Using Electricity More Efficiently: Demand-Side Opportunities 4

Commercially available energy-efficient technologies offer abundant opportunities to cut electricity consumption in the residential, commercial, and industrial sectors. The major electricity uses across all sectors are lighting, space conditioning, water heating, motors, drives, and appliances. Studies of energy efficiency opportunities have identified a variety of technologies for each of these applications that offer cost-effective savings and rapid paybacks. Still other energy-saving technologies are not currently cost-effective in most applications, but could prove more financially attractive if economies of scale cut costs, if energy prices rise, or if policy interventions provide additional incentives to install them.

This chapter briefly examines some of the energy efficiency opportunities in the residential, commercial and industrial sectors, including a profile of electricity use in each sector, examples of electricity-saving technologies, estimates of potential savings, and major factors influencing technology adoption.

HOW MUCH ELECTRICITY CAN BE SAVED?

Estimates of how much energy can be saved through more efficient electric technologies vary. Some of the differences in the estimates are attributable to what measure of energy efficiency is used—maximum technical potential, cost-effective potential, or achievable or likely savings potential. (See box 4-A.) The studies vary in assumptions about technology penetration rates, energy demand, consideration of cost-effectiveness and discount rates,

The Electric Power Research Institute (EPRI) has estimated that if the existing stock of equipment and appliances were replaced with the most efficient commercially available technologies, projected U.S. electricity use in the year 2000 could be cut by 27 to 44 percent without any diminution of services.[1] (See

[1] Barakat & Chamberlin, *Efficient Electricity Use: Estimates of Maximum Energy Savings*, EPRI CU-6746 (Palo Alto, CA: Electric Power Research Institute, March 1990), hereafter referred to as EPRI, *Efficient Electricity Use*.

Box 4-A-Estimating Energy Efficiency Savings

Estimates of potential energy savings from efficient technololgies vary considerably. At least part of the difference in estimates can be attributed to what is being estimated. Most published estimates use one of the following measures:

Maximum technical potential, or MTP, is a measure of the most energy that could be saved if all possible efficiency improvements were made with the most efficient technologies adopted in all new and existing applications (i.e., 100 percent penetration reached. Achieving MTP savings assumes agressive government and private efforts and implementation of policies designed to make efficient alternatives attractive to everyone. Supporting policies rnight include, for example, increased R&D to lower costs, Information program, and rebates and other financial incentives.

Cost-effective potential is an estimate of the energy savings that could reobtained if efficient techndogies are installed in new and replacement applications whenever they are cost-effective. Cost-effective potential is lower than MTP and depends on projections of future marginal electricity costs and rates. Several cost-effectiveness tests are in common use in utility planning and rate regulation. See chapter 6 for more on cost-effectiveness tests.

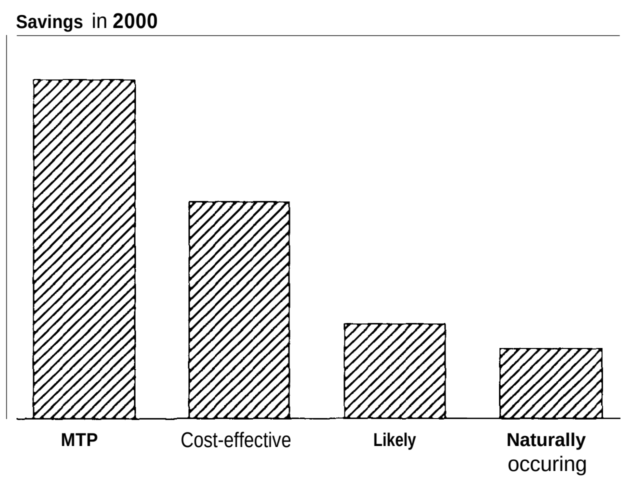
Likely energy efficiency savings estimates are used in utility planning and reflect judgments about the savings from efficient technologies adopted in response to utility programs. Likely impacts are lower than cost-effective potential because of the influenoe of various factors inducting, for example: lack of customer awareness of potential savings or utility programs, customer reluctance to convert with new or different technologies, and constraints on the supply or deliverabilityof the technology.

Natural occurring energy efficiency savings estimates reflect estimates about the penetration of energy efficient technologies in response to normal rnarketplace conditions and existing standards In the absence of new utility or other programs to encourage their adoption. The savings arise from installation of newer, more efficient technologies- but not necessarily the most efficient technologies commercially available--in new and replacement applications. Estimates of naturally occurring savings are used by utilities to evaluate the effectiveness of efficiency programs. Actual electricity use is compared to what consumption would have been if efficiency levels were frozen at a base year's level and then the effects of naturally occurring savings are subtracted to yieid the savings attributable to the utility program

The figure shows a conceptual comparison of the relative magnitude of different estimates of energy efficiency potential.

In this chapter, OTA has adopted the MTP estimates from efficient electric technologies published in a 1967 report for the Electric Power Research Institute (EPRI).[1] The EPRI analysis provides one of the few comprehen-

EPRI Base Case Usage and Maximum Technical Potential (MTP) From Electricity-Savings Technologies



[1] Barakat & Chamberlin, Inc., *Efficient Electricity Use: Estimates of Maximum Energy Savings*, EPRI CU-6746(PaloAlto, CA: The Electric Power Research Institute, March 1990).The Electric Power Research Institute Isa research organization supported by the electric utility industry.

sive and economy-wide examinations of the potential energy efficiency savings.

The EPRI MTP estimates of savings from efficient electric technologies in the year 2000, included savings from: 1) using the most efficent electricity-saving technologies available for new Installations and replacement of all the existing stock of installed electric equipment; and 2)replacing less-efficient fossil-fired equipment with more efficient electrotechnologies in industrial processes. EPRI's MTP estimates compared with current and projected electricity use by sector are shown in table 4-1.

The estimates of savings were developed using a baseline projection of eletricity demand in the year 2000, which includes naturally occurring improvements in efficiency and the effects of mandatory standards and a best ease scenario in which all applicable technologies are replaced instantaneously with the most efficient commercialty available electric equipment.

The MTP estimates are subject to a great deal of uncertainty including:

- the efficiency levels of new and existing equipment;
- the unknown impacts from naturally occurring efficiency Improvements; and
- physical constraints that limit the applicability, compatibility, or deliverability of efficient equipment.

To account for these uncertainties, the EPRI report used two scenarios reflecting a range of Impacts from technology adoption: an 'optimistic" or high impact scenario assuming adoption of all commercially available technologies (i.e., no prototypes, demonstration models, or lab bench-scale technology@, and a conservative" or low impact scenario reflecting possible constraints on the perpetration rates due to technology applicability and manufacturer capacity. Neither estimate reflects considerations of cost-effectiveness, the economic tradeoffs between efficiency improvements and equipment cost.

table 4-l.) (EPRI is the joint research institute supported by funds from America's electric utilities.) The EPRI analysis presents its best-case estimates of the most energy that could be saved through efficient technologies, further improvements in existing technologies, and policy initiatives such as information programs, rebates and other incentives that make the alternatives attractive to everybody. The range in their estimates from "conservative low impacts" to best-case, "high" impacts reflects uncertainties in technology applicability, manufacturing capabilities, and performance characteristics.

The analysis did not include assessments of the cost-effectiveness of the technologies in particular applications or projections of future electricity costs and rates that would strongly influence cost-effectiveness determinations. Considerations of cost, practicality, and capital availability may preclude attainment of the maximum savings potential, but nevertheless EPRI believes that many opportunities remain for substantial gains.[2] The EPRI maximum technical potential estimates are cited in this chapter to provide some measure of prospective energy savings that can be targeted.

Amory Lovins and others at the Rocky Mountain Institute have estimated the maximum technical potential of efficiency savings as high as 75 percent by 2010.[3] Other studies have included considerations of cost-effectiveness in their estimates.

2 OTA's own analysis concluded that cost effective, energy-efficiency measures could yield savings of one-third in total energy use in the residential and commercial sectors by 2015 over a business as usual scenario. In fact total energy use in these sectors would decline somewhat under an aggressive efficiency strategy. These two sectors combined are often dubbed "the buildings sector" because energy use for building systems (space heating and conditioning, ventilation% lighting, and water heating) has made up the overwhelming bulk of energy consumption in these two sectors. Reported energy use for the buildings sector includes building systems, appliances, office systems, and other electrical equipment. U.S. Congress, Office of Technology Assessment, Building Energy *Efficiency*, OTA-E-5 18 (Washington, DC: U.S. Government Printing Office, May 1992), p. 3, hereafter referred to as OTA, *Building Energy Efficiency*.

3 *See, e.g., the estimates* from Rocky Mountain Institute cited in Arnold P. Fickett, Clark W, Gellings, and Amory B. Lovins, "Efficient Use of Electricity," *Scientific Amen'can,* September 1990, pp. *65-74.*

Table 4-1—EPRI Base Case Usage and Maximum Technical Potential (MTP) From Electricity-Savings Technologies (gigawatt-hours)

	Electricity consumption		Electricity savings			
Residential end uses sector	1987 Base GWh	2000 Base GWh	Low case GWh	% of base	High case GWh	% of base
Space heating	159,824	223,024	71,915	32.20/.	122,285	54.8%
Water heating	103,499	134,509	43,481	32.3	88,995	66.2
Central air conditioning	78,127	90,134	26,265	29.1	30,996	34.4
Room air conditioning	15,254	13,063	2,421	18.5	4,222	32.3
Dishwashers	15,308	23,707	1,240	5.2	6,233	26.3
Cooking	30,390	39,271	3,115	7.9	7,132	18.2
Refrigeration	146,572	139,255	30,716	22.1	66,896	48.0
Freezer	59,779	48,073	11,534	24.0	15,594	32.4
Residual appliances	240,861	353,620	98,242	27,8	141,552	40.0
Total residential	849,613	1,064,656	288,929	27.1%	483,904	45.5%
Industrial end uses						
Motor drives	570,934	780,422	222,226	28.5%	351,040	45.0940
Electrolytic	98,193	138,273	25,950	18.8	41,124	29,7
Process heating	83,008	125,274	9,928	7.9	16,606	13.3
Lighting	84,527	114,097	19,016	16.7	38,032	33.3
Other	8,453	9,192	0	0.0	0	0.0
Total industrial[a]	845,266	1,167,413	277,119	23.7	446,802	38.3%
Commercial end uses						
Heating	77,245	128,322	16,335	12.7%	30,333	23.694.
Cooling	154,299	208,106	62,432	30.0	145,674	70.0
Ventilation	76,959	96,094	28,828	30.0	48,047	50.0
Water heating	24,068	39,794	15,917	40.0	23,876	60.0
Cooking	16,172	26,381	5,276	20.0	7,914	30.0
Refrigeration	60,883	81,652	9,925	12.2	27,857	34.1
Lighting	238,488	283,124	62,916	22.2	157,291	55.6
Miscellaneous	108,447	177,254	32,228	18.2	64,456	36.4
Total commercial	756,561	1,040,726	233,858	22.5940	505,448	48.6%
Total	2,451,440	3,272,795	799,905	24.4%.	1,436,154	43.9%

[a] Sum of end uses may not add to total due to rounding.

SOURCE: Office of Technology Assessment, 1993, based on 8arakat and Chamberlin, Inc., *Efficient Electricity Use: Estimate of Maximum Energy Savings*, EPRI CU-6746 (Palo Alto, CA: Electric Power Research Institute, March 1990), p. 3.

OTA's report *Energy Technology Choices: Shaping Our Future*[4] moderate-efficiency scenario assumes adoption of all cost-effective efficiency measures (defined as measures that repay their added incremental costs with energy savings over their lifetimes). The scenario also assumes adoption of a variety of government policy initiatives to overcome significant market, institutional, and behavioral barriers that have hampered full use of cost-effective, energy-savings opportunities. Under the moderate-efficiency scenario, electricity demand in 2015 would be 25 percent less than the baseline demand (which assumes some naturally occurring efficiency improvements, but no significant policy initiatives).[5]

[4] U.S. Congress, Office of Technology Assessment *Energy Technology Choices: Shaping Our Future*, OTA-E-493 (Washington DC: U.S. Government Printing Office, July 1991), hereafter referred to as OTA, *Energy Technology Choices*.

[5] Ibid., p. 130. See chs. 4 and 5 for details on the scenarios and government policy initiatives.

The 1991 National Energy Strategy projects that electricity consumption in 2010 will be about 12 percent less than the current policy baseline due to cost-effective energy savings from proposed initiatives to promote utility integrated resource planning (and associated demand-side management programs), building and appliance efficiency standards, and industrial conservation research and development.[6]

Other studies on energy efficiency opportunities in specific sectors or regions have yielded similar estimates of cost-effective savings potential.

There is considerable agreement among the various energy efficiency potential studies about the most promising strategies for achieving more efficient use of electricity. They include:

- improvements in the thermal integrity of building shells and envelopes;
- improvements in the efficiency of electric equipment;
- lighting improvements;
- net efficiency gains from shifting energy sources from fossil fuels to electricity (electrification); and
- optimization of electricity use through better energy management control systems, shifts in time of use, and consumer behavior and preference changes.

ENERGY-EFFICIENCY OPPORTUNITIES FOR RESIDENTIAL CUSTOMERS

The residential sector essentially consists of all private residences including single and multifamily homes, apartments, and mobile homes. Institutional residences, such as dormitories, military barracks, nursing homes, and hospitals are included in the commercial sector, About 22 percent of total primary energy consumption in the United States can be attributed to residential sector energy demand. Total energy expenditures by the residential sector in 1990 were $110.5 billion.[7]

Figure 4-1 shows direct on site energy consumption in the residential sector.[8] Electricity at present supplies about 30 percent of residential energy needs and this share is expected to grow as electric heating and appliance loads grow. Natural gas supplies 47 percent of residential energy use mostly for space and water heating. The remaining residential energy consumption consists of oil (15 percent), coal (1 percent), and other energy sources (7.6 percent), predominantly *firewood.*[9]

The residential sector accounts for about 34 percent of all **U.S.** electricity sales. In 1990, total residential electricity sales (exclusive of conversion and transmission losses) were 924 billion

[6] *National Energy Strategy: Powerful Ideas for America, First Edition 1991/1992* (Washington, DC: U.S. Government Printing Office, February 1991), app. C, pp. C25-26.

