Chapter 2

Technologies Affecting Demand

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Technologies Affecting Demand

After the oil crises of the 1970s, the United States made tremendous strides in improving energy efficiency. This was accomplished by technological advances in energy-using equipment and production processes and structural shifts in the economy toward less energy-intensive products and services. By the mid-1980s, however, stable oil prices and supplies shifted the Nation's focus away from energy efficiency to other issues. As a result, energy use began to rise and energy efficiency improvements slowed. Many opportunities for improving efficiency were not realized. Recent events in the Middle East have renewed concerns about U.S. dependence on foreign energy supplies and stimulated interest in energy efficiency. There are a variety of technologies that have the potential for improving energy efficiency over the next 20 years. New technologies are constantly being added. This chapter describes some of these technologies. (See table 2-l.) But first, the chapter characterizes energy use today, the changes that have occurred since the early 1970s, and what we can expect in the future. Also, this chapter discusses nontechnical factors that influence energy use.

U.S. ENERGY USE

In 1989, the United States used a record-breaking amount of energy. (See table 2-2.) Low oil prices stimulated economic growth (3 percent in 1989) and an increase in energy demand. Petroleum consumption accounted for the lion's share (42 percent) of total U.S. energy use. Natural gas use rose substantially, while coal use registered a slight increase from 1988 to 1989.[1]

Net energy imports also grew, with petroleum accounting for most of the trade. Petroleum net imports reached their highest level since 1979, accounting for 41 percent of U.S. crude oil demand in 1989. Record energy use and a slight decline in domestic production accounted for the increase.[2] The U.S. Department of Energy (DOE) indicates that petroleum net imports for 1990 declined by 2 percent.[3]

All sectors of the economy experienced increased energy use in 1989. In fact, the residential/commercial and transportation sectors used more energy than ever before.[4] (See table 2-3.) While energy use increased, energy intensity[5] declined by 1.7 percent. According to the U.S. Energy Information Agency (EIA), favorable weather conditions contributed to the decline.

Changes in Energy Use From 1972 To 1988[6]

From 1972 to 1988, two trends in energy consumption are discernible. The frost trend, from 1972 to 1985, can be characterized by decreasing energy use per dollar of gross domestic product (GDP) and rising energy prices. This was a departure from the 1950s and 1960s when energy use and GDP increased at the same rate. From 1985 to 1988, the trend of steady decreases in energy intensity was broken.

Changes in Energy Use From 1972 To 1985

Between 1972 and 1985, energy use remained essentially flat (0.3 percent per year) while the economy experienced an average growth rate of 2.5 percent per year. This relatively flat level of energy use coupled with economic growth resulted in a drop in energy intensity by 2.4 percent per year or about 25 percent over this period. Fuel use also changed during this period. An almost nearly equal increase in coal and electricity use was offset by a relatively large decrease in crude oil and natural gas consumption.

The implementation of energy efficiency improvements in production processes and structural shifts in the economy toward less energy-intensive

[1] U.S. Energy reformation Administration, Department of Energy, *Annual Energy Review 1989,* DOE/EIA-0384(89), May 24, 1990, P. 1.

[2] Ibid., p. 2.

[3] U.S. Energy reformation Administration, *Monthly Energy Review March 1991, DOE/EIA-0035(91 /03), Mm. 28,* 1991.

[4] U.S. Energy Information Administration, op. cit., footnote 1.

[5] Energy intensity is defined as the amount of energy used per net unit of economic value (e.g., Btu per dollar of gross domestic product).

[6] Much of the information in this section is drawn from the OTA report, *Energy Use and the* Us. *Economy,* OTA-BP-E-57 (Washington, DC: U.S. Government Printing Office, June 1990).

