh.

Electricity use is given in terms of total equivalent primary energy input (exajoules—left-hand scale), and net consumption (1,000 BkWh—right-hand scale).
Source: Energy Information Administration, U.S. Department of Energy.

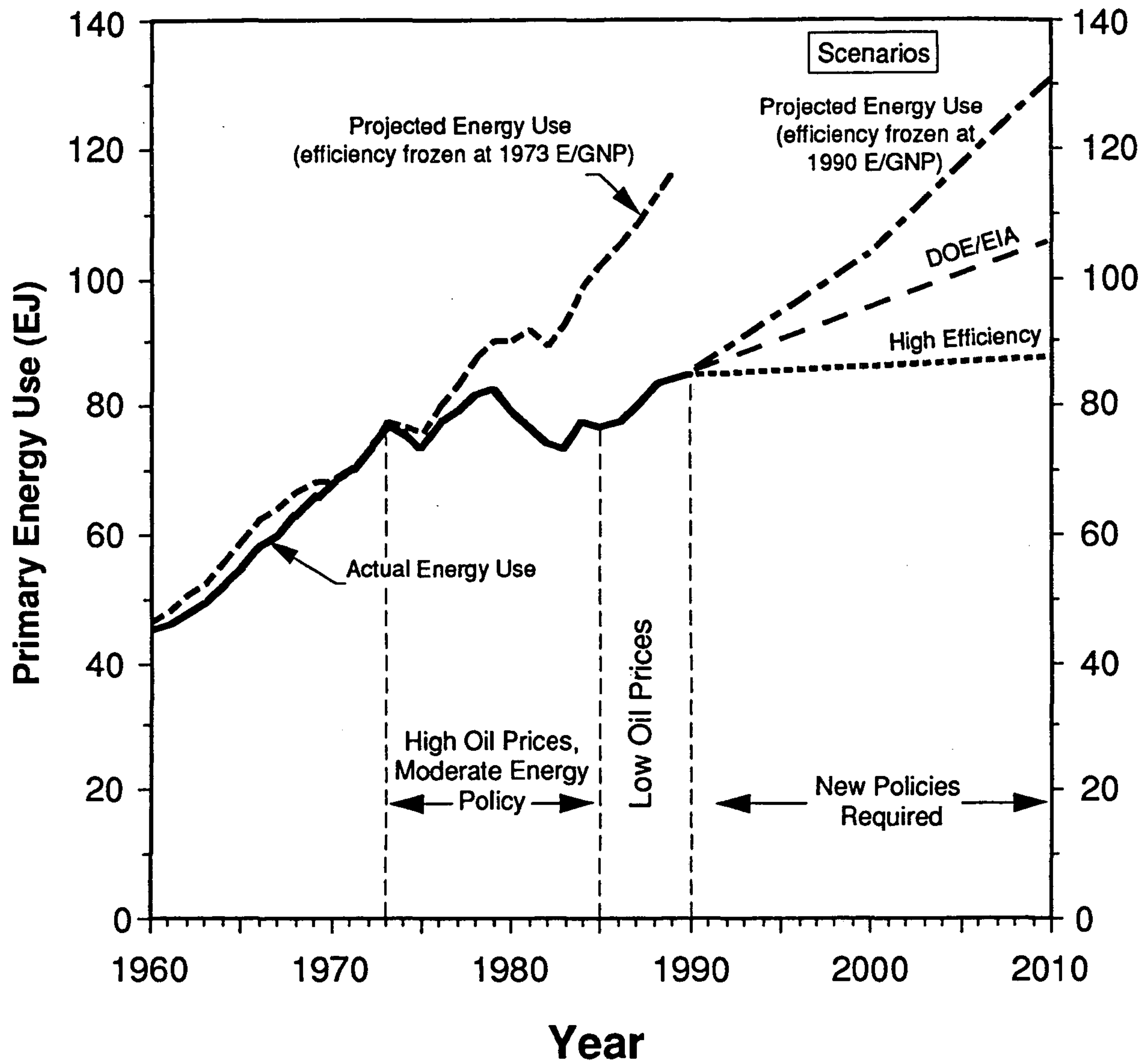


Figure 4. Aggregate U. S. Energy Use and Projections. Prior to 1990, projected energy use assumes the 1973 aggregate energy intensity (E/GNP) remained constant. Starting in 1990, the scenarios compare constant energy intensity, the 1991 DOE/EIA reference case forecast, and a "high efficiency" forecast based on 14 policy proposals presented in H. Geller et al., *Getting America Back on the Energy-Efficiency Track: No-Regrets Policies for Slowing Climate Change*, American Council for an Energy-Efficient Economy, 1991. Note: To calculate economic savings, multiply y-axis by $5.50/MBtu.