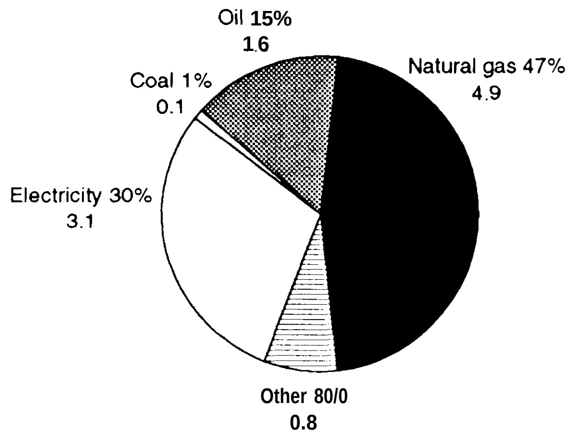
[7] U.S. Department of Energy, Energy Information Administration, ''Energy Preview: Residential Energy Consumption and Expenditures Preliminary Estimates, 1990, *Monthly Energy Review April 1992, DOE/EIA-O035(92/04) (Washington DC*: U.S. Government Printing Office, April 1992), p. 1.

[8] Historical energy use statistics of the Energy Information Administration do not separate residential and commercial energy use. Residential energy use share is based on Gas Research Institute estimates from Paul D. Holtberg, Thomas J. Woods, Marie L. Lihn, and Annette B. Koklauner, Gas *Research Insights" 1992 Edition of the GRI Baseline Projection of U.S. Energy Supply and Demand to 2010* (Chicago, IL: Gas Research Institute, April 1992) hereafter referred to as 1992 *GRI Baseline Projection);* and U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1991*, DOE/EIA-0384(91) (Washington, DC: U.S. Government Printing Office, June 1992), table 17.

[9] If the residential sector's share of direct primary energy consumption is augmented by its pro-rate share of primary energy consumed by electric utilities in the generation, transmission and distribution of electricity for residential customers, electricity accounts for some 60 percent of primary energy consumption attributable to the residential sector. The existence of these sizable conversion and delivery losses associated with end-use electricity consumption means that energy savings at the point of use are magnified in their impacts on utilities and overall primary energy use.

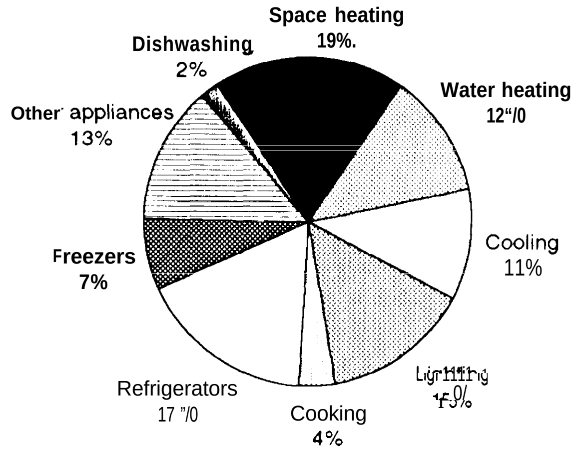
[10] U.S. Department of Energy, Energy Information Administration, *Electric Power Annual 1990*, DOE/EIA-0348(90) (Washington, DC: U.S. Government Printing Office, January 1992), table 1, p, 16, hereafter referred to as DOE, *Electric Power Annual 1990.*

Figure 4-1—Residential On-Site Energy Consumption by Source, 1990 (quadrillion Btus)



SOURCE: Office of Technology Assessment, 1993, based on data from the U.S. Department of Energy, Energy Information Administration, and the Gas Research Institute. Figure excludes generation and transmission losses.

Figure 4-2—Residential Electricity Use by Application, 1987



SOURCE: Office of Technology Assessment, 1993, based on data from the U.S. Department of Energy and the Electric Power Research Institute.

kilowatt-hours (kWh) at a cost of $72 billion.[10] Residential electricity demand growth is driven by population, climate, number of households, the number of persons per household, regional population growth patterns, increased demand for electricity-intensive services (e.g., air-conditioning, clothes-dryers) and size of residences.[11] Among factors that tend to limit growth are the decline in population growth, the increased efficiency of new housing stock and appliances, and retrofits of existing housing units.[12] Various forecasts peg expected growth in residential electricity demand at from 1 to 2 percent per year.[13]

Figure 4-2 shows household electricity use by application.[14] Within each of the categories shown there are a number of attractive and cost-effective options for cutting household electricity use, without diminishing the services provided.

EPRI's analysis of maximum technical potential estimated that residential electricity use in 2000 could be reduced by from 27 to 45 percent if the most efficient end-use technologies currently available commercially were used to replace the existing stock of electric appliances in homes. The EPRI study did not include estimates of total costs for achieving this maximum technical potential, nor any analysis of the cost-

10 U.S. Department of Energy, Energy Information Administration, *Electric Power Annual 1990*, DOE/EIA-0348(90) (Washington DC: U.S. Government Printing Office, January 1992), table 1, p. 16, hereafter referred to as DOE, *Electric Power Annual 1990*.

11 See OTA, *Building Energy Efficiency*, supra note 2, at 15 and 1992 *GRI Baseline Projection*, supra note 8.

12 1992 *GRI Baseline Projection*, supra note 8, p. 27.

13 U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 1993*, DOE/EIA-0383(93) (Washington, DC: U.S. Government Printing Office, January 1993) table 21, p. 78.

14 EPRI, *Efficient Electricity Use*, supra note 1, table 1-1, p. 3.

effectiveness of replacing working appliances with more efficient models. Other studies have included cost-effectiveness considerations in their analyses and generally found considerable opportunities for electricity savings in the residential sector at a cost less than that of supplying electricity .15

Residential Energy Efficiency Technologies

There are a variety of technologies available to cut residential energy use without diminishing the services provided. Some of these technologies are listed in table 4-2. The basic strategies for cutting electricity use in the residential sector are:

- Improving residential building shell efficiency through better insulation by cutting conductive heat losses and gains through ceilings, walls, and floors; installing storm doors and windows; and cutting air infiltration by caulking gaps and weatherstripping around doors, windows, joints and other spaces.
- Choosing more efficient appliances for new installations and accelerating the retirement of older less efficient appliances.
- Improving the management of residential energy use through better maintenance, energy management controls, load shifting, and changes in occupant behavior.

Improving the energy efficiency of existing buildings is one of the most promising and vital areas for energy savings. Space heating and cooling account for 30 percent of residential electricity use. Improved thermal integrity in new and existing residential buildings can reduce heating and cooling loads and save electricity.

Replacement of existing buildings by energy-efficient new buildings is slow and expensive; most of the existing housing stock will continue in use for the next 30 to 40 years or more. There are over 90 million residential units in the United States, and we are adding between 1 and 2 million units per year. Although by the year 2000 there will be 10 to 15 million new units, about 90 percent of the units existing in 2000 have already been built, and by the year 2010 it is estimated that about 70 percent of homes will consist of housing stock built before 1985.[16]

The most cost-effective time to incorporate energy-saving measures into buildings is when they are built, remodeled or rehabilitated. In fact, failure to make accommodation for energy-saving technology in material and design choices at this stage causes lost energy savings opportunities—for example, e.g., using the standard 2-by-4 dimension lumber in exterior walls instead of 2-by-6 construction that allows for more insulation, or not selecting the most energy efficient windows.

Careful attention to energy efficiency features in the design, siting, and construction of residential housing can save electricity. Over the past two decades, because of high energy prices, building code requirements, and greater attention to energy

15 See OTA, *Building Energy Efficiency*, supra note 2, at pp. 29-30. A study of electricity use in U.S. residences by researchers at Lawrence Berkeley Laboratories estimated that residential electricity demand in 2010 could be cut by 37 percent from a "frozen" efficiency baseline (i.e., excluding 'naturally' occurring efficiency gains over the period) by aggressive use of commercially available technologies with a cost of conserved energy below 7.6 cents/km using a discount rate of 7 percent. SeeJ. Koomey et. al, *The Potential for Electricity Efficiency Improvements in the U.S. Residential Sector,* LBL-30477 (Berkeley, CA: Lawrence Berkeley Laboratory, July 1991), pp. 35-36. Artother analysis of possible electricity savings in Michigan found achievable savings of 29 percent in residential electricity use by 2005 at reasonable cost over a business-as-usual baseline with aggressive conservation programs and commercially available technologies. F. Krause et al., *Final Report: Analysis of Michigan's Demand-Side Electricity Resources in the Residential Sector, vol.* 1, Executive Summary, LBL-23025 (Berkeley, CA: Lawrence Berkeley Laboratory, April 1988). Researchers estimated that current residential electricity *use in New York* State could be cut 34 percent at a cost below that of supplying electricity-less than 7 cents/kWh, assuming a 6-percent discount rate. American Council for an Energy Efficient Economy, *The Potential for Energy Conservation in New York State,* NYSERDA Report 89-12 (Albany, NY: New York State Energy Research and Development Authority, September 1989), pp. S-5-6.

16 Oak Ridge National Laboratory, Energy *Technology R&D: What Could Make a Difference?* vol. 2, p@ 1 of *3,* ORNL-6541/v2/p1 (Oak Ridge, TN: Oak Ridge National Laboratory, December 1989) pp. 15,45.

Table 4-2-Selected Energy Efficiency Technology Options for the Residential Sector

Building envelope improvements	***Alr-conditioners***
Cut conductive heat losses/gains; control infiltration	Central air-conditioners
. Weatherstripping and caulking	■ More efficient units
, Insulation improvements	■ Frequent cleaning of filters and coils
■ Storm windows and doors	
, Design and siting of new structures	Room air-conditioners
	■ More efficient units
Space heating	■ Frequent cleaning of filters and coils
Use heat pumps instead of resistance heat	
Air source heat pumps	***Refrlgerators and freezers***
■ More efficient models	Efficient motors and controls
■ Improved technology	Improved gaskets and seals
Ground-source heat pumps	Improved insulation
Solar heating	Improved malntenance
	■ Clean coils often
Energy management controls and systems	
■ Set-back thermostats	***Lighting***
■ Smart house/smart systems	Replace incandescent with fluorescent and compact fluorescent
. Zoned heat systems	
	Reduced wattage incandescent
Air distribution systems	Dimmers, controls, and sensors
■ Improved insulation	Reflective fixtures
■ Reduced duct leakage	
	Cooking
Water heating	More efficient ovens and stoves
Blanket wrap of existing tanks	Alternative cooking devices
More efficient tanks	■ Microwave ovens
increased insulation for tanks and pipes	■ Convection ovens
Low-flow devices	. Induction cooktops
Thermal traps	
Set-back thermostats	***Dishwashers***
Heat-pump water heaters	Energy-saver cycles
Alternative water heating systems	No-heat drying
■ Heat recovery water heaters	Reduced hot water usage
■ Solar water heat systems	
Reduced thermostat settings	

SOURCE: Office of Technology Assessment, 1993.

efficiency, newer residential buildings make greater use of energy-efficient features.[17] In fact, new houses built in 1985 were much more energy efficient than those built in 1973 and were better insulated and had more energy-efficient win-dews.[18] Design features to take advantage of passive solar heating and daylighting can also be incorporated into new units for additional sav-ings.

The rate of replacement of major appliances with newer, more efficient models has been slow and will continue to be so in the absence of policy initiatives or large changes in energy prices. Major electric appliances such as furnaces, heat pumps, central air-conditioners, water heaters, and refrigerators often are in use for 10 to 20 years or more and are unlikely to be replaced unless they fail. It could take as long as 20 years to realize potential savings from currently available

[17] OTA, *Building Energy Efficiency*, Supra note 2.

[18] Ibid., p. 18.

efficient new equipment.[19] Not installing the most energy-efficient model initially creates lost efficiency opportunities for a decade or more. Assuring the installation of the most efficient appliances and accelerating the replacement of older inefficient appliances offer prospects for reaping energy savings.

Building shell improvements in existing buildings are effective means of cutting heating and cooling costs and increasing occupant comfort. The most common weatherization retrofits include: installing more insulation in ceilings, walls, and floors; adding storm windows and doors, and weatherstripping and caulking windows and doors. One study of home retrofits found variations in savings attributable to climate and differences in individual building characteristics. Average savings of 12 to 21 percent in heating energy demand and payback periods of about 6 years were found for ceiling and wall insulation. Another intensive experiment in weatherization cut space heating electricity use by two-thirds.[20] According to DOE surveys many Americans have already taken some steps to improve the energy efficiency of their homes.[21] Even where some weatherization measures have been reported it is likely that additional efficiency upgrades are possible.

Caulking gaps around windows and doors can reduce infiltration, and thereby reduce energy use for space heating and cooling.

SPACE HEATING

About one-quarter of American homes (22 million units) depend on electric heat and each year more and more electrically heated units are added.[22] Electric space heating accounts for 19 percent of residential electricity consumption. There are two basic categories of electric space heating systems: electric resistance heat systems (including electric furnaces, baseboard heaters, and portable heaters) and electric heat pumps (including air-source heat pumps, and ground-source heat pumps). Electric resistance heating systems are virtually 100 percent efficient, that is 100 percent of the energy delivered to the system is converted to heat, so that there are few technical opportunities to improve on their performance.