Table 2-l—Technologies Affecting Demand

Technology	Sector	Availability	Comments
Variable speed heat pump	Residential/commercial	C,N	Improves energy efficiency and provides more flexible control. 'Widely used in Japan. Increasing market share in United States.
Scroll-type compressors (heat pump/air conditioning)	Residential/commercial	C	Newer scroll-type compressors are 10 to 20 percent more efficient than reciprocating ones. Widely produced in Japan.
Thermally active heat pump	Residential/commercial		Could have significant impact in 10 to 20 years.
Low-emissive windows	Residential	C,R	Significant impact on reducing thermal energy loss in homes. Research needed on improving durability, lowering emittance, and reducing condensation.
Heat pump water heaters	Residential/commercial	C	Offers significant reduction in electricity use; premium cost. Commonly used in Scandinavia.
Alternative insulation materials	Residential	R	Needed to counter loss of chlorofluorocarbon-blown insulation. Now being developed and tested.
Refrigerator insulation	Residential	R	Greatest potential for appliance efficiency improvements. New products include vacuum insulation, compact vacuum insulation, and soft vacuum insulation.
Efficient lighting products	Residential/commercial	C,N,R	Combination of lighting options can cut commercial energy use significantly. Improved fluorescent, compact fluorescents, and electronic ballasts commercially available. Research and development continuing on improving phosphors.
Building energy management and control systems	Residential/commercial	C,N	Greatest potential for savings in the commercial sector. Advances in this technology have been continual.
Industrial process changes:			
—Separation	Industrial	C,N,R	Improvements in separation and control, and the use of membrane technology and solvent extraction could reduce energy use considerably.
-Catalytic reaction	Industrial	C,N,R	By increasing reaction rates, lower temperatures and pressures can be used that reduce heating and compression requirements. Discover and use of new synthetic zeolites have contributed to energy efficiency gain in petroleum refining and chemicals industries.
—Computer control and sensors	Industrial	C,N	Improved monitoring and control optimizes conversion and distribution of energy. Potential savings range from 5 to 20 percent.
Advanced turbine:			
—Steam-injected gas turbine (STIG)	Industrial/utility	C,N	Currently used in cogeneration applications.
—Intercooling (ISTIG)	Industrial/utility		Has potential to raise efficiency to about 50 percent. Maybe better suited for utility applications; pilot-plant stage.
Electric motors	Industrial	C	Adjustable-speed drive and new high-efficiency motors account for about half of the total potential savings in U.S. motors.
2-stroke engine	Transportation	R	Holds promise for long term. Questions remain about ability of engine to comply with emissions standards.
Direct injection/adiabatic diesel	Transportation	C,R	Limited passenger car application in Europe; offers considerable efficiency improvements for both light-duty vehicles and heavy trucks. Questions remain regarding meeting more stringent emission standards.
Ultra-high bypass engines	Transportation	C	Can raise efficiency by about 20 percent but costs two times as much as current generation bypass engines.
Alternative fuels:			
—Alcohol fuels	Transportation	C,N,R	Use of methanol and ethanol should result in greater engine efficiency but costs are higher.
—Electricity	Transportation	R	Big greenhouse advantage if derived from nuclear or solar energy.

KEY: C = commercial; N = nearly commercial; R = research and development needed.

SOURCE: Office of Technology Assessment, 1991.

industries were primarily responsible for lowering energy intensity and changes in fuel use during this period. About two-thirds of the decline in energy intensity can be attributed to energy efficiency improvements. The remaining third came from a shift in the economy caused by changes in consumer demand and by technological improvements in production processes that indirectly saved energy. If energy efficiency improvements had not been implemented during this period, the United States would have required 20 percent more energy in 1985 to produce its output.

Energy consumption per household declined as well. A decrease in use of distillate fuel oil and

Table 2-2—Energy Overview, Selected Years, 1970-89 (quadrillion Btu)

Activity and energy source	1970	1975	1980	1985	1986	1987	1988	1989
Production:								
Crude oil and lease condensate	20.40	17.73	18.25	18.99	18.38	17.67	17.28	16.12
Natural gas plant liquids	2.51	2.37	2.25	2.24	2.15	2.22	2.26	2.16
Natural gas[a]	21.67	19.64	19.91	16.91	16.47	17.05	17.49	17.78
Coal	14.61	14.99	18.60	19.33	19.51	20.14	20.74	21.35
Nuclear electric power	0.24	1.90	2.74	4.15	4.47	4.91	5.66	5.68
Hydroelectric power	2.63	3.15	2.90	2.94	3.02	2.59	2.31	2.77
Other[b]	0.02	0.07	0.11	0.21	0.23	0.24	0.23	0.22
Total production	62.07	59.86	64.76	64.77	64.23	64.82	65.97	66.07
Imports:								
Crude oil[c]	2.81	8.72	11.19	6.81	9.00	10.07	11.03	12.60
Petroleum products[d]	4.66	4.23	3.46	3.80	4.20	4.10	4.72	4.57
Natural gas	0.85	0.98	1.01	0.95	0.75	0.99	1.30	1.39
Other[e]	0.07	0.19	0.31	0.54	0.48	0.60	0.52	0.40
Total imports	8.39	14.11	15.97	12.10	14.43	15.76	17.56	18.95
Exports:								
Coal	1.94	1.76	2.42	2.44	2.25	2.09	2.50	2.64
Crude oil and petroleum products	0.55	0.44	1.16	1.66	1.67	1.63	1.74	1.84
Other	0.18	0.16	0.14	0.14	0.14	0.13	0.17	0.29
Total exports	2.66	2.36	3.72	4.23	4.05	3.85	4.41	4.77
Adjustments	–1.37	–1.07	-1.05	1.31	-0.36	0.12	1.08	1.10
Consumption:								
Petroleum products[h]	29.52	32.73	34.20	30.92	32.20	32.87	34.23	34.20
Natural gas	21.79	19.95	20.39	17.83	16.71	17.74	18.55	19.40
Coal	12.26	12.66	15.42	17.48	17.26	18.01	18.85	18.90
Nuclear Power	0.24	1.90	2.74	4.15	4.47	4.91	5.66	5.70
Hydroelectric power[i]	2.65	3.22	3.12	3.36	3.39	3.07	2.64	2.92
Other	–0.04	0.09	0.08	0.20	0.21	0.25	0.27	0.20
Total consumption	66.43	70.55	75.96	73.95	74.24	76.84	80.20	81.35