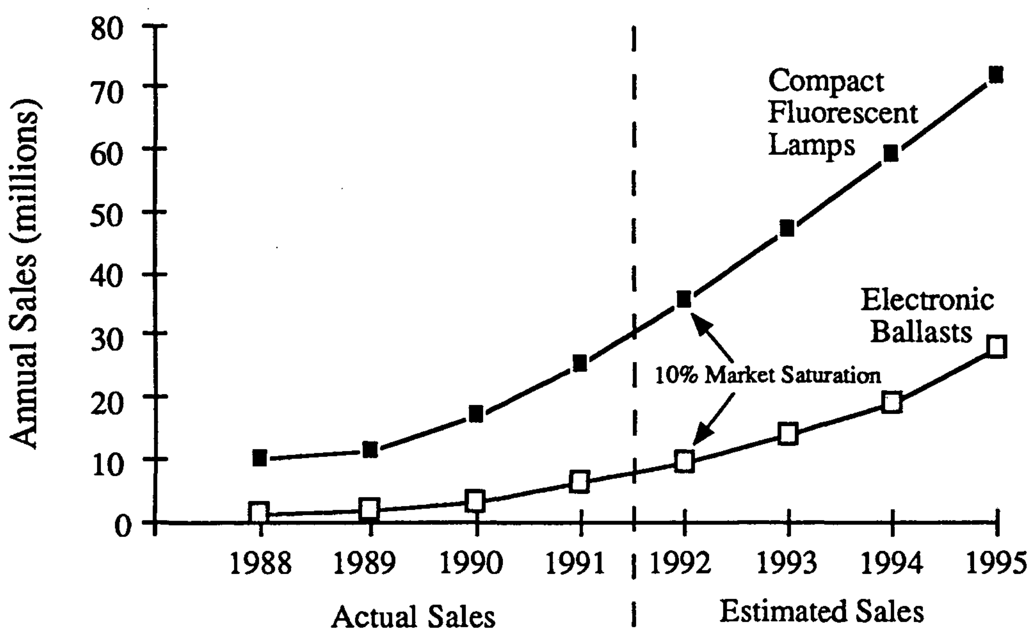


Figure 5. Recent and Estimated U.S. Sales of Compact Fluorescent Lamps (CFLs) and Electronic Ballasts. Data taken from a recent survey of utilities, lamp companies, ballasts companies, lighting management companies, and federal agencies. Market saturation levels are calculated to be annual sales of 60 million electronic ballasts and 250 million CFLs (see Table 3). For both products, sales in 1991 represent 10% of market saturation and sales are doubling every 2 years. In about 5 years, annual sales will be 50% of market saturation.
Source: Electric Power Research Institute, *Survey and Forecast of Marketplace Supply and Demand for Energy-Efficient Lighting Products,* TR-100288, prepared for EPRI, California Institute for Energy Efficiency, U.S. Environmental Protection Agency - Global Change Division, and U.S. Department of Energy - Federal Energy Management Program by Lighting Research Institute and Plexus Research, Inc., in print.