Electric heat pumps use a reversible vapor compression refrigeration cycle to transfer heat from an outside source to warm indoor spaces in the winter; in summer, the cycle reverses to cool indoor spaces by removing heat from inside and discharging it outdoors. The most commonly used heat pump is the air-source heat pump that uses the ambient air as its heat source. On average heat pumps are twice as energy efficient as electric resistance systems. However, the performance of heat pumps is highly variable and dependent on sizing, climate, and the rated performance of the heat pump. At about 23° F, heat pumps begin to lose their heating capacity

19 Oak Ridge National Laboratory, supra note 16, p. 47 — projecting about 30 percent savings in total end-use energy.

20 OTA, *Building Energy Efficiency*, supra note 2, pp. 45-46 citing the Hood River Project.

21 OTA, *Building Energy Efficiency*, supra note 2, p. 46, citing a survey by the Us. Department of Energy.

22 u.S. Department of Energy, Energy Information Administration, *Housing Characteristics 1987* DOE/EIA-0314(87) (Washington, DC: U.S. Government Printing Office, May 1989), hereafter referred to as DOE, *Housing Characteristics 1987;* OTA, *Building Energy Efficiency* supra note 2, p. 39 reports that 23 percent of new single family homes are equipped with heat pumps.

and in moderate to cold climates they must have a backup heat source, usually an electric resistance heater. There is a considerable range in the performance of residential heat pumps currently on the market. The typical heat pump has a heating efficiency (heating season performance factor, or HSPF) of about 6.9 Btus per watt-hour and a cooling efficiency (seasonal energy efficiency ratio, or SEER) of about 9.1 Btus per watt-hour. See box 4-B for a description of common energy efficiency measures. The best units currently on the market have efficiencies of 9.2 HSPF and 16.4 SEER.[23] Federal minimum efficiency standards for heat pumps sold after 1992 specify 6.8 HSPF and 10.0 SEER.[24]

Another variant of the heat pump, the ground-source heat pump uses groundwater, or the ground itself as the heat source. This technology offers an advantage over air-source heat pumps, in that ground temperatures seldom drop below freezing, thus there is no loss of heating capacity or resultant need for supplemental resistance heat.

For both heat pump and electric resistance heat systems, improving the thermal integrity of the building shell or envelope and insulating and plugging leaks in air distribution ducts can also cut heat losses and reduce the heating loads.

EPRI estimated that a combination of envelope improvements, a shift to electric heat pumps, and improvements in heat pump efficiencies could result in savings of 40 to 60 percent in space heating electricity demand in 2000 over 1987 stock.

SPACE COOLING

Air-conditioning accounts for about 11 percent of residential energy consumption and this demand is projected to grow as more homes are air-conditioned. Over two-thirds of U.S. homes are now air-conditioned; 40 percent have central air-conditioning and 29 percent have room units. Over three-quarters of new housing units have central air-conditioning. But this growth in air-conditioning demand has been offset by increases in the efficiency of both central and room air-conditioning units.

The most efficient central air units on the market today have a SEER of 16.9 Btus per watt-hour[25] and new Federal appliance standards in effect in 1992 will require a minimum SEER of 10 Btus per watt-hour. Just 10 years ago, the average efficiency for new central air systems was 7.8 Btus per watt-hour. These gains were due to more efficient fan motors and compressors, larger evaporator coils and condensers, and reduced airflow resistance. EPRI estimated that as of 1987, the stock of central air units in use had an average SEER of 7 Btus per watt-hour—considerably below the most efficient systems on the market. New installations and replacement of existing units with higher-efficiency central air units could cut electricity use by central air-conditioners in 2000 by 29 to 34 percent or more according to EPRI.

Room or ‘window’ air-conditioners have also improved with the addition of more efficient motors for fans and compressors, better fan blade design, larger heat exchangers, reduced airflow path resistance and better low-temperature refrigerant line insulation.[26] Efficiencies vary according to model sizes and features, but nevertheless new units today use about 30 percent less electricity to operate than units sold in 1972. The most efficient units available today, with SEERS of 12 consume half the electricity of 1972 models. EPRI estimated that the 1987 stock of room

23 American Council for an Energy. Efficient Economy, The *Most Energy-Efficient Appliances 1989-1990* (Washington, DC: American Council for and Energy-Efficient Economy, 1989), pp. 18-19, hereafter referred to as ACEEE, *The Most Energy-Efficient Appliances.*

24 OTA, *Building Energy Efficiency*, supra nOte 2, p. 39.

25 ACEEE, The Most *Energy-Efficient Appliances 1989-90,* supra note 23, pp. 16-17.

26 Battelle-Columbus Division and Enviro-Management & Research, Inc., *DSM Technology Alternatives*, EPRI-EM-5457, Interim Report (Palo Alto, CA: Electric Power Research Institute, October 1987); hereafter EPRI, *DSM Technology Alternatives.*

Box 4-B-Measuring Energy Efficiency

Various measures are used to indicate the energy efficiency of electrical devices. The following are among the most common measures for residential and commercial equipment

The energy efficiency ratio (EER) Is used to measure the coding performa- of heat pumps and air-conditioners. EER is expressed as the number of Btus[1] of heat removed from the conditioned space per watt-hour of electricity consumed (i.e., the cooling output divided by the power consumption). Typical EERs for room air-conditioners are 8.0 to 12.0 Btus per watt-hour. The higher the EER the more efficient the air conditioner.

The seasonal energy efficiency ratio (SEER) is used to measure the seasonal coding efficiency of heat pumps. SEER is expressed as the number of Btus of heat removed from the conditioned space per watt-hour of electricity consumed under average U.S. climate conditions. Unlike the EER, the SEER incorporates seasonal performances under varying outdoor temperatures and losses due to cycling. Typical SEERS are 9.0 to 12.0 Btus per watt-hour.

The heating seasonal performance factor (HSPF) is a measure of the seasonal heating efficiency of heat pumps under varying outdoor temperatures, losses due to cycling, defrosting, and backup resistance heat for average U.S. climate conditions. HSPF is expressed as the number of Btus of heat added to the conditioned space per watt-hour of electricity consumed. Typical values are 7.0 to 12.0 Btus per watt-hour.

The efficiency factor (EF) is a measure of the energy efficiencyof water heaters based on the energy used to provide 84 gallons of hot water per day.

The annual energy coat (AEC), required by Federal appliance labeling regulations, reflects the cost of energy (usually electricity) needed to operate a labeled appliance for 1 year at a specified level of use. The AEC label provides information on the costs of operating the labeled appliance and similar models over a range of energy prices (e.g., cents per kilowatthour) to account for variations in local rates.

1 Btu is shorthand for British thermal unit, a basic unit of energy defined as the amount of heat needed to raise the temperature of 1 pound of water 1° F (at 39.1° F). A Btu is equivalent to 252 calories.

SOURCES: Office of Technology Assessment, 1993, based on U.S. Congress, Office of Technology Assessment Building *Energy Efficiency,* OTA-E-518 (Washington, DC: U.S. Government Printing Office, May 1882), p. *68* and American Council for an Energy-Effkient Economy, The *Most Energy-Efficient Appliances,* 1989-edition (Washington, DC: American Council for an Energy-Efficient Economy, 1989).

air-conditioners had average SEER of 6.5 Btus per watt-hour. Using the most efficient room units for new and replacement installations could cut room air-conditioner electricity use by 19 to 32 percent by 2000 according to EPRI's analysis.

Better maintenance of air-conditioners can also boost efficiency. A dirty filter can cut efficiency by 10 percent. Cleaning air-conditioner coils and cleaning or replacing dirty falters can preserve efficiency.

Heat pumps are also used for space cooling. Today's typical heat pump has a SEER of 9, but commercially available high-efficiency models have SEERS up to 16.4. New Federal standards effective in 1992 will set minimum cooling efficiency for new heat pumps at 10. Careful selection and sizing of heat pumps to match cooling loads, especially in hot climates, can increase efficiency.

WATER HEATING

Electric water heating is used in about 37 percent of American homes and makes up about 12 percent of residential electricity consumption. Electric resistance water heaters are the most common type of electric water heater in use today and new units incorporating better tank insulation and improved heat transfer surfaces, use 10 to 15 percent less electricity than models of 10 years ago. (On average, larger size hot water tanks are less efficient.) Other electricity-saving measures include wrapping the outside of the hot water tank with an insulating blanket, insulating hot water pipes, and installing devices such as low-flow showerheads, aerators, and self-closing hot water faucets. EPRI estimated that use of these energy-saving measures could cut water heating power needs by 20 to 30 percent in 2000.

Shifting to alternative electric water heating systems, such as heat-pump water heaters, heat-recovery water heaters, and solar hot water systems can achieve efficiencies of up to 70 percent. Overall, EPRI estimated that the range of efficient electric water heating technologies offered savings of from 40 to 70 percent.

REFRIGERATORS AND FREEZERS

Together, refrigerators and freezers make up about 24 percent of residential electricity demand. Both technologies have seen substantial increases in efficiency over the past 20 years, but opportunities for significant improvements in performance remain.

The typical refrigerator on the market today uses just 45 percent of the electricity needed to run the average 1972 model.[27] A combination of technological gains has produced these savings, including: more efficient fans, motors, and compressors; better and more compact insulation; improved door seals and gaskets; and dual compressors. DOE researchers believe that it is technically feasible to cut electricity needed to run today's average new model almost 50 percent further. EPRI's analysis estimates that more efficient refrigerators could cut energy use about 22 to 48 percent in 2000 over the 1987 stock. Even more efficient refrigerators are available today than those assumed in the EPRI report. so that the maximum potential savings probably understate the potential.

Freezers account for 7 percent of residential electricity use and are found in about 34 percent of U.S. households. Stand alone freezers also have seen significant efficiency gains over the past 20 years as a result of advances in refrigeration technology. The typical model sold today uses half the electricity of the average 1972 model and as with refrigerators, additional efficiency gains are probable.

More efficient freezers could save 24 to 32 percent over energy required for the 1987 stock according to EPRI analyses.

Complicating the drive for more efficient refrigerators and freezers is the need to find replacements for the chlorofluorocarbons (CFCS) used as refrigerants and in insulation that offer equivalent or improved performance. Box 4-C describes the ''Golden Carrot' award program—a contest sponsored by a consortium of electric utilities in cooperation with the U.S. Environmental Protection Agency to spur the commercialization of more efficient refrigerators.

As with air-conditioning, maintenance practices can affect the efficient operation of refrigerators and freezers. Cleaning refrigerator coils two to three times per year can save about 3 percent of annual refrigerator electricity use at little or no cost.[28]

LIGHTING

About 15 percent of household electricity load is lighting. As in other sectors, use of more energy-efficient lighting products can save electricity for residential customers. OTA's recent report *Building Energy Efficiency* estimated that efficient lighting could cut residential lighting electricity use by one-third if one-half of all residential incandescent lights were replaced by compact fluorescents.[29] Assuming the light is used 6 hours per day, OTA calculated a payback

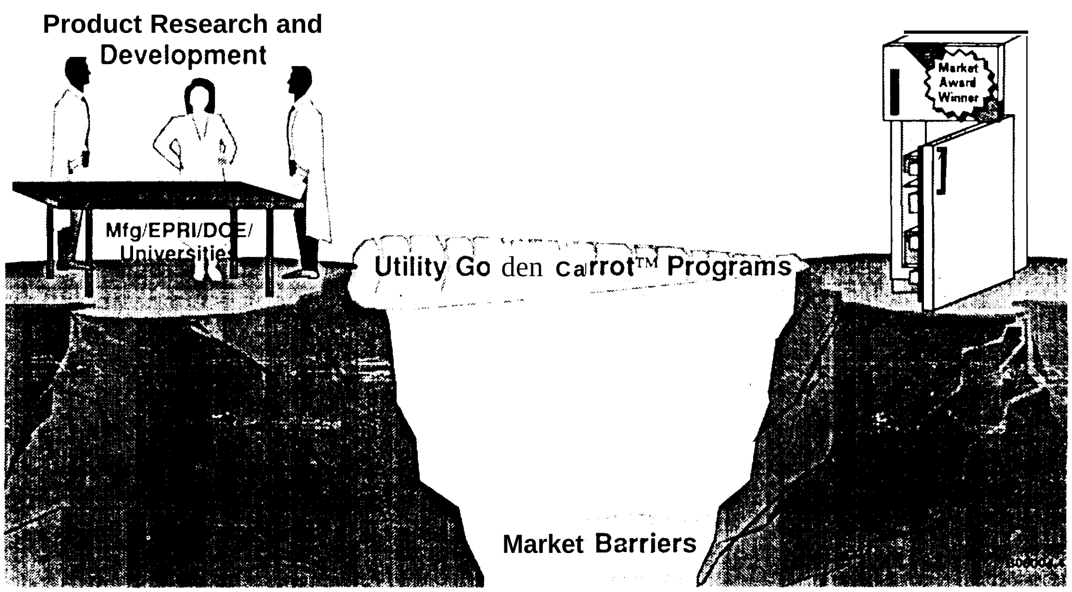
27 See OTA, *Building Energy Efficiency*, supra note 2, pp. 60-61, and table 2-13.

28 Stephen Cowell, Steve Gag, and Jackie Kelly, "Energy Fitness: Canvassing Urban Neighborhoods, " *Home Energy*, vol. 9, No. 2 March/April 1992, pp. 27-33, at p. 30.