[a]Dry natural gas.
[b]Includes electricity produced from geothermal, wood, waste, wind, photovoltaic, and solar thermal sources connected to electric utilitydistribution systems (see note below).
[c]Includes imports of crude oil for the Strategic Petroleum Reserve, which began in 1977.
[d]Includes imports of unfinished oils and natural gas plant liquids.
[e]Includes coal, coal coke, and hydroelectric power.
[f]Includes natural gas, coal coke, and hydroelectric power.
[g]A balancing item. Includes stock changes, losses, gains, miscellaneous blending components, and unaccounted for supply.
[h]Petroleum products supplied includes natural gas plant liquids and crude oil burned as fuel.
[i]Includes industrial generation of hydroelectric power and electricity imports.
[j]Includes electricity produced from geothermal, wood, waste, wind, photovoltaic, and solar thermal sources connected to electric utility distribution systems (see note below) and net imports of coal coke.

NOTE: Data do not include the consumption of wood energy (other than that consumed by the electric utility industry), which amounted to an estimated 2.4 quadrillion Btus in 1987. This table also does not include small quantities of other energy forms for which consistent historical data are not available, such as geothermal, waste, wind, photovoltaic, or solar thermal energy sources except that consumed by electric utilities. Sum of components may not equal total due to independent rounding.

SOURCE: U.S. Energy Information Administration, *Annual Energy Review* 1989, DOE/EIA-0384(89) May 24, 1990; *Monthly Energy* Review *April* 1991, DOE/EIA-0035 (91/04), Apr. 26, 1991, p. 17.

kerosene accounted for most of the decline.[7] Higher oil prices triggered conservation, efficiency improvements, and fuel switching. The two recessions that occurred during this period also helped to restrain consumption. The OTA report *Energy Use and the U.S. Economy* provides a detailed discussion of shifts in energy use over the last two decades and what is likely to happen in the future.

Changes in Energy Use From 1985 To 1988

Energy use increased by 8 percent, a significant departure from the previous 13-year trend. More than half of the increase was supplied by petroleum. All sectors of the economy contributed to the increase. Although energy use rose, energy intensity continued to drop because of the pace of economic growth (11 percent in 3 years). But the level of

[7]U.S. Energy Information Administration, op. cit., footnote 1, p. 19.

Table 2-3-Consumption of Energy by Sector,[a] 1970-89 (quadrillion Btu)

Year	Residential and commercial[b]	Industrial[b]	Transportation[b]	Electric utilities	Total
1970	21.71	28.63	16.09	16.27	66.43
1971	22.59	28.57	16.72	17.15	67.89
1972	23.69	29.86	17.71	18.52	71.26
1973	24.14	31.53	18.60	19.85	74.28
1974	23.72	30.69	18.12	20.02	72.54
1975	23.90	28.40	18.25	20.35	70.55
1976	25.02	30.24	19.10	21.57	74.36
1977	25.39	31.08	19.82	22.71	76.29
1978	26.09	31.39	20.61	23.72	78.09
1979	25.81	32.61	20.47	24.13	78.90
1980	25.65	30.61	19.69	24.50	75.96
1981	25.24	29.24	19.51	24.76	73.99
1982	25.63	26.14	19.07	24.27	70.85
1983	25.63	25.75	19.13	24.96	70.52
1984	26.50	27.73	19.87	25.98	74.10
1985	26.73	27.12	20.10	26.48	73.95
1986	26.83	26.64	20.76	26.64	74.24
1987	27.62	27.87	21.36	27.55	76.84
1988	29.00	29.01	22.19	28.63	80.20
1989	29.50	29.46	22.38	29.20	81.35

[a]Data do not include consumption of wood energy (other than that consumed by the electric utility industry) which amounted to an estimated 2.4 quadrillion Btu in 1987. This table does not include small quantities of other energy forms for which consistent historical data are not available, such as geothermal, waste, wind, photovoltaic, or solar thermal energy sources except that consumed by electric utilities.

[b]Includes those fossil fuels consumed directly in the sector, utility electricity sales to the sector, and energy losses in the conversion and transmission of electricity. Conversion and transmission losses are allocated to sectors in proportion to electricity sales to sectors.

NOTE: Sum of components may not equal total due to independent rounding.

SOURCE: U.S. Energy Information Administration, *Annual Energy Review* 1989, DOE/EIA-0384(89), May 24, 1990; *Monthly Energy Review April 7991*, DOE/EIA-0035 (91/04), April 26,1991, p. 35.

decline slowed considerably to -0.8 percent per year during this period.