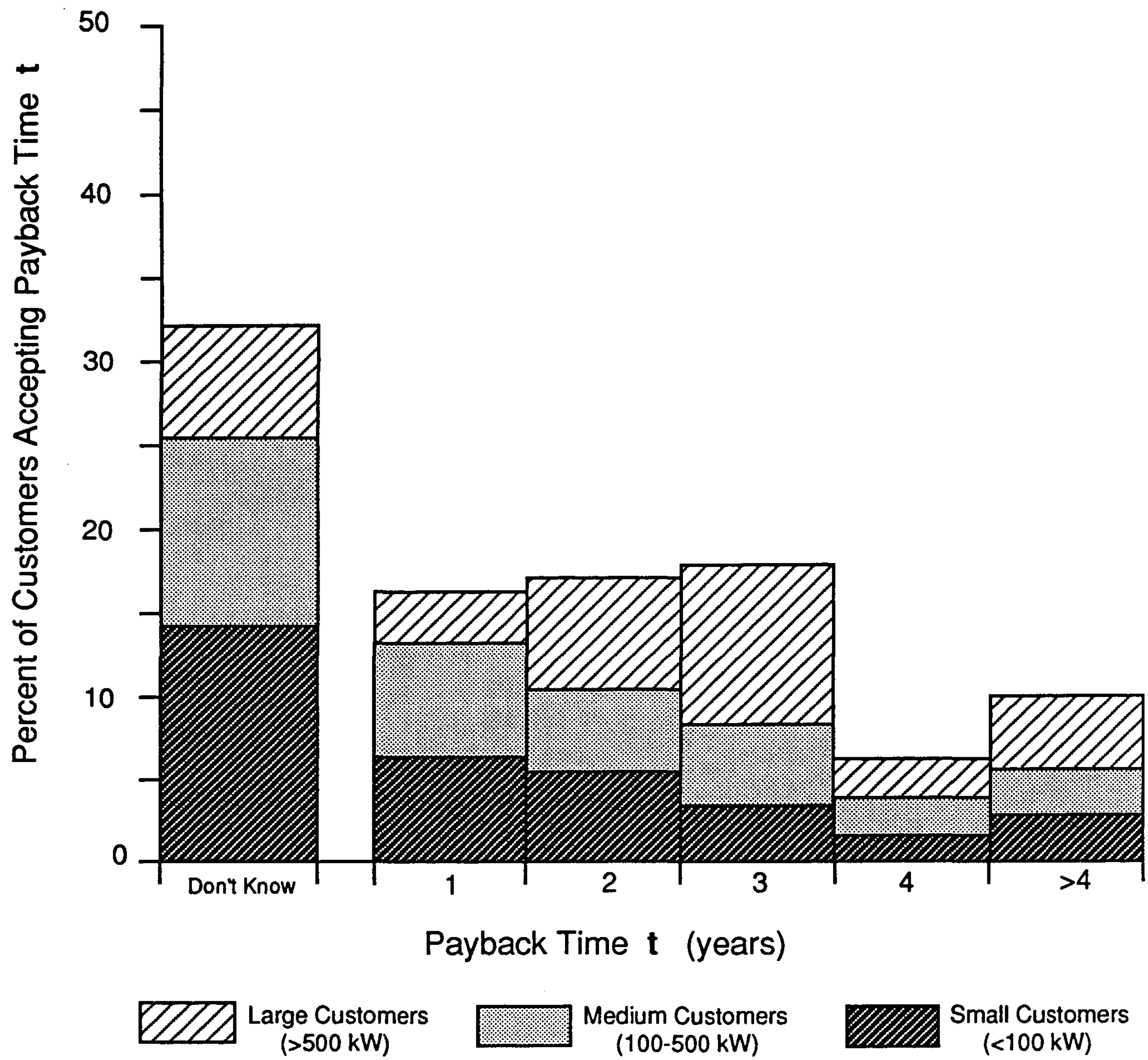


Figure 6. Maximum Tolerable Payback Time for Investments in Energy Efficiency in U.S. A survey of the 660 commercial customers of Potomac Electric Power Company was conducted to determine their typical payback thresholds for investments in energy efficiency. Thirty-three percent of the customers responded that they didn't know their preferred payback period, while 52 percent preferred payback periods of 3 years or less.

Source: Barker, B.S., et al., *Summary Report: Commercial Energy Management and Decision Making in the District of Columbia.* Potomac Electric Company. December 1986.