29 OTA, *Building Energy Efficiency*, supra note 2, p. 50.

Box 4-C-The "Golden Carrot™" and the Quest for a Super-Efficient Refrigerator

In an innovative effort to overcome market barriers that have slowed the commercialization of more energy-efficient consumer appliances, 25 U.S. utilities joined to offer a "Golden Carrot™" in the form of a $30-miliion award to the winner of a design competition for an advanced, energy-saving refrigerator that is free of ozone-depleting chlorofluorocarbons (CFCS). The consortium, the Super-Efficient Refrigerator Program, Inc. (SERP), was formed in collaboration with the U.S. EPA Global Change Division's green programs, EPRI, and others. Its member utilities provide electric service to more than one quarter of the Nation's households. The award will provide the winning manufacturer with a subsidy of over $100 per refrigerator. In return, the new super-efficient refrigerator will be delivered in participating utilities' service areas before it is available to other distributors.



U.S. ENVIRONMENTAL PROTECTION AGENCY

Among the disincentives that the SERP program and possible future "Golden Carrot™" competitions are intended to counter are consumer reluctance to try new products and the higher first cost of more energy-efficient or green products. By offering a subsidy for development of the winning design and guaranteed orders for a sizable initial manufacturing run, SERP hopes to create a market pull for the energy-saving product, lower product development risks, and allow the manufacturer to achieve economies of scale in production. This should accelerate commercialization and result in a lower market price for the product than in the absence of the incentive. It will also help speed the commercialization of replacements of CFCS that are to be phased out of production by 1995.

The competition challenged manufacturers to commit to producing a CFC-free refrigerator at least 25 percent more efficient than the 1993 Federal energy efficiency standards require and to deliver them to participating utilities' service areas in 1994-97. The manufacturer must agree to assemble the refrigerators in North America. Additional points in the competition could be awarded for achieving greater efficiency levels.

Bids were due in October 1992 and all but 1 of the 15 major U.S. manufacturers entered the competition. Submittals were reviewed based on a number of key factors including proposed design, efficiency levels, incentive requested, marketing plans, and technological experience. In December 1992, Whirlpool Corp. and Frigidaire Co. were selected as finalists to design the new refrigerator.

(Continued **on next page)**

Box 4-C--The "Golden Carrot™" and the Quest for a Super-Efficient Refrigerator-(Continued)

The winner announced in June 1993 was Whirlpool Corp., which will deliver about 250,000 SERP **refrigerators in various models between 1994 and 1$97.** SERP **refrigerator will be priced the same as other models with similar features.**

EPA estimates that a super-efficient refrigerator has the potential to save 300 to 400 kWh/year over its its lifetime and save its owners a total of **aout $500 on utility bills. It also is expected to eliminate 9,000 dioxide emissions compared with current models.**

SOURCES: U.S. Enviromental Protection Agency, Office of Atmospheric ***Programs,1992Accomplishments*** **and Prospec for 1993, vol. 1 :Global Change Division, EPA 430-K_92-031 , November 1992, PP. 11-12. Gary Fermnstrom, "Buildinq a Better Refreigerator,' Environment, September/October 1992, p. 27;** "24 Utilities Sponsoring 'Super-Fridge' Contest to Get an Edge in Marketing,' **Electric Utility Week, July 5, 1993, p. 4.**

period of **1.7 years** for a $20 compact fluorescent bulb.[30] Compact fluorescent also last 10 to 13 times longer than standard incandescent bulbs. EPRI estimated maximum potential lighting related savings at from 20 to 40 percent in 2000.

Depending on applications, compact fluorescent bulbs can cut energy use per bulb by two-thirds over standard fluorescent. Even standard fluorescent offer energy savings over incandescent bulbs for equivalent lighting output. But consumers often find fluorescent lighting unacceptable or unattractive for some purposes. The extent to which energy-efficient lighting can cut electricity demand in the residential sector is highly uncertain and depends on consumer preferences and applications. Manufacturers of compact fluorescent continue to make progress on adapting these lamps for more common residential fixtures and to improve the quality of light provided, which may hasten acceptance by residential customers.

Other options such as lower-wattage "energy-saver' incandescent, reflector fixtures, task lighting, dimmers, and automatic lighting controls can also shave lighting energy use. Increased use of daylighting through windows, skylights, and clerestories can also reduce the need for interior lighting.

COOKING

Electric ranges and ovens account for 4 percent of household electricity demand. Newer models, particularly self-cleaning ovens are more efficient than current stock owing to a number of changes: more insulation, better seals, improved heating elements and reflective pans, reduced thermal mass, reduced contact resistance, and better controls. The penetration of microwave ovens, convection ovens, and induction cooktops also offer energy savings. It is uncertain whether microwave ovens, which cook food with one-third the electricity required for standard electric ranges and ovens, will actually result in reduced cooking loads as consumers may tend to use them more as an adjunct to conventional appliances. EPRI estimates that replacement of the 1987 stock of ranges and ovens with more efficient models could produce savings of 10 to 20 percent in electricity demand for cooking in 2000.

DISHWASHERS

Dishwashers account for about 2 percent of household electricity use and are found in 43 percent of households. Energy-saving features such as better insulation, water temperature boosters, water saver cycles, and air drying cycles can cut electricity consumption. Total savings are dependent on the customers use of energy-saving

30 Ibid., p. s3. Also assuming electricity at 7.8 cents/kWh, O labor costs.

cycles. EPRI estimates that improved dishwashers could cut dishwasher electricity demand in 2000 by 10 to 30 percent over 1987 stock.

OTHER APPLIANCES

The remaining household electric appliances, such as clothes washers and dryers, televisions, stereos and other electronic equipment, vacuums, small household appliances, power tools, and home computers account for about 13 percent of present residential electricity use. This portion of household electricity demand is expected to grow with greater saturation of clothes washers and electronic equipment. Newer models will be more energy efficient, and EPRI estimate, that this trend is expected to result in electricity consumption that is 10 to 20 percent less than equivalent 1987 models by 2000.

Estimating net efficiency gains from more efficient appliances is difficult, however, because energy services are growing, and households may use the energy savings to buy larger appliances or increase the utilization of the equipment.

Obstacles to Residential Energy Efficiency

Total residential energy use in 1990 was over 1 quad less than it was in 1978, even as the number of households grew from 77 million to 94 million, reflecting a steady improvement in residential energy efficiency.[31] Over this period the energy intensity of new living space has decreased and many older units were retrofitted with a variety of energy-saving measures. Major household appliances use significantly less electricity to operate than comparable models of 20 years ago.

Household electricity use also has grown from 24 percent of residential energy use in 1978 to 30 percent in 1990, but growth in residential electricity demand has been less than it might have been without energy efficiency gains. These gains are attributable to several factors in addition to evolutionary efficiency gains: higher energy prices during the 1970s and early 1980s; energy efficiency requirements in building codes; appliance labeling and efficiency standards; government and utility energy education efforts; utility conservation programs; and more awareness of energy efficiency by consumers, equipment vendors, and building professionals and tradespeople.

Even with the admirable gains that have been made in energy efficiency since the 1970s, there remains a sizable gap between the most energy-efficient products on the market to day and the products in use in American homes. More efficient options exist for almost all of the major electricity uses at home. The potential energy and cost savings from residential energy-efficiency investments are significant according to many efficiency proponents. For many measures the energy savings over the lifetime of the investment would exceed the initial cost, in some cases offering payback periods of 2 years or less.

If energy efficiency investments are such attractive investments, why then haven't they been enthusiastically embraced by American consumers? Analysts commonly cite a host of disincentives that have tended to dampen the pace and extent of efficiency savings. These include a number of institutional, economic, behavioral, and practical matters.

OTA's *report Building Energy Efficiency* found a confluence of factors resulted in underinvestment in residential energy efficiency. Decisionmaking affecting household energy efficiency is fragmented among: residents (homeowners and renters); architects; developers; builders; equipment manufacturers and vendors; and a host of Federal, State, and local government agencies. For all of these decisionmakers, energy efficiency is only one of many attributes considered in making choices that affect home energy use and

[31] U.S. Department of Energy, Energy Information Administration, *Annual Energy Review* 1991, DOE/EIA-0384(91) (Washington, DC: U.S. Government Printing Office, June 1992), tables 17 and 21, hereafter referred to as DOE, *Annual Energy Review 1991.*

it competes against such characteristics as lower first cost, appearance, convenience, features, and hassle-avoidance. For most decisionmakers, energy efficiency has not been a high priority. In all too many instances, residential consumers are effectively precluded from energy efficiency opportunities because design and major equipment choices are made by others-by architects, builders, and developers for new housing, and by landlords for the one-third of residential units that are rented.

Although energy-efficient residences and high-efficiency appliances offer electricity savings and lower life-cycle costs over less efficient versions, these potential cost savings provide only weak financial incentives for several reasons.

First, residential electricity prices seem to have only a weak influence on energy choices for most ratepayers, and almost no influence on third-party decisionmakers (developers, builders, equipment vendors and manufacturers, and landlords and tenants who do not pay monthly electric bills). Residential electricity prices have declined steadily in real terms over the past decade. Moreover, residential rates usually do not reflect the higher costs of using electricity at times of peak demand, nor the social and environmental costs (externalities) of generating electricity.

Future savings from energy-efficiency investments are heavily discounted. Studies have found that residential consumers demand a short payback period for efficiency investments-2 years or less for home appliances, for example.

Many decisionmakers are driven by the desire to keep first-costs low; few pursue the goal of minimizing life-cycle costs (the sum of capital and operating costs over the life of the equipment—or e.g., the initial purchase cost of an appliance plus the cost of annual electric bills, maintenance and repairs), This so-called first-cost bias is especially strong when energy-efficient equipment costs more and others (home purchasers or tenants) will reap the benefits of lower electric bills. First-cost bias is also strong for low-income consumers who lack either the cash or access to credit to pay for the more efficient and expensive equipment.

Reliable, understandable information on energy use and costs is often lacking or hard to use. Consumers that would like to give greater weight to energy efficiency in their decisions—whether motivated by lower life-cycle costs, environmental concern, technological fascination-have few alternatives. Government and private programs for energy-efficiency ratings of homes and apartments are only just beginning. The effectiveness of federally required labeling for major appliances is uncertain and has not been adequately assessed.[32]

Energy efficiency is often misperceived as requiring discomfort or sacrifice, rather than as providing equivalent services with less energy. The poor popular image of home energy efficiency as meaning cold showers, darkrooms, and warm beers hampers consumer acceptance and diminishes incentives for housing developers and equipment manufacturers to make efficiency a selling point for their products. Without a market pull for efficiency, equipment manufacturers and building suppliers give less emphasis to efficiency in product design and research.

The typical low turnover rate in the housing stock and slow rate of replacement of major appliances mean that efficiency improvements in the residential sector will significantly lag behind technical potential. Without aggressive efforts in response to government policy and/or an energy crisis, this lagging response will continue.[33]

From a somewhat different analytical perspective, the Bush Administration also found progress in residential energy efficiency unacceptably slow. President Bush's National Energy Strategy

32 See discussions in OTA, *Building Energy Efficiency*, supra note 2, ch. 4 and U.S. Congress, Office of Technology Assessment, *changing by Degrees: Steps to Reduce Greenhouse Gases, OTA-O-482* (Washington, DC: U.S. Government Printing Office, February 1992), ch. 4.

33 OTA, *Building Energy Efficiency*, supra note 2, p. 85.

(NES) found that "a number of institutional and market barriers' limited consumer responses to the higher energy prices of the 1970s and early 1980s. Strongly reflecting the economic policy framework of its analysis, the NES concluded that "Our stock of housing and appliances is still far less energy efficient than would be economically optimal.' '[34] Among the ''significant market barriers' in the residential sector identified by the NES were:

- Traditional energy price regulation and ratesetting that do not reflect the full costs to society of energy use, thus causing individual consumers to undervalue energy-efficiency investments and renewable resources.
- Failure of market mechanisms to induce adoption of economical energy-saving measures by residential customers, particularly in situations where those who must pay for such devices cannot expect any economic benefits.
- First-cost bias tendency of buyers (especially builders and homebuyers) to minimize upfront costs of residential property and major appliances.
- Mortgage lending practices that fail to consider the lower total cost of energy-saving homes in calculating mortgage eligibility.
- Low incomes of some energy users that often make them unable to finance energy-efficiency improvements no matter what the payback period is.
- Absence of credible data on reliability and cost of energy-saving technologies for builders, architects, utility programs, mortgage lenders, and individual consumers.
- Fragmented and cyclical nature of homebuilding industry that contributes to a reluctance to try innovative energy-saving designs, products, and construction techniques and makes concerted industry-led efficiency initiatives unlikely.
- Inadequate implementation and enforcement of energy building codes because of lack of resources to check actual plans and construction sites and to educate builders.
- Inadequate energy-efficiency investment in public sector housing because many local housing authorities lack funds and management incentives to improve efficiency.
- Slow turnover of residential structures and long lifetimes of heating and cooling systems.

The premise of institutional and market barriers to energy efficiency has wide acceptance among energy analysts, government policymakers, State regulators and utility executives. There are others, generally economists of the classical and neoclassical persuasions, who reject this conclusion of market failure, however. They adhere to a belief that present energy efficiency characteristics represent the informed decisions of knowledgeable consumers who have compared alternative investment opportunities and selected energy conservation that offers equal or better returns.[35]

As will be seen in the following sections, Federal, State, and utility programs have attempted to counter these constraints with varying degrees of success. Reducing these disincentives to energy efficiency will be key in attaining energy efficiency goals.