An increase in the level of overall spending and a shift in spending toward more energy-intensive products are two of the factors that contributed to the increase in energy use. For example, Federal Government spending dramatically changed as nondefense purchases fell by 16 percent over the 3-year period, and defense purchases grew by 1O percent. In addition, household spending shifted away from nondurable to durable goods like furniture and electronics. OTA found no evidence that businesses' energy efficiencies declined during this period.

Future Energy Use

Increases in energy use should be less in the future than what was experienced between 1985 and 1988, when the annual gross national product (GNP) growth rate was 2.9 percent. The U.S. Department of Labor's moderate economic growth scenario assumes a 2.3 percent GNP growth rate for 1988-2000. In addition, structural changes that result in less energy use and improvements in energy efficiency are likely to continue in the future.

The impact of technology on future energy use is speculative. A variety of energy-saving technologies are available and have the potential for significant energy efficiency gains. The critical factor is whether there is a willingness to implement these technologies. Implementation or adoption will depend on the costs of the technology and the energy it saves, government policies, and consumer acceptance.

Moreover, business decisions to invest in energy-saving technologies are made in the context of many other competing criteria. Industry makes investment decisions that affect energy efficiency on the basis of a strategic planning process that considers not only energy costs but also a number of other factors. The most important of these factors are perception of product demand and competition; the cost of capital, materials, and labor; and government policy.[8]

[8]U.S. Congress, Office of Technology Assessment, *Industrial Energy Use, OTA-13198* (Washington, DC: U.S. Government Printing Office, June 1983), p. 9.

Energy Use by Sector—An Overview

Residential/Commercial Sector

In 1989, energy use in the residential and commercial sectors accounted for about 36 percent of total U.S. energy use. (See table 2-3.) Space heating and cooling accounted for almost 59 percent of the total energy used in the residential sector in 1987 (the most recent year for which data are available), as shown in table 2-4.[9]

Natural gas is the primary energy source for space heating in the residential sector. Electricity is essentially the only energy source for air conditioning and the major source for appliances, which commonly include refrigerators, TVs, ovens, and clothes washers.

In the commercial sector, a few end-uses account for a major portion of total energy use: space heating, cooling and ventilation, and lighting. Electricity is the predominant energy source in commercial buildings, followed by natural gas. In 1986 (the most recent year for which data are available), electricity accounted for almost half of total commercial sector energy use, followed by natural gas (34 percent) and fuel oil (9 percent).[10]

From 1979 to 1986, energy consumption per household declined considerably. A number of factors were responsible for the 20-percent drop in residential energy intensity: reduced household size, improved shell and equipment efficiencies, and lifestyle changes. In the commercial sector, energy use per square foot declined from 115,000 Btus in 1979 to about 89,000 Btus in 1986. The 23-percent drop in commercial energy intensity was the result of efficiency improvements in new buildings and retrofits to existing ones. Geographical shifts and the changing mix of commercial buildings also contributed to the decrease.[11]

The energy intensity of commercial buildings will probably continue to decrease as new, more efficient technologies are absorbed and new construction practices are implemented, but the level of decline will slow due to the proliferation of electronic equipment, such as personal computers, copiers, and communications equipment. From 1984 to 1989, the number of computer workstations increased from 6.5 to 25.3 million.[12] Modern office equipment now requires as much electricity as is used for lighting. In addition, some modern, more powerful electronic equipment may require more electricity than older models. For example, a laser printer requires 5 to 10 times as much electricity as an old impact printer. And, more powerful desktop computers use almost two times as much electricity as the previous generation.

A number of organizations forecast residential and commercial energy use. A few of these are presented in tables 2-5 and 2-6. Each of the forecasts took into account a number of variables, including energy prices, GNP growth, and building and housing stock expansion. With the exception of the American Gas Association (AGA) forecast, residential electricity demand was projected to rise. The electrification of space and water heating was cited as one of the major reasons for the increase in electricity demand. AGA projected no increases in residential electricity demand from the period 1985 to 2000.[13]

These forecasts for commercial energy use are in general agreement for 2000; however, by 2010 forecasts diverge. The variations are a result of different assumptions, perspectives, and forecasting approaches. For example, the EIA forecast assumes electricity prices decrease at an average rate of 0.7 percent per year, while the AGA assumes electricity prices increase at an average rate of 1.9 percent per year.[14]

A variety of energy-efficient products and systems have been developed and commercialized over the past decade. These and new promising energy efficiency developments are the focus of the section

[9] U.S. Energy Information Administration, op. cit., footnote 1, p. 43.

[10] Ibid., p. 57.

[11] Ibid., p. 41.

[12] U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States 1990*, 110th Edition Washington DC: U.S. Government Printing Office) 1990, "Computers in the Office," special feature.

[13] Howard S. Geller, American Council for an Energy-Efficient Economy, *Residential Equipment Efficiency: A State-of-the-Art Review*, contractor report prepared for the Office of Technology Assessment, May 1988, pp. 39-40.