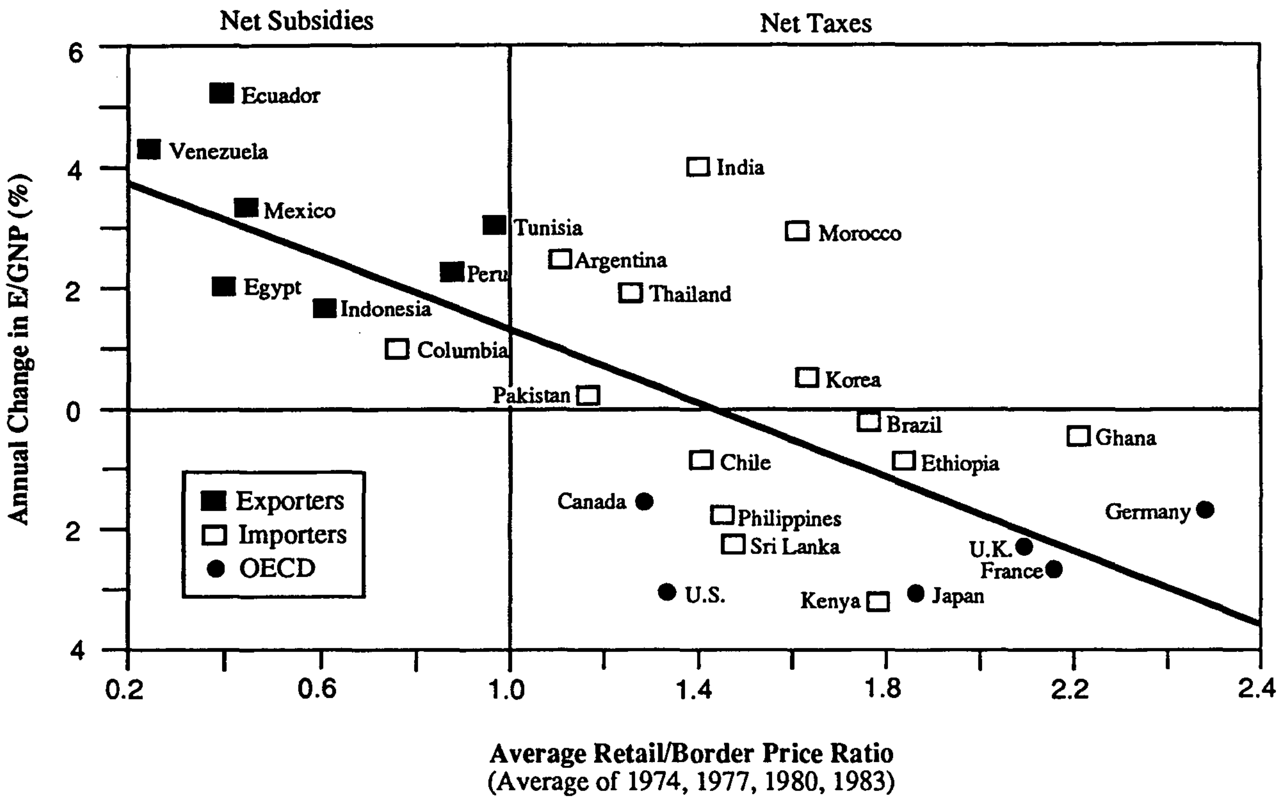


Figure 7. Changes in Commercial Energy Efficiency and Retail/Border Price Ratios. Inflation corrected annual averages, 1973 to 1983.
Source: Kosmo, M., *Money to Burn? The High Costs of Energy Subsidies,* World Resources Institute, 1987.

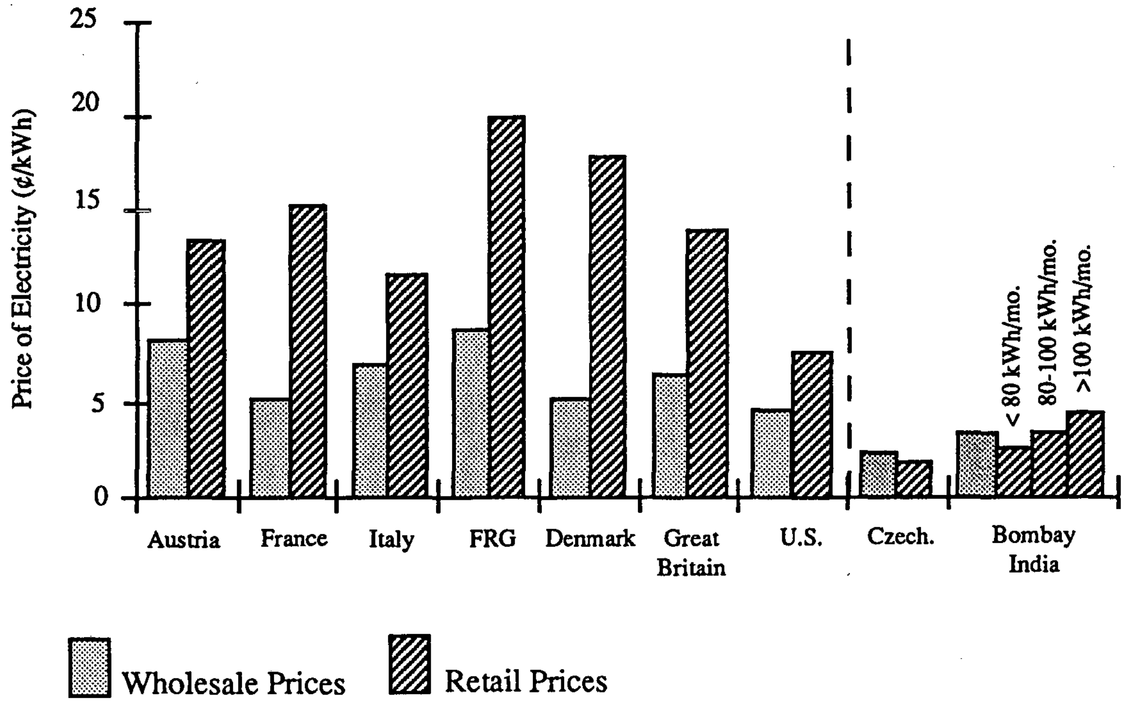


Figure 8. Comparison of 1990 Wholesale and Retail Prices of Electricity in Europe, U.S., Czechoslovakia, and Bombay, India. Retail prices are significantly higher than wholesale prices in the industrialized countries in Europe. In many developing and Eastern European countries, retail electricity prices are heavily subsidized. Such subsidized energy hampers the market for energy efficiency. Note that in Bombay, there is a progressive tariff block with retail prices increasing as consumption increases.
Sources: European and Czechoslovakian prices from CSFR National Utility, *Electricity in the Economy*. Bombay Suburban Electric Supply (BSES) prices from A. Gadgil, LBL. U.S. prices (retail = commercial and residential, wholesale = industrial) from EIA, *Monthly Energy Review*, 1990.

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720