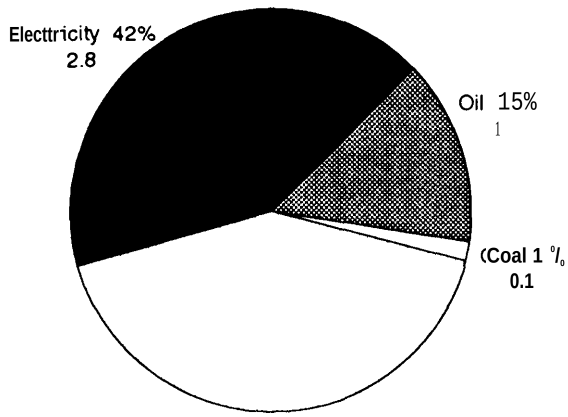
ENERGY EFFICIENCY OPPORTUNITIES IN THE COMMERCIAL SECTOR

The commercial sector consists of all businesses that are not engaged in transportation or industrial activity and includes, for example, offices; retail stores; wholesalers; warehouses; hotels; restaurants; religious, social, educational and healthcare institutions; and Federal, State,

34 *National Energy Strategy: Powerful Ideas for America,* supra note 6, p. 42.

35 See the discussion of failure of classical model to explain efficiency gap or consumer behavior as noted in Florentin Kraus and Joseph Eto, *Least-Cost Utility Planning: A Handbook for Public Utility Commissioners: Volume 2, The Demand Side Conceptual and Methodological Issues* (Washington, DC: National Association of Regulatory Utility Commissioners, December 1988),

Figure 4-3--Commerciai Sector On-site Energy Consumption, by Source, 1990 (quadrillion Btus)



SOURCE: Office of Technology Assessment, 1993, based on data from the U.S. Department of Energy, Energy Information Adminlstra-tlon, and the Gas Research Institute.

and local governments. In 1990 the commercial sector accounted for about 14 percent of total primary energy use.[36] Figure 4-3 shows energy consumption (excluding electricity conversion and transmission losses) in the commercial sector. Electricity and natural gas each supply about 42 percent of commercial sector energy needs, with oil (15 percent) and coal (1 percent) supplying the remainder.[37]

In 1990 the commercial sector consumed about 751 billion kWh of electricity at cost of $55 billion.[38] Commercial establishments made up about 28 percent of total electric utility retail sales in 1990. In addition to purchased electricity, a growing number of commercial facilities have resorted to cogeneration or self-generation to meet some or all of their electricity demand; this output is not included in commercial sector electricity consumption estimates, but fuels used to produce this power axe included in overall commercial energy consumption.[39]

Figure 4-4 shows commercial electricity use by application. Heating, ventilating, and air-conditioning (HVAC) dominates, comprising 37 percent of commercial electricity use (space heating, percent; cooling, percent; and ventilation, percent). Water heating accounts for an additional 3 percent. Lighting accounts for an estimated 29 percent of commercial load.[40] Refrigeration (7 percent); cooking (2 percent), and miscellaneous equipment including elevators, escalators, office computers, printers, telephone systems, and other commercial equipment (21 percent). Sixty percent of electricity use in commercial establishments is for nonspace heating purposes. These nonspace conditioning applications are projected to grow faster than commercial square footage to over 65 percent of electric load by 2010.[41] The heat generated by rniscellaneous equipment add to demands for cooling, but lowers space heating loads.

Electricity demand in the commercial sector is driven by the growth in square footage in commercial buildings and the intensity of service demand-for space cooling, lighting, and office

36 1992 *GRI Baseline Projection,* supra note 8.

37 Adjusting for conversion and distribution losses of utilities for serving commercial loads, electricity accounted for 69 percent of total primary energy consumption by the commercial sector. OTA, *Building Energy Efficiency,* supra note 2, p. 24, note 37.

38 DOE, *Electric* Power *Annual 1990,* supra note 9.

39 Many commercial facilities are cogenerators—with natural gas the most common fuel. Opportunities to combine heating and or cooling plants with power generation abound in large institutions, and concentrated urban commercial areas. Cogeneration can add to overall efficiency of energy use in the sector, but in part means a shift of primary energy consumption from the electric utility sector.

40 Estimates of commercial ii@@ electricity use vary, some estimates place lighting at 40 percent of commercial load reflecting the high percentage Of lighting loads in office buildings. For purposes of this analysis we have adopted the estimates used in EPRI's analysis.

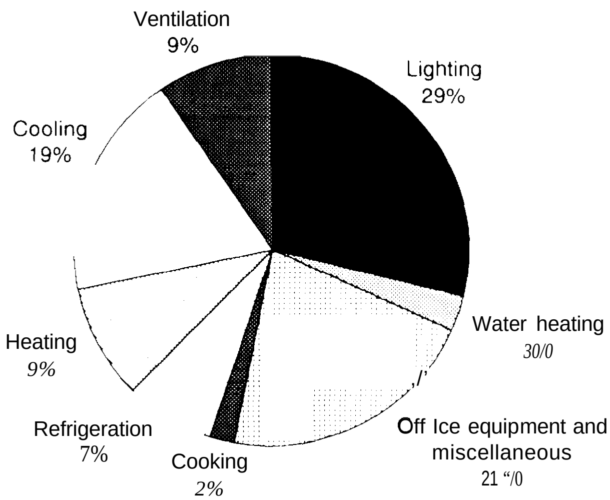
41 GRI 1992 *Baseline* Projection, supra note 8 and EPRI, *Efficient Electricity Use,* supra note 1.

equipment, for example.[42] On average, office, health care, and food service establishments are the most energy-intensive commercial buildings. Between 1970 and 1989, the amount of commercial square footage and electricity use each grew by 45 percent.[43] Even so, newer commercial buildings have tended to be more energy efficient incorporating more insulation, better windows, lighting and more efficient space-conditioning equipment, thus tempering the growth in electricity demand.

Commercial building energy intensity (i.e., energy use per square foot) has remained flat for the past two decades, even as demand for air-conditioning, computers and other equipment grew. Complicating this trend has been the growth in commercial electricity demand due to a shift from on-site use of primary fuels-oil, gas, and coal—to electricity. Thus primary fuel use transferred from the commercial sector to the utility sector, and may even have resulted in a net increase in primary energy consumption, because of the losses involved in electricity generation and delivery.

At present there are over 4.5 million commercial buildings in the United States with a total of over 61 billion square feet.[44] Each year about 1 billion square feet of new commercial space is added—10 to 15 billion total square feet will be added this decade. There is great diversity in the size and energy using characteristics of these commercial buildings. Smaller commercial building energy systems are similar to those in houses and small apartment buildings. Larger buildings, however, have complex HVAC systems and activities inside the building-lighting, occupancy, electric and other equipment-can add to energy demand and determine equipment choices. Buildings larger than 10,000 square feet make up almost 80 percent of building square footage and offer many opportunities for electricity savings.

Figure 44-Commercial Sector Electricity Use by Application, 1987



SOURCE: Office of Technology Assessment, 1993, based **on data *from* the Electric Power Research Institute and U.S. Department of Energy.**

▮ Energy Efficiency Technologies for the Commercial Sector

Space-conditioning, lighting, and building shell weatherization are primary targets for improving energy efficiency and saving electricity in the commercial sector. In addition, large commercial buildings are suitable targets for utility load management programs designed to shift energy use away from peak hours, but not necessarily resulting in lower overall energy demand, through installation of technologies such as storage heating and cooling systems. There are also potential energy savings in other commercial applications. See table 4-3.

42 See OTA, *Building Energy Efficiency,* supra note 2, at p. 21.

43 DOE, *Annual Energy Review 1991*, supra note 31.

44 U.S. Department of Energy, Energy Information Administration, *Commercial Building Characteristics 1989,* DOE/EIA-0246(89) (Washington, DC: U.S. Government printing Office, January 1991) table 61, p. 122; hereafter DOE, *Commercial Building Characteristics 1989,*

Table 4-3-Selected Energy Efficiency Technology Options for the Commercial Sector

Heating, ventilation, and alr-condltlonlng (HVAC) systems

Building envelope efficiency improvements
- Weatherstripping and caulking
- Insulation
- Storm windows and doors
- Window treatments

Space heating

improved commercial heat pumps

Air-source heat pumps
- More efficient models
- Improved technology

Ground-source heat pumps

Heat recovery systems

Energy management controls and systems
- Set-back thermostats
- Smart buildings and smart systems
- Zoned heat systems

Thermal storage systems

Cogeneration systems

District heating systems

Space cooling

More efficient cooling systems
Cool storage systems
District cooling systems

Vent//at/on

Air distribution systems
- Improved insulation
- Reduced duct and damper leakage
- Separate make up airflows for cooling exhaust systems
- Economizer controls

Improved HVAC maintenance

Integrated HVAC systems

WaterheatIng

Blanket wrap for water tanks
Commercial heat pump water heaters
Integrated heating and hot water systems
Heat recovery water heat systems
Increased insulation of tanks and pipes
Flow restrictors
Service/point of use water heaters

Commercial lighting

Delamping
Lighting fixture retrofits
Electronic ballasts for fluorescent
High-effidency lamps
Reflectors
Increased use of daylighting
High-intermit y lighting applications
Increased use of task lighting
Compact fluorescent
(LED) signs
Lighting control systems: timers, occupancy sensors, photocells, dimmers

Commercial refrigerators and freezers

Efficient motors and controls
Improved insulation and seals

Commercial cooking

Energy+efficient commercial electric ranges, stoves, fryers, ovens and broilers
Microwave cooking
Convection cooking
Induction cooking

Miscellaneous electrical equipment and office machines

More efficient motors and drives for elevators, escalators, and other building systems
Improved hardware and software for office equipment
Integrated building energy management and control systems

SOURCE: Office of Technology Assessment, 1993.

Analysis of potential efficiency opportunities by EPRI found that commercially available electric equipment could reduce commercial electricity in year 2000 by 22 to 49 percent from what consumption would be without the use of these technologies if efficiency were frozen at 1987 levels. Commercial applications with the most significant savings potential in the EPRI analysis were lighting, cooling, and miscellaneous electric equipment.

IMPROVEMENTS IN COMMERCIAL BUILDING EFFICIENCY

Turnover of commercial building space is more rapid than residential, but it is evident that a large portion of commercial space in use for the next few decades is already in place. Analysts estimate that one-half of the commercial space in 2010 has already been built, and 80 percent of the existing stock of commercial buildings will still be in use for the next 30 years.[45]

The pace of new commercial construction provides opportunities for efficiency gains in both building shell, equipment, and appliances. Measures to increase the efficiency of commercial buildings include improved design, siting, and construction techniques, better insulation, and more efficient equipment choices.

The remodeling and rehabilitation of commercial space offers additional opportunities. There is considerable potential for energy-efficiency improvements in existing commercial buildings. According to DOE surveys, while 84 percent of buildings are reported to have installed building shell conservation features, there remains a considerable pool of buildings that have not installed basic measures. The most frequently reported measure is ceiling insulation, 67.5 percent, weatherstripping or caulking, 61 percent, and wall insulation, 47 percent. Storm windows and multiple-glazing were reported in 32 percent of buildings, and shades and awnings and reflective shading glass or films were reported for 21 percent of buildings.[%]

HEATING, VENTILATION, AND AIR-CONDITIONING

Space Heating. Just under one-quarter of commercial buildings rely on electric heating systems.[47] Most of these buildings are located in the South and West.

Installation of more efficient electric heating equipment, such as heat pumps instead of resistance heat, coupled with a combination of measures such as building shell improvements, window treatments, heat recovery, and improved maintenance practices can cut electricity demand for space heating. Further savings are possible with integrated heat pump systems that provide heating, cooling and water heating. These potential savings are offset by the expected increase in heating load attributable to reduced internal heating gains from installation of energy-efficient lighting measures. Use of the best available energy efficiency measures could reduce space heating electricity demand in 2000 by 20 to 30 percent from what would be required from the 1987 stock of commercial buildings and equipment, according to EPRI.

District heat, in which a central plant provides heat, and often hot water for all buildings within a complex or downtown area, also offers efficiency opportunities, particularly if coupled with cogeneration.[48]

Cooling. Commercial cooling loads are the biggest component of summer peak load for most utility systems. Over 70 percent of commercial buildings have cooling systems and 96 percent of these systems are electric. Common commercial cooling equipment includes packaged cooling system, individual air-conditioners, central chillers, and heat pumps. Often these systems are integrated with the building ventilation and air transport systems. Commercial cooling load is driven by building size, external temperature, and internal heat gains from electric and other equipment and occupants. Over 6 percent of commercial buildings maintain separate cooling systems for computer areas.[49]

Energy-efficient cooling options for commercial buildings include more efficient air-conditioners, heat pumps, high-efficiency chillers, chiller capacity modulation and downsizing, window treatments, radiant barriers, energy management control systems, and improved operation and maintenance. Reduced internal heat gain

45 O& Ridge National Laboratory, supra note 16, p. 45.

46 DOE, *Commercial Building Characteristics 1989,* supra note 44, table 103, pp. 198-199.

47 Ibid., table 66, p. 132.

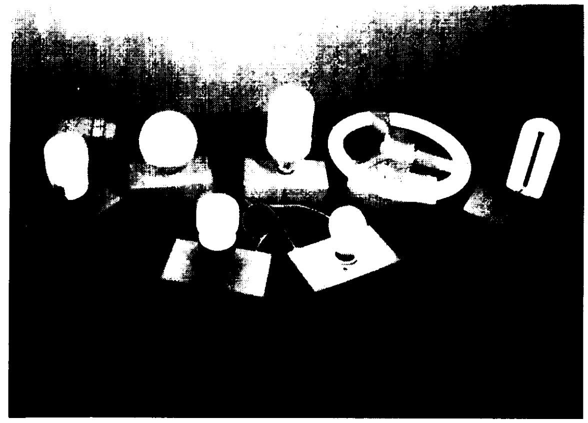
48 See discussion of district heat in OTA, *Building Energy Efficiency,* supra note 2, p. @.