[14] Howard S. Geller, American Council for an ~er~.Efficient Economy, *Commercial Building Equipment Efficiency: A State-of-the-Art Review*, contractor report prepared for the Office of Technology Assessment, May 1988, p. 3.

Table 2-4-Household Energy Consumption by Application and Fuel Source, 1978,1980-82, 1984, and 1987

	Consumption (quadrillion Btu)					
Application and fuel source	1978	1980	1981	1982	1984	1987
Space heating:						
Natural gas	4.26	3.32	3.81	3.31	3.51	3.38
Electricity[a]	0.41	0.28	0.30	0.27	0.30	0.28
Distillate fuel oil and kerosene	2.05	1.32	1.13	1.05	1.10	1.05
Liquefied petroleum gases	0.23	0.25	0.22	0.19	0.21	0.22
Total	6.95	5.17	5.45	4.81	5.13	4.94
Air conditioning.[b]						
Electricity[a]	0.31	0.32	0.33	0.30	0.36	0.44
Water heating:						
Natural gas	1.04	1.24	1.10	1.08	1.10	1.10
Electricity[a]	0.29	0.31	0.33	0.33	0.32	0.31
Distillate fuel oil and kerosene	0.14	0.24	0.21	0.09	0.15	0.17
Liquefied petroleum gases	0.06	0.07	0.06	0.06	0.06	0.06
Total	1.53	1.86	1.69	1.56	1.62	1.64
Appliances:						
Natural gas	0.28	0.38	0.49	0.39	0.35	0.34
Electricity	1.46	1.55	1.53	1.52	1.53	1.72
Liquefied petroleum gases	0.03	0.04	0.03	0.04	0.04	0.04
Total	1.77	1.97	2.05	1.95	1.92	2.10
Total[b]	10.56	9.32	9.51	8.62	9.04	9.13
Natural gas[b]	5.58	4.94	5.39	4.77	4.98	4.83
Electricity	2.47	2.46	2.48	2.42	2.48	2.76
Distillate fuel oil and kerosene	2.19	1.55	1.33	1.14	1.26	1.22
Liquefied petroleum gases	0.33	0.36	0.31	0.29	0.31	0.32

[a]Includes electricity generated for distribution from wood, waste, geothermal, wind, photovoltaic, and solar thermal electricity.
[b]Includes a small amount of natural gas used for air conditioning.

NOTE: Sum of components may not equal total due to independent rounding.

SOURCE: U.S. Energy Information Administration, *Annual Energy Review* 1989, DOE/EIA-0384(89) May 24, 1990.

"Opportunities for Energy Efficiency Improvements in the Residential and Commercial Sectors."

Industrial Sector

In 1989, energy use in the industrial sector accounted for about 36 percent of total U.S. energy use.[15] Energy is used for direct heat, steam generation, machinery operation, and feedstocks. Oil is frequently used for the production of direct heat or steam generation. Coal is used more for steam generation. Natural gas is dominant in mining and manufacturing because it burns cleanly and is available. Natural gas has also been used as a feedstock for fertilizers. Electricity is primarily used for motors.

Over the years, the industrial sector has continued to rely on these three fossil fuels and electricity, but their relative contributions have changed. For example, coal accounted for a 26-percent share of industrial energy in 1960 but registered only a 13-percent share in 1989. From 1960 to 1989, petroleum's share ranged from 33 to 41 percent to its present 37-percent share. Natural gas use was very similar to that of petroleum. During the same period, electricity use increased from 7 to 14 percent.[16]

Since 1972, the industrial sector has takennumerous steps to reduce its energy use per unit of output. A number of process changes and the application of new technologies, such as sensors and control systems, heat recovery systems, and continuous steel casting have improved energy efficiency. For example, U.S. industries used less energy in 1985 than in 1963 to produce the same mix and level of products. A discussion of promising energy-efficient technologies follows in the section "Opportunities for Energy Efficiency Improvements in the Industrial Sector."

Transportation Sector

In 1989, the transportation sector accounted for about 27 percent of total energy consumption in the United States. The sector, which is almost totally

[15]U.S. Energy Information Administration op. cit., footnote 1, p. 13.

[16]Ibid., p. 21.