49 DOE, *Commercial Building Characteristics 1989,* supra note 44, table 94, p. 183.

from installing efficient lighting systems also cuts cooling load. Excluding lighting-related savings, EPRI estimated that cooling requirements can be reduced by 30 percent or more in commercial buildings. Including lighting efficiency packages with cooling system improvements could provide total savings of over 80 percent according to EPRI estimates. However, the need to find replacements for CFCS now used in cooling systems could result in newer cooling technologies that may reduce some possible efficiency gains. EPRI therefore estimates maximum potential electricity savings in commercial space cooling in 2000 to be from 30 to 70 percent over 1987 performance levels.[50]

Another energy efficiency strategy for commercial cooling that may not always result in a net reduction in electricity demand is the use of cool storage systems that shift all or part of a buildings' air-conditioning electricity demand from peak to off-peak hours. Typically, ice or chilled water is produced in a refrigeration system at night and used to meet some or all of the next day's air-conditioning needs. Cool storage systems offer financial savings for customers through lower off-peak rates and peak reduction for utilities.[51]

Ventilation. Air transport and ventilation systems are a critical component of modern large commercial buildings. Improving the energy efficiency of ventilation and air transport systems can be attained through a variety of measures: viable air volume systems; low-fiction air distribution designs; high-efficiency electric motors; variable speed drives; heating, cooling, and lighting improvements; and improved operation and maintenance practices. EPRI estimates that ventilation electricity use can be reduced by 30 to 50 percent through a comprehensive package of measures.



U.S. DEPARTMENT OF ENERGY

Compact fluorescents, which use 75 percent less energy than standard incandescent lamps, are available in a variety of designs.

LIGHTING

About 29 percent of commercial electricity consumption is for lighting. Commercial lighting requirements are met with a combination of incandescent, fluorescent, and high-intensity discharge lamps and most commercial buildings have a mixture of these fixtures. Fluorescent lamps are already extensively used in the commercial sector. About 78 percent of commercial floorspace is lit with fluorescent and high-efficiency ballasts have been installed in about 40 percent of this space.[52]

A range of cost-effective technologies is available to cut lighting loads. Ready savings can be achieved in many commercial buildings by delamping to lower lighting levels, using lower wattage fluorescent, and replacing incandescent with more efficient fluorescent or compact fluorescent lamps where appropriate. More advanced lighting system efficiency upgrades include installation of high-efficiency electronic ballasts, aluminum and silver film reflectors, daylight dimming, occupancy sensors, use of high-

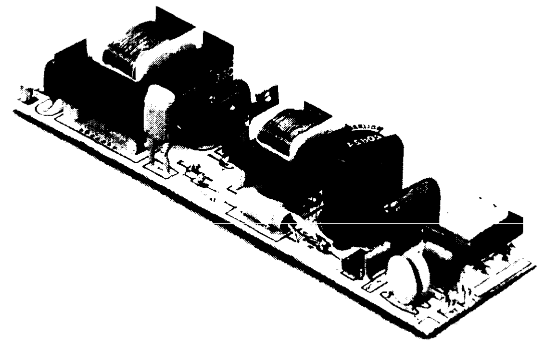
50 EPRI, *Efficient Electricity Use,* supra note 1, p. 50.

51 EPRI, *DSM Technology Alternatives,* supra note *26,* pp. B-394.

52 DOE, *Commercial Building* Characteristics *1989,* supra note 44, table 101, p. 195. It is not reported whether the high-efficiency ballasts have been installed in all fluorescent fixtures lighting these spaces.

pressure sodium lamps instead of mercury vapor lamps in high-intensity discharge fixtures. In new construction and remodeling, better lighting system design and greater use of daylighting can also cut lighting requirements.

Estimates of lighting savings involve interactions among package components and are not necessarily the sum total of individual measures. Building characteristics also influence potential savings. In addition lighting upgrades can cut cooling costs by reducing internal heat gain, but add to heating loads. EPRI estimates potential electricity savings from more efficient commercial lighting in 2000 to range from 30 to 60 percent over 1987 stock.[53]


ADVANCE TRANSFORMER CO.

Electronic ballasts can cut fluorescent lighting energy use by 20 to 25 percent.

COMMERCIAL REFRIGERATION SYSTEMS

Commercial refrigeration in retail stores, restaurants, and institutions can be a significant load. About 20 percent of commercial buildings are, equipped with commercial refrigeration systems; about 16 percent have commercial freezers. EPRI estimates that commercial refrigeration electricity use can be cut by 20 to 40 percent from 1987 performance levels by combining a variety of efficiency improvements. Examples include: more efficient fan motors and compressors, multiplex unequal parallel compressors, advanced compressor cycles, variable speed controls, evaporatively cooled condensers, floating head pressure systems, air barriers, food case enclosures, electronic controls, and improved maintenance practices. Electricity savings are highly site specific and depend on previous saturation of these technologies.

WATER HEATING

About 48 percent of commercial buildings with hot water systems[54] use electricity as the sole or supplemental water heat source. Hot water heating **accounts** for about 3 percent of commercial electricity use.

There are a number of efficiency measures for commercial hot water systems on the market. These measures include many also used in residential applications, such as water heater wraps, low flow devices, hot water pipe insulation, and installation of valves that reduce convection loses. Commercial heat-pump water heaters and heat recovery systems can provide energy savings of one-third or more over conventional resistance systems. Integrated heat pumps can provide heating, cooling, and hot water for commercial buildings. Lowering the hot water thermostat can reduce electricity use while still providing adequate water temperatures for most uses. EPRI estimates potential savings in water heating electricity use in 2000 of 40 to 60 percent over 1987 stock.[55]

COOKING

Commercial cooking equipment accounts for about 2 percent of commercial sector electricity use. Microwaves, convection ovens, and mag-

53 OTA, *Building Energy Efficiency*, supra note 2, p. 50, for estimates Of savings in the commercial sector.

54 DOE, *Commercial* Building *Characteristics 1989,* supra note 44, table 76, p. 148.

55 EPRI, *Efficient* *Electricity Use,* supra *note* 1, p. 51.

netic induction cooktops can cook food with less time and energy than more conventional electric stoves and ovens and are seeing greater use in commercial establishments. A range of technological improvements are available to cut electricity use in commercial ranges, ovens, broilers, griddles, and fryers. Examples include: increased insulation, better heating elements, more precise temperature controls, reflective pans, reduced thermal mass, and less contact resistance. EPRI estimates that by incorporating a combination of efficiency measures, electricity use by commercial electric stoves and ovens in 2000 could be from 20 to 30 percent less than that required for 1987 stock.[56]

MISCELLANEOUS COMMERCIAL SYSTEMS AND EQUIPMENT

Residual electric systems and equipment (e.g. elevators, escalators, telephone systems, office machines, food preparation and other equipment) account for 21 percent of commercial sector electricity use and will continue to grow.

EPRI estimates that overall savings from expected efficiency advances in miscellaneous commercial sector equipment will range from 10 to 30 percent. Expected improvements in hardware, software, and system operations could offer maximum potential savings of up to 50 percent for office equipment in 2000. EPRI also calculates maximum potential savings of up to 35 percent in 2000 from the use of high-efficiency motors and adjustable-speed drives in elevators and escalators.[57]

The Federal Government, through the Environmental Protection Agency's green programs and Federal procurement policies, is seeking to overcome some of the market barriers to more energy-efficient computer equipment. (See box 4-D.)

Barriers to Energy Efficiency in the Commercial Sector

There remains a significant gap between the electricity-using characteristics of the present stock of commercial buildings and equipment and the energy-saving potential of the most efficient buildings and equipment marketed today. As with the residential sector, many economic, institutional, and behavior influences hamper greater commercial sector investment in energy efficiency.

Some influences are shared with other sectors. The normally slow turnover in commercial buildings and major equipment, albeit more rapid than in the residential sector, means that actual efficiency savings lag considerably behind technical potential. Relatively low energy prices that do not reflect all societal and environmental costs of energy production and use also lead to undervaluing of energy and underinvestment in efficiency by commercial consumers. (This persists even though commercial customers are in general more price-sensitive than residential customers, and utility bills for commercial establishments can be quite large.) Choices affecting commercial energy demand are made by a large number of decisionmakers — architects, designers, developers, building owners, tenants, equipment manufacturers and vendors, and local building authorities. The plethora of decisionmakers and the absence of any direct economic benefit in efficiency for many of them lessens the impact of existing weak financial incentives and fragrnents the potential constituency for efficiency improvements.

Several factors contribute to limited financial incentives to invest in efficiency. Energy costs of buildings can often be a small fraction of total business expenses and thus gain little management attention as a means of saving money .58

56 Ibid.

57 Ibid., p. 52.

58 According to some estimates, for large office buildings and retail space energy costs are less than 5 percent Of total annual operating costs per square foot and are dwarfed by other business costs. OTA, *Building Energy Efficiency*, supra note 2, pp. 81-82,

Box 4-D-EPA and Green Computers

Computer equipment and other electric office machines are among the fastest growing components of commercial energy consumption. They now total about **5 percent and are expected to total 10 percent by 2000.** Surveys have determined that most personal computers are left turned on when not in use during the day, overnight **and on weekends. Desktop computers typically have been designed with little consideration for energy efficiency, unlike portable or laptop models that incorporate a number** of energy-saving measures to save battery power. if desktops were equipped with technologies that allowed them to "nap" or shutdown when not in use and return quickly to full power capability when needed, EPA **estimated that such computers could save 50 percent of the energy used to run them. Green** computers thus became one of the first commercial consumer products targeted by EPA's pollution prevention programs to increase consumer and manufacturer awareness of energy efficiency benefits, and to create a new market for energy-efficient equipment.

Using a model similar to the Green Lights Program (see chapter 7), EPA entered into discussions with manufacturers of computers, peripherals, and microprocessors. Manufacturers agree to produce products that meet certain efficiency improvements and sign a mernorandum of understanding with EPA. The manufactures are then eligible to use the "Energy Star™-EPA Pollution Preventer" logo in the marketing and displaying of the products. For example, personal computers with the capability of switching to a low power mode of 30 watts or less (about 75 percent less than current models) qualify for the EPA logo that identifies new high efficiency equipment. EPA is expanding the use of such voluntary agreements for related computer products including printers, monitors and other pieces of office equipment.

U.S. ENVIRONMENTAL PROTECTION AGENCY

Energy Star Computers could save enough electricity each year to power Vermont and New Hampshire, cut electricity bills by $1 billion, and reduce CO_2 *pollution equivalent to emissions from* 2.5 *million autos.*

By May 1993 EPA had reached agreement with an impressive array of companies producing personal computers and related products. Charter partners in EPA's Energy Star™ computer program represent 60 percent of the U.S. market for computers and monitors, and 60 percent of the laser printer market. An Energy Star™ allies, program has been established enlisting agreements from components and software makers. Intel Corporation, one of the world's major microprocessor manufacturer, has committed to incorporating energy-saving technologies into all future microprocessors. The first products bearing the Energy Star logo will be available in 1993.

The widespread penetration of energy-saving computer technologies offers significant benefits to consumers, the economy, and the environment. The cost of operating a typical 150-watt personal computer 24 hours per day year round can be $105/year (assuming electricity costs at $0.08/kWh) and uses 1,314 kWh/yr. Turning the machine off at night reduces the operating cost to $35/year and cuts energy consumption to 433 kWh/year. Using technology that conserves power when the machine is not **active** during the day could cut costs to $1 7/year for 216 kWh/year. EPA estimates that green computers could save a total off $1.5 to $2 billion in annual electricity bills and avoid emissions of 20 million tons of carbon dioxide, 140,000 tons of sulfur dioxide, and 75,000 **tons of nitrogen dioxide by** 2000.

SOURCES: U.S. Environmental Protection Agency, Office *of Atmospheric Programs, 7992 Accomplishments* and Prospecft for *1993, vol.* 1: Global Change Division, EPA 430-K-92-031, November 1992, pp. 9-10. Brian J. Johnson and Catherine R. Zoi, "El% Energy Star Computers: The Next Generation of Office Equipment," in American Council for an Energy-Efficient Economy, *ACEEE 1992 Surnmer Study on Energy Efficiency in Buildings, vol. 6* (Washington DC: American Council for an Energy-Efficient Economy, 1992), pp. 6.107-6.114.

330-075 : QL 30-93-4

Energy efficiency is only one consideration in decisions affecting energy use--first-cost, appearance, comfort, and other performance features may overshadow potential lifecycle cost savings from efficiency. Building owners and tenants tend to place greater emphasis on occupant comfort and productivity and may be reluctant to make any changes that might affect building operations. One-quarter of commercial space is leased and lower energy bills offer no incentives for building landlords when the tenants are responsible for paying electric bills. Where landlords pay utility bills and energy prices are included in rent, building occupants may have little financial incentive to choose high-efficiency equipment or to invest in energy-savings maintenance.[59]

When efficiency investments are considered, commercial sector decisionmakers also tend to require short payback periods of 1 to 3 years. Lack of resources or access to capital can discourage some possible commercial sector efficiency investments, particularly for nonprofit institutions and small businesses. Cost-effective, low-risk measures that could cut operating costs are often given low priority in government facility management. Even when government facility managers are aware of potential savings, budgetary and procurement constraints limit investments in efficiency for government owned or occupied facilities.[60]

The energy efficiency industry is still in its infancy and the small pool of trained vendors, installers, and auditors available to serve commercial establishments and utility programs can limit achievable energy savings at least in the short term. The relative newness of the industry and absence of a proven track record of delivering savings may make many in the commercial sector reluctant to make significant investments in energy efficiency. Indeed, savings from early building retrofit investments have been less than expected on average, and unpredictable for individual buildings, adding to the perceived riskiness of the investment.[61]

Nevertheless, the commercial sector remains a prime and potentially profitable target for utility, private sector and government efforts at improving energy efficiency.

ENERGY EFFICIENCY OPPORTUNITIES IN THE INDUSTRIAL SECTOR

The industrial sector includes both manufacturing enterprises (i.e., businesses that convert raw materials into intermediate or finished products) and nonmanufacturing enterprises, such as agriculture, forestry, fishing, construction, mining, and oil and gas production. The industrial sector is characterized by the diversity of energy uses, equipment, and processes and is the largest energy sector, consuming 37 percent of U.S. total primary energy use in 1990. Patterns of industrial energy use are further complicated by the use of oil, gas, and coal as feedstocks and for cogeneration. Figure 4-5 shows industrial energy use for fuel and power only.

Industrial energy use is variable, reflecting economic conditions, structural changes, interfuel competition, and rate of investment. Patterns of industrial energy use and energy intensity of industry also vary significantly by region. Price is the major determinant in most industrial energy choices, and head-to-head competition among fossil fuels is intense. Price however is not the sole consideration—availability, reliability, and quality also drive industrial energy decisions. Another trend is the growth in industrial cogeneration, which is generally viewed as a positive development for efficiency, but, which in effect transfers demand and losses between industrial

59 Ibid., p. 54.

60 U.S. Congress, Office of Technology Assessment *Energy Efficiency in the Federal Government: Government by Good Example?* OTA-E-492 (Washington DC: U.S. Government Printing Office, May 1991).

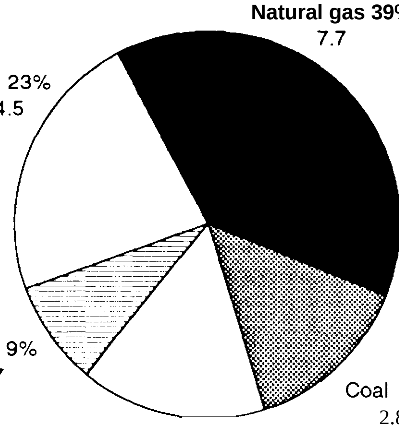
61 Oak Ridge National Laboratory, supra note 16, pp. 45-46.

sector and utilities. Moreover there has been a general trend toward electrifying many process technologies and a shift in energy and electric intensity of manufacturing. The relationship of efficiency gains and structural changes in U.S. industry was examined in detail in an OTA background paper, *Energy Use and the U.S. Economy.*[62] A companion new OTA report, *Industrial Energy Efficiency,* was published in summer 1993.

There are five major fuel and power demands in the industrial sector: process steam and power generation (36 percent), process heat (29 percent), machine drive (14 percent), electrical services(4 percent), and other (including off-highway transportation, lease and plant fuel use, and mining) (16 percent).[63] The industrial sector derives 40 percent of its fuel and power needs from natural gas, 25 percent from oil, 15 percent from purchased electricity, 9 percent from coal, and the remaining 9 percent from waste fuels and other sources. Electricity competes with other fuels, particularly natural gas, for direct heat applications.[64] For other uses, purchased electricity competes with the options of self-generation or cogeneration. It is estimated that in 1989, the industrial sector produced about 153,270 gigawatt-hours of electricity on-site. Surplus electricity production was sold to local utilities.[65] To avoid doublecounting, fuel used for industrial self-generation or cogeneration is usually attributed to primary fuels.

In 1990 industrial consumers purchased 946 billion kWh from electric utilities at a cost of $45 billion.[66] Sales to industrial users accounted for 35 percent of electric utility revenues from sales to end-users/ultimate customers. Electricity consumption in the industrial sector is divided among

Figure 4-5--industrial Energy Use for Fuel and Power, 1989 (quadrillion Btus)



SOURCES: Office of Technology Assessment, 1993, based on data from the Gas Research Institute.

the manufacturing enterprises (87 percent); agriculture (5 percent) and construction and mining (8 percent).

The major industrial electricity uses are motor drive, electrolytic, process heat, and lighting (see figure 4-6). Table 4-4summarizes EPRI estimates of 1987 industrial energy consumption for these applications by industrial subsectors (SIC codes), manufacturing loads and nonmanufacturing loads.

The most electricity-intensive manufacturing activities (including on-site generation) are chemical products, primary metals, pulp and paper, food, and petroleum refining, together accounting for more than half of manufacturing electricity use. The pulp and paper and chemical products

62 U.S. Congress, Office of Technology Assessment, *Energy Use and the U.S. Economy,* OTA-BP-E-57 (Washington, DC: U.S. Government *Printing* Office, June 1990).

63 1992 *GRI* Baseline *Projection,* supra note 8, p. 36.

64 Ibid, p. 41.

65 Ibid.

66 DOE, *Electric power Annual 1990,* supra note 10, table 1.

Table 4-4—Industrial Electricity Use by Application and Industry, 1987 (gigawatt-hours)

Category SIC code	Total electricity consumption (GWh)	Motor drive (GWh)	Percent	Electrolytics (GWh)	Percent	Process heating (GWh)	Percent	Lighting (GWh)	Percent	Other (GWh)	Percent
Manufacturing											
Major electricity users[a]											
28 Chemicals	141,191	90,250	63.9%	36,810	26.1%	668	0.5%	13,464	9.5%	0	0%
26 Paper	83,219	74,364	89.4	0	0.0	1,870	2.2	6,985	8.4	0	0
20 Food	47,213	40,544	85.9	0	0.0	1,202	2.5	5,466	11.6	0	0
33 Primary metals	146,410	54,482	37.2	58,956	40.3	25,785	17.6	7,187	4.9	0	0
29 Petroleum	41,444	8,108	91.9	0	0.0	401	1.0	2,936	7.1	0	0
32 Stone, clay, and glass	34,019	27,192	79.8	0	0.0	5,077	14.9	1,822	5.3	0	0
37 Transportation equipment	37,560	21,539	57.3	101	0.3	13,895	37.0	2,025	5.4	0	0
35 Industrial machinery	33,194	16,598	51.1	101	0.3	12,692	38.2	3,442	10.4	0	0
34 Fabricated metal prod.	31,045	13,937	44.9	2,225	7.2	267	41.7	1,923	6.2	0	0
36 Electronics	32,299	27,679	85.7	0	0.0	267	0.8	4,353	13.5	0	0
22 Textiles	25,509	20,760	81.4	0	0.0	802	3.1	3,948	15.5	0	0
30 Rubber and plastics	28,809	26,510	88.9	0	0.0	1,069	3.6	2,227	7.5	0	0
Total all manufacturing	736,950	495,012	67.2%	98,193	13.3%	[illegible],959	10.7%	64,787	8.8%	0	0%
Nonmanufacturing											
Agriculture	44,541	23,283	52.3%	0	0%	*040	91%	1,985	26.9%	5,132	11.5%
Mining	55,676	50,615	90.9	0	0	0	0.0	3,525	6.3	1,509	2.7
Construction	8,098	2,025	25.0	0	0	0	0.0	4,230	52.2	1,811	22.4
Total nonmanufacturing	10[illegible]315	75,923	70.1%	0	0%	4,049	3.7%	19,740	18.2%	8,452	7.8%
Total industrial	845,266	570,934	67.5%	98,193	11.6%	83,008	9.8%	84,527	10.0%	8,453	1.0%

[a] Industries using more than 25,000 (GWh) annually.

SOURCE: Office of Technology Assessment, 1993, based on data from Barakat & Chamberlin, Inc., *Efficient Electricity Use: Estimates of Maximum Energy Savings*, EPRI CU-6746 (Palo Alto, CA: Electric Power Research Institute, March 1990), p. 69.

subsectors have significant cogeneration capacity-mostly freed by waste fuels.

Efficient Industrial Technologies

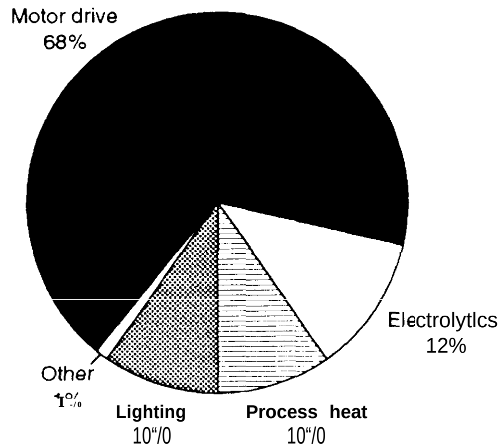
There are several strategies for improving energy efficiency in the industrial sector, including making existing electricity applications more efficient, shifting industrial processes from fossil fuel to electrotechnologies for net energy savings, and using more industrial cogeneration for net energy savings over purchased electricity.

EPRI estimates that application of more efficient industrial equipment and processes offers potential savings of from 24 to 38 percent of their projected base-case electricity use in 2000.[67] The most promising targets for potential efficiency gains are high efficiency electric motors and variable speed drives, improved electrolytic processes, industrial process waste heat recovery, and more efficient lighting technologies. (See table 4-5.) All but electrolytic technologies have a wide and diverse range of potential applications across the industrial sector.

ENERGY-EFFICIENT ELECTRIC MOTORS AND DRIVES

There is great diversity in industrial applications of electric motors and drives: pumps, fans, compressors, conveyors, machine tools, and other industrial equipment. Motor drive end-uses account for an estimated 70 percent of electricity load in manufacturing. High-efficiency electric motors combined with adjustable-speed drives (ASDS) offer significant electricity savings potential.

Figure 4-8-industrial Electricity Use by Application, 1987



SOURCE: Office of Technology Assessment, 1993, based on data from the Electric Power Research Institute.

Electric motors are available in standard and high-efficiency models and energy efficiency of both vary according to size. In general, larger motors are more efficient than smaller ones in both standard and high efficiency models. The high-efficiency models cost from 10 to 30 percent more than the standard versions,[68] but have efficiency increases of 8 percent for smaller motors and 3 percent for larger motors.[69] Energy-efficient motors typically have longer operating life than standard motors. The initial capital costs of electric motors are usually only a fraction of their operating costs. For example, annual energy costs for an electric motor might run as much as 10 times its initial capital cost; increasing its efficiency from 90 to 95 percent could mean

67 EPRI, *Efficient Electricity* Use, supra note 1, p. 61.

68 American Council for an Energy-Efficient Economy and New York State Energy Office, *The Achievable Conservation Potential in New York State from Utility Demand-Side Management Programs,* final report, Energy Authority Report 90-18 (Albany, NY: New York State Energy Research and Development Authority, November 1990), p. 48.

69 EPRI, *DSM Technology Alternatives,* supra note 26, p. C-41.

Table 4-5-Selected Energy Efficiency Technology Options for the Industrial Sector

Electric motors and drives
. High-efficiency motors
■ Variable speed drives
. Optimal sizing of motors and loads, serial motors
Waste heat recovery systems
■ Industrial process heat pumps
. Industrial heat exchangers
, Vapor recompression systems
Electrolytic processing
Chlor-alkali production
■ Improved membrane and diaphram cells for chlor-alkali production
Aluminum smelting
, Improved efficiency in Hall-Heroult smelting process
■ Alternative aluminum reduction technologies
industrial Lighting
Delamping
Lighting fixture retrofits
Electronic ballasts for fluorescents
High-efficiency lamps
Reflectors
Increased use of daylighting
High-intensity lighting applications
increased use of task lighting
Compact fluorescents
LED signs
Lighting control systems-timers, occupancy sensors, photocells, dimmers
industrial eiectro-technologies
Plasma processing
Electric arc furnaces
Induction heating
industrial process heat pumps
Freeze separation
Ultraviolet processing/curing
industrial cogeneration systems
High-efficiency industrial boilers
Integrated process heat/steam and power production

SOURCE: Office of Technology Assessment, 1993.

savings of 50 to 60 percent of its capital costs in a single year.[70]

Many industrial motors are often run at less than maximum power because of varying loads. Electronic adjustable speed drives allows an electric motor to operate at reduced speed when maximum power is not needed, saving energy. ASDS are appropriate in applications with high operating hours where motors are often operated at less than full load.

There are three targets for displacing standard-efficiency motors with high-efficiency motors: selecting new or replacement motors, rewinding of existing motors, and retrofitting of existing motors that do not need repair or replacement.

High-efficiency variable-speed motors offer tremendous potential for efficiency. Various studies have yielded estimates of potential savings of 20 to 50 percent depending on circumstances for application of ASDS. Use of high-efficiency electric motors can provide savings of an additional 3 to 10 percent. Overall efficiency improvements in motor drive of 35 to 50 percent over 1987 equipment were assumed in EPRI's analysis.[71] Motor drive improvements offered nearly 80 percent of estimated savings in their analysis, with over 90 percent of these savings in just a few industry categories.

WASTE HEAT RECOVERY

Waste heat recovery systems improve energy efficiency by using heat from fuel combustion or excess thermal energy from a process steam product. An estimated one quarter to one-half of the process heat used by industry is discharged as hot gases or liquids.[72] There are various approaches to capturing energy from these sources of waste heat. The choice depends on characteristics of the heat source, process needs, and economics. Heat exchangers are used to transfer heat from a high-temperature waste exhaust source, such as combustion gases, to a cooler supply stream such as steam for lower temperature uses. Low-temperature waste heat streams

70 U.S. Congress, Office of Technology Assessment, *Industrial Energy Use, OTA-B 198* (Washington, DC: U.S. Government Printing Office, June 1983) p. 50. (Available from the National Technical Information Service, Springfield, VA, NTIS Order #PB83-240606.)