Table 2-5-Comparison of Residential Energy Use Forecasts

Forecast	Primary energy use (quadrillion Btu) 1985	1990	2000	2010
Lawrence Berkeley Laboratory (1987,)[a]	15.5	17.0	18.0	19.9
U.S. Department of Energy (1985)[b]	—	17.8	19.8	21.3
U.S. Energy Information Administration (1987)[c]	15.2	16.9	18.6	—
Data Resources, Inc. (1986)[d]	15.0	16.8	17.9	18.7
Gas Research Institute (1985)[e]	—	16.9	17.8	18.7
American Gas Association (1986)[f]	14.3	13.8	14.8	—
Oak Ridge National Laboratory[g]	16.0	17.2	18.4	20.4
National Energy Strategy[h]	—	18.2	(20.8)	23.3

[a]Computer run provided by Jim McMahon, Lawrence Berkeley Laboratory, Berkeley, CA, November 1987.
[b]Office of planning, Policy and Analysis, U.S. Department of Energy, "National Energy Policy Plan Projections to the Year 2010," Washington, DC, 1985.
[c]U.S. Energy Information Administration, "Annual Energy Outlook 1987,"DOE/EIA-0383(87), Washington, DC, March 1988 (base case).
[d]Data Resources, Inc., "Energy Review," Lexington, MA, summer 1966.
[e]Gas Research Institute, "1987 GRI Baseline Projection of U.S. Energy Supply and Demand to 2010," Chicago, IL, December 1987. (Not including wood and other renewable energy sources.)
[f]American Gas Association, "AGA-TERA Base Case 1986-l," Artington, VA, January 1986.
[g]Oak Ridge National Laboratory, "Energy Efficiency: How Far Can We Go?" ORNL/TM-1 1441, January 1990, p.7.
[h]National Energy strategy, First Edition 1991/1992 (Washington, DC: U.S. Government printing office, February 1991), p. C-l 5. NOTE: Year 2000 NES projection interpolated from 1990 and 2010 figures.

SOURCES: Brookhaven National Laboratory, "Analysis and Technology Transfer Annual Report-1986," Upton, NY, August 1987; and other references cited above.

Table 2-6-Comparison of Commercial Energy Use Forecasts

Forecast	Primary energy use (quadrillion Btu) 1985	1990	2000	2010
Lawrence Berkeley Laboratory (1987)[a]	11.6	13.3	15.8	18.5
U.S. Department of Energy (1985)[b]	—	13.3	16.1	18.0
U.S. Energy Information Administration (1987)[c]	11.6	12.8	15.4	—
Data Resources, Inc. (1986)[d]	11.5	12.8	14.6	17.4
Gas Research Institute (1985)[e]	—	12.2	14.0	16.7
American Gas Association (1986)[f]	12.7	13.3	15.6	—
Oak Ridge National Laboratory[g]	10.8	13.1	16.0	18.8
National Energy Strategy[h]	—	13.8	(17.6)	21.3

[a]Pacific Northwest Laboratory Commercial Energy Use Model.
[b]Office of planning, Policy and Analysis, U.S. Department of Energy, "National Energy Policy Plan Projections to the Year 2010," Washington, DC, 1985.
[c]U.S. Energy Information Administration, "Annual Energy Outlook 1987," DOE/EIA-0383(87), Washington, DC, March 1988 (base case).
[d]Data Resources, Inc., "Energy Review," Lexington, MA, summer 1986.
[e]Gas Research Institute, "1987 GRI Baseline Projection of U.S. Energy Supply and Demand to 2010," Chicago, IL, December 1987. (Not including renewable energy sources.)
[f]American Gas Association, "AGA-TERA Base Case 1986-l," Arlington, VA, January 1986.
[g]Oak Ridge National Laboratory, "Energy Efficiency: How Far Can We Go?" ORNL/TM-1 1441, January 1990, p.7.
[h]National Energy Strategy, First Edition 1991/1992 (Washington, DC: U.S. Government Printing Office, February 1991), p. c-15.

NOTE: Year 2000 NES projection interpolated from 1990 and 2010 figures.

SOURCES: Brookhaven National Laboratory, "Analysis and Technology Transfer Annual Report-1986," Upton, NY, August 1987; and other references cited above.

dependent on petroleum, used 10.85 million barrels per day in 1989, which is more than the United States produces domestically. Its share of total U.S. petroleum consumption was almost 63 percent.[17] The total U.S. automobile fleet alone accounts for about 30 percent of all U.S. oil consumption; the total light-duty fleet, which also includes vans and light trucks, accounts for about 39 percent. The automo-

[17]Ibid., p. 137.

bile and light-duty fleets are the largest available targets for reducing U.S. oil use.

Over the last two decades, tremendous strides in automobile fuel efficiency have been made. The fuel efficiency of the new car fleet has essentially doubled between 1974 and today. The potential for further reducing energy use in the transportation sector is promising if the industry is given enough lead time. A number of new energy-saving technologies are either on the market or under investigation. They offer the potential to significantly improve fleet fuel economy in the long term (by 2010). In addition, recent interest in developing alternative transportation fuels can have positive effects on energy demand by diversifying fuel supplies and/or reducing demand for gasoline. In the short term, however, a number of factors are expected to slow down the rate of efficiency improvement. These include increasing sales of new high performance and luxury cars, growth in the use of light trucks for passenger travel, and a continued demand for certain older car models. A discussion of promising technologies and alternative fuels follows in the section "Opportunities for Energy Efficiency Improvements in the Transportation Sector. '