71 EPRI, *Efficient Electricity Use*, supra note 1, p. 59.

72 EPRI, *DSM Technology Alternatives,* supra note 26, p. c-8.

can be upgraded to supply heat for higher temperature processes via industrial heat pumps or vapor recompression systems, Analyses for EPRI found that installation of heat recovery devices can reduce a plant's overall energy requirements by at least 5 percent with paybacks of less than 2 years. The most cost-effective time to incorporate the systems is during new construction or modernization projects and most applications have been custom designed. Heat recovery devices displace conventional energy sources (such as purchased electricity) and are used in processes requiring a constant heat source. Hence they are attractive to utilities as means to reduce base loads and peak loads,

Waste heat recovery in industrial process heat systems can provide electricity savings of 5 to 25 percent according to EPRI estimates. Very little waste heat recovery currently exists, so there is potential for significant improvement. EPRI assumed an average of 10 to 15 percent savings.

ELECTROLYSIS

An estimated 12 percent of industrial electricity use is used for electrolysis. Electrolysis is a method for separating and synthesizing chemicals or metals by using electricity to produce chemical reactions in aqueous solutions or molten salts. At present the two largest industrial applications of electrolysis are aluminum reduction in the primary metals processing industry and the production of chlorine and caustic soda from salt brines in the chemical products industry.

Electricity is the most costly material in aluminum production. In the century-old Hall-Heroult process alumina refined from bauxite ore is reduced via electrolysis to molten aluminum,[73] The smelting process is continuous. Alumina is dissolved in a molten electrolytic bath in carbon lined steel cells or pots, In each pot a direct current is passed from an carbon anode suspended in the cell through the bath to the carbon lining of the cell producing a chemical reaction. Molten aluminum is siphoned from the bottom of the pots and is then formed into aluminum ingots or further refined and/or alloyed into fabricating ingot. A single potline can consist of from 50 to 200 cells with a total voltage of 1,000 volts at currents of 50,000 to 250,000 amperes. U.S. smelters use from 6 to 8 kWh to produce each pound of aluminum.

The efficiency of aluminum production has improved steadily. Following World War II about 12 kWh of electricity was needed to produce one pound of aluminum; today, through greater economies of scale and process controls, the most efficient smelters use half that electricity per pound.[74] Further efficiency gains are promised by advanced electrolytic reduction methods including bipolar cells, inert anodes, and wettable cathodes. None of these technologies, however is currently installed, but EPRI estimates that they could potentially yield efficiency savings by year 2000 of some 30 to 50 percent over current methods. These improvements are highly attractive given the high electric intensity of aluminum production and are significant for regions where such production is concentrated, such as the Pacific Northwest.

Chlor-alkali production is second to aluminum in terms of electricity consumption and uses about 30 percent of electric power used for electrochemical production .75 Chlorine and caustic soda (sodium hydroxide) are produced from salt brine by electrolysis in either the diaphragm or mercury cell. Mercury cells account for about 20 percent of U.S. capacity. Throughout this century economies of scale have produced steady efficiency gains in chlor-alkali production as newer and larger cells required less energy to

73 U.S. Congress, Office of Technology Assessment, *Nonferrous Metals: Industry Structure: Background Paper, OTA-BP-E-62* (Washington, DC: U.S. Government Printing Office, September 1990), pp. 25-26.

74 Ibid.

75 EPRI, *DSM Technology Alternatives,* supra note 26, pp. c-5-c-6.

drive the chemical reactions.[76] In the membrane cell, different constituents of the solution are separated by selective diffusion through the membranes. EPRI analyses estimated that use of membrane cells to replace diaphragm cells could save 10 percent of electricity used in chlor-alkali production. Other analyses have estimated savings of up to 25 percent over current methods.

Adaptation and improvement of electrolytic separation methods, including electrodialysis which uses electric current to accelerate membrane separation, for other inorganic and organic processes also can yield efficiency gains over conventional methods.

LIGHTING

Lighting accounts for about 10 percent of electricity use in the industrial sector. As in the commercial and residential sectors, more efficient lighting technologies offer promises of electricity savings across the industrial sector too, Industrial lighting efficiency upgrades such as delamping, reduced wattage fluorescent, high-efficiency ballasts, reflective fixtures, occupancy sensors, replacing incandescent lamps with compact fluorescent, and greater use of daylighting. EPRI analyses estimate that lighting efficiency packages offer savings of from 36 to 49 percent. Lighting upgrades can also lower cooling loads, but increase heating loads.

ELECTRIFICATION OF INDUSTRIAL PROCESSES

Electrification offers the potential for net savings in fossil fuel use even as it increases electricity demand in the industrial sector. There has been a continuing trend toward electrification of many industrial processes and end-uses. Cost has been a major factor, but increasingly, reliability, flexibility, and reduced environmental impacts on-site have made electrification an attractive option for improving industrial productivity. There are a variety of electrotechnologies that could boost industrial electricity use over the next several decades, while providing net savings in fossil fuel consumption. EPRI looked at the possible net energy savings from five such technologies.

Freeze concentration uses refrigeration processes to separate and concentrate constituents from mixed dilute streams. Separation of constituents from process streams is a major energy use in the industrial sector and many techniques such as distillation rely on high temperatures produced by burning fossil fuels. It takes less energy (about 150 Btu) to freeze a pound of water than the 1,000 Btu needed to boil it.[77] Shifting to freeze separation could cut overall energy consumption and displace industrial fossil fuel use. More energy-efficient refrigeration technologies add to the attractiveness of freeze concentration as an alternative separation technique. Currently used for treating hazardous wastes, concentrating fruit juices, and purifying organic chemicals, the technique is being investigated for broader industrial application.

Industrial process heat pumps can replace indirect resistance heating for certain low temperature applications (below 280 to 3000 F) in lumber, pulp and paper, food, chemical, and petroleum subsectors.

Electric arc furnaces allow direct melting of raw steel and uses less energy than fossil-freed furnaces. Electric arc furnaces have already gained a significant foothold in the steel industry accounting for an estimated 34 percent of steel produced in 1985. Continuation of this trend to 56 percent or more by 2000 was projected. Electric arc furnace foundries are also used to produce steel castings and increased use of this technology also promises net fossil fuel savings.

Plasma processing uses a high intensity electric arc to generate ionized gases at temperatures up to 10,000° F and more, far exceeding the

76 OTA, *Industrial Energy Use,* supra note 70, p. 123-124.

77 Oak Ridge National Laboratory, supra note 16, p. 71.

2,800°F practical limit for fossil fuel combustion.[78] The technology offers high energy density and temperature capability, controllability, and fuel flexibility compared with conventional combustion technologies. Plasma processing can be expanded in already established uses for cutting, welding, heat treating, and burning and into promising new applications in electric arc furnace dust processing, cupola refits with plasma torches, ferroalloy production, and ore reduction. Use for chemical production also is said to have future commercial potential.

Ultraviolet **curing** uses ultraviolet radiation produced by ionizing gases in an electrical arc or discharge, such as in a high-pressure mercury vapor lamp, to change the molecular structure of a coating to make it a solid. UV curing offers large energy and cost savings compared with thermal curing and is expected to gain increasing market penetration especially in quickcuring applications. An additional and significant environmental and health benefit is the elimination of solvents in the curing process.

Potential Savings. EPRI estimates that all these technologies offer strategic load growth to electric utilities, while resulting in net savings in fossil fuel use overall. Maximum application of these technologies could add 319 trillion Btu of fossil fuel in electric utility generation, but at the same time yield a net savings of 290 trillion Btus in these industrial processes.

COGENERATION

Cogeneration is the simultaneous or sequential production of both electrical or mechanical power and thermal energy from a single energy source.[79] On-site industrial cogeneration has grown significantly since the late 1970s as a result of higher energy prices, volatile energy prices, and uncertainty over energy supplies. Implementation of the Public Utility Regulatory Policies Act of 1978 (PURPA), which required electric utilities to provide interconnections and backup power for qualifying cogeneration facilities and to purchase their excess power at the utilities' avoided cost, reduced institutional barriers to the expansion of cogeneration. PURPA was intended to promote industrial cogeneration as a means of improving efficiency especially in the use of premium fossil fuels (gas and oil) and encouraging the use of waste fuels.

In most industrial cogeneration systems, fuel is burned frost to produce steam that is then used to produce mechanical energy at the turbine shaft or to turn the shaft of a generator to produce electricity. The steam leaving the turbine is then used to provide process heat or drive machines throughout the host industrial plant and related facilities. From an energy policy perspective, the attraction of cogeneration is the ability to improve fuel efficiency. Cogeneration systems achieve overall fuel efficiencies 10 to 30 percent higher than if power and heat were provided by separate conventional energy conversion systems, i.e., less energy than if the fossil fuel were burned in an industrial boiler to provide process heat and at an off-site utility power plant to generate electricity to be transmitted to the industrial site. (This aspect of cogeneration efficiency depends on the fuel that is burned to produce electricity) Cogeneration can also be attractive as a means of quickly adding electric generating capacity at sites where thermal energy is already being produced.

Industrial cogeneration is concentrated in the pulp and paper, chemicals, steel, and petroleum refining industries. Often the industrial cogenerators can take advantage of waste fuels to fire their boilers for heat and power. Natural gas has been the fuel of choice for many qualifying cogeneration plants under PURPA.

Cogeneration does not always provide significant efficiency advantages, however. Almost the entire output of newer combined-cycle, natural

78 EPRI, *DSM Technology Alternatives*, supra note 26, p. C-21-22.

79 OTA, *Energy Technology Choices*, supra note 4, p. 39.

gas-fired cogeneration systems is electric power generation with little steam for process applications. In this case, there is a much smaller efficiency gain from cogeneration and a net shift in primary fuel demand from the utility sector to the industrial sector. Thermal conversion losses in electric utility and industrial combined cycle generating units are similar, there are some small savings in avoided transmission and distribution losses. If a significant portion of the cogenerated power is sold to the local electric utility, these transmission and distribution gains would largely disappear.

Industrial cogeneration makes up the overwhelming bulk of the explosive growth of so called independent power producers in the past decade. While cogeneration was initially viewed by many utilities as a threat to their market share. It is increasingly accepted as an alternative power source and has been integrated into some utilities load management and resource plans. In fact a number of utility companies have independent power subsidiaries or affiliates that are partners in industrial cogeneration projects.

In 1989, Edison Electric Institute estimated that cogeneration accounted for about 73 percent of the operating capacity of nonutility power plants.[80]

Industrial cogeneration plants will benefit from many of the same efficiency improvements as utility generation as many use the identical technologies. In addition, better integration of industrial cogeneration and utility system operations through planning and dispatch offers net improvements to system efficiencies.

■ Constraints on Efficiency Gains in the Industrial Sector

There have been significant energy efficiency gains in the industrial sector over the past two decades. Industrial energy use per unit of output (energy intensity) has been declining since 1970. At the same time, more and more industrial processes have been electrified. Even so, OTA found that opportunities for further gains in energy efficiency have by no means been exhausted.[81]

The industrial sector faces some of the same constraints as other sectors: low energy prices, failure of energy prices to reflect societal and environmental costs, multiplicity of decision-makers, and reluctance to adopt unproven new technologies. Energy efficiency choices tend to be made in new investments and when equipment must be repaired or replaced which creates a normal lag time between the development of new electricity-saving technologies and their dispersion throughout industry. But certain barriers are less applicable-for example, the disconnect between those who pay for energy-efficient improvements and those who benefit is rarely present. Of all sectors, the industrial sector is probably the most responsive to price signals, so that the argument that there are market failures resulting in an underinvestment in energy efficiency here (from the perspective of myriad industrial consumers) is hardest to make. Nevertheless, certain characteristics of industrial decisionmaking about energy choices can result in lower adoption rates for energy-efficient equipment than might be desirable from a societal or utility perspective.[82]

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80 Edison Electric Institute, *1989 Capacity and Generation of Non-Utility Sources of Energy,* Washington DC, April 1991, P. 29.

131 OTA, Energy *Technology Choices,* supra note 4, p. 38.

82 OTA has examined industrial energy investment decisionmaking in a number of reports. The most recent effort is in a forthcoming report *Industrial Energy Efficiency,* to be published in summer 1993. Other OTA reports include *Industrial Energy Use (1983),* supra note 70; *Energy Technology Choices,* supra note *79;* and U.S. Congress, Office of Technology Assessment, *Industrial and Commercial Cogeneration, OTA-E-192* (Washington DC: U.S. Government Printing Office, February, *1983).* (Available from the National Technical Information Service, NTIS Order #PB83-180457.)

Economic considerations dominate investment decisions in the industrial sector. For most industries energy costs and electricity costs are only a small part of operating costs and thus may not enjoy a high priority. Industries that are highly energy and electricity intensive have a stronger incentive to invest in efficiency, while others do not even though there may be substantial and cost effective opportunities. Most firms regard energy efficiency in the context of larger strategic planning purposes. Investments are evaluated and ranked according to a variety of factors: product demand, competition, cost of capital, labor, and energy. Energy-related projects are not treated differently from other potential investments and must contribute to increased corporate profitability and enhanced competitive position. As a result incentives aimed at reducing energy demand growth or improving efficiency in the industrial sector must compete with other strategic factors and therefore have to be substantial to make a significant impact.

In addition to lack of strong financial incentives and management indifference, industrial energy efficiency gains are also hampered by lack of information, and shortages of skilled designers, installers, and auditors. Highly specialized and plant- or application-specific analyses are often required to identify optimal and appropriate energy savings improvements because of the diversity of industrial processes, equipment, and energy applications. President Bush's National Energy Strategy report found that the industrial sector tended to underfund investment in energy efficiency R&D because of the belief that competitors could quickly adopt process or technology advances, thus minimizing any potential competitive advantage.[83]

overall, in past studies OTA has found that the best way to improve energy efficiency in the industrial sector is to promote general corporate investment in new plant and equipment-newer generally means more energy-efficient.

83 *National Energy Strategy: Powerful Ideas for America*, supra note 6, p. 56.