OPPORTUNITIES FOR ENERGY EFFICIENCY IMPROVEMENTS IN THE RESIDENTIAL AND COMMERCIAL SECTORS

From 1974 to 1986, technical advances in energy-using equipment and building construction practices and materials have significantly improved energy efficiency in the residential and commercial sectors. High energy prices during this period were the impetus for the rapid development and implementation of a variety of energy-saving technologies. Strong government support for research and development (R&D) programs in energy efficiency also contributed to accelerating technology development. However, considerable potential for energy savings remains. In recent years lower energy prices have slowed the rate of efficiency improvement and dampened the prospects for near-term commercialization of new technologies. In addition, Federal funding for energy technology R&D has declined over the last decade. Increasing Federal R&D support could accelerate the development and deployment of energy saving technologies. The following section discusses opportunities for improving energy efficiency in the residential and commercial sectors.

Opportunities for Improving Space Heating and Cooling Efficiency

Space heating and cooling are the most energy-consuming applications in households and commercial buildings. Space heating alone accounts for about two-thirds of total residential sector energy use.[18]

In homes and commercial buildings that use fuels for space heating, newer more energy efficient furnaces and boilers are already common. The Gas Appliance Manufacturers Association (GAMA) estimates that about 47 percent of all new gas furnaces sold have efficiency ratings of between 65 and 71 percent. Gas furnaces with efficiency ratings of 80 percent make up about 33 percent of the market, and 90-percent efficient furnaces make up about 20 percent of the market.[19] Since the early 1980s, these highly efficient furnaces have been promoted by manufacturers and relatively well-received by consumers.

The decision to purchase a super efficient furnace must weigh the increase in initial cost against the increased savings. An Illinois Department of Energy and Natural Resources survey indicates that natural gas furnaces in the 90+-percent efficiency range cost on average about $2,100 to $2,600. An 80-percent efficient furnace can be installed for an average of about $1,500. A comparison of annual savings and paybacks from furnace replacements is shown in figure 2-1.[20]

The best modern furnaces are already close to maximum efficiency (within 10 percent of maximum theoretical efficiency). Improvements in energy efficiency in the sector will depend less on new technology than on encouraging people to use the best available equipment.

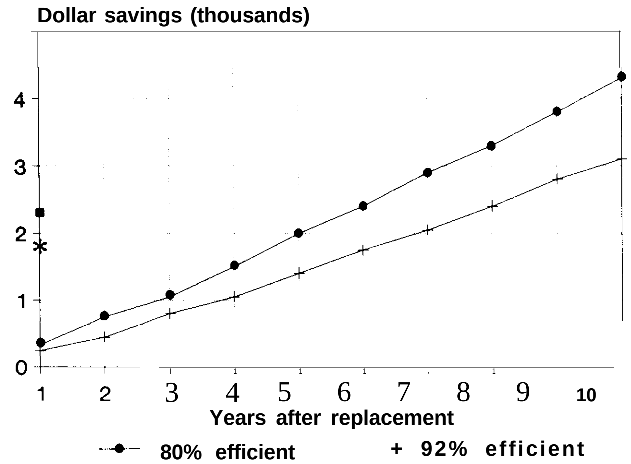
In addition, older furnaces can be retrofitted to achieve higher efficiencies by adding such features

[18] Ibid., p. 43.

[19] Henry C. Kurth and Nicolas P. Hall, ''Furnace Replacement: The High Efficiency payOff," *Home Energy*, vol. 7, No. 3, May/June 1990, p. 22.

[20] Ibid.

Figure 2-l—Furnace Replacement Accumulated Savings (60 percent efficient v. 80 and 92 percent)



With 5-percent escalation included, 92 percent efficient furnaces take 2 years more to pay for themselves than the 80 percent efficient furnaces.

SOURCE: "Furnace Replacement: The High Cost Efficiency Payoff," *Home Energy,* vol. 7, No. 3, May/June 1990.

as flame-retention burners, electric ignition, power burners, and condensing heat extractors. Flame retention burners are a cost-effective measure for oil furnaces. Double-digit energy savings with paybacks of 2 to 5 years are typical for this retrofit. However, other retrofit programs have had mixed success, indicating that investments have to be chosen carefully.[21]

In homes and commercial buildings that use electricity to space heat, heat pumps offer a major opportunity for improving energy efficiency. Heat pumps typically consume one-third to one-half as much electricity for heating as do electric resistance-based systems. However, heat pumps operate at cooler temperatures than furnaces, so the air from the vents may feel drafty and heat the house more slowly. In 1987, heat pumps were used in about 25 percent of all electrically heated housing units. The number of commercial buildings with heat pumps nearly doubled between 1983 and 1986.[22]

Current heat pump technologies do not operate near their maximum theoretical efficiency. Thus, the opportunities for improvement are significant. For example, the development of variable speed controls for capacity modulation will improve efficiency and provide a better match between output and space conditioning needs. One estimate notes that variable speed heat pumps will use 25 to 50 percent less electricity than typical heat pumps installed in the mid-1980s.[23] Incorporating variable speed controls also provides quieter operation, more flexible control, better dehumidification capability, and the possibility of self-diagnostic features.

Variable-speed heat pumps have been available in Japan since the early 1980s. About one-half of all heat pumps in Japan use variable-speed control.[24] Variable-speed heat pumps are also available in the United States. The number of manufacturers offering this technology is growing; and newer, more efficient models are continually being tested and marketed.

Improvements in compressors for heat pumps and air conditioners also promise to have higher efficiency rates than conventional types. For example, newer scroll-type compressors have efficiencies of 10 to 20 percent higher than reciprocating compressors. In addition, scroll-type compressors are smaller, lighter, and quieter. They are widely produced in Japan and are expected to be produced and used in the United States in the near future.

The next major advance in heating/cooling technology may be the thermally active heat pumps (TAHP). A TAHP is similar to a conventional electric heat pump except that the electric motor is replaced by "something" that burns fuel, e.g., an internal combustion engine. Two of the advantages of TAHPs are that they can use a variety of fuels, and they are more efficient than a comparable electric system. TAHPs use exhaust heat from the engine to supplement the heating cycle.[25] TAHPs could have a significant impact on residential and commercial energy use in the next 10 to 20 years, but they will

[21] Sam Cohen, "Fifty Million Retrofits Later," *Home Energy, vol. 7, No. 3, May/June* 1990, pp. 14-15.

[22] U.S. Energy Information Administration, *Housing Characteristics 1987*, DOE/EIA-0314(87), May 1989, p. 12; and *Characteristics of Commercial Buildings 1986,* DOE/EIA-0246(86), September 1988, p. 21.

[23] Geller, Residential *Equipment Efficiency*, op. cit., footnote 13, p. 20.

[24] Debbie Lowe, "A New Generation of Heat Pumps," *Home Energy,* vol. 6, No. 2, March/April 1989, p. 12.

[25] Oak Ridge National Laboratory, *Energy Technology R&D: What Could Make a Difference?* vol. 2, Part 1, "End-Use Technology," ORNL-65441 1 V2/P1, December 1989, pp. 33-34.

have to be competitive with conventional systems in terms of first cost and maintenance.

Both DOE and the Gas Research Institute (GRI) have funded research on TAHPs. A number of advanced TAHPs have been developed. These include internal combustion engine-driven units, Ike-piston Stirling engine systems, and absorption systems. In the United States, the internal combustion engine-driven units are in the prototype stage and have been tested in the laboratory. The Japanese are also doing research in this area and have manufactured and field-tested a number of internal combustion-driven systems. The best performances are comparable to the best electric systems in cooling, about 75 percent better in heating, and very competitive in operating costs.[26]

Several Stirling engine-driven heat pumps have been developed and tested. Stirling engines are attractive as heat pump drivers because they have the potential to be highly efficient, quiet, and long lasting. The performance of Stirling engine-driven heat pumps has been similar to that of the internal combustion engine.[27]

Similar progress has been made in advanced absorption systems. A number of advanced absorption systems are under development and have been tested in the laboratory. They are about 20-percent more efficient in cooling than the best absorption chillers[28] available.[29] Cost studies have shown that the installed cost for a small absorption heat pump is in the range of installed costs for a gas furnace plus an electric air conditioner.[30]

Other refrigeration equipment efficiency improvements are being developed. These include the use of capacity modulating systems and novel refrigeration cycles. These advancements could improve energy efficiency by 30 to 50 percent.[31]

Opportunities for Improving Building Envelope Efficiency

Efforts are being directed at improving the thermal efficiency of building envelopes. Much of the research has focused on materials that have higher thermal resistance per unit thickness and new envelope configurations that are more thermally resistant.

For wall systems, alternative construction practices have promising potential for improving efficiency. These include innovative designs that keep the structural elements away from the exterior shell and retrofit insulation practices that shield existing thermal bridges (highly conductive heat flow paths). Thermal bridges can reduce the overall thermal efficiency of some wall systems by 30 percent. Demonstration homes in Minnesota that use new insulation techniques use 68-percent less heat than the average U.S. home.[32]

Prospects for new high-thermal-resistant products for wall systems are being explored. These include evacuated or foam cores molded to conform to the exterior shape of the building and molded fiber walls.[33]

Improving the thermal resistance of roofs is somewhat difficult because roofing materials are compact and not much can be done to improve thermal resistance per unit thickness except to focus on materials. Alternatives to chlorofluorocarbon foam insulation are being developed and tested. In addition, waterproof membranes must be developed that can maintain their resiliency through continual thermal stressing over periods of 20 years or more. And, improved techniques must be developed for fastening roof elements to the structural building.[34]

‘Ibid., p. 34.

27Ibid., p. 35.

28Absorption chillers are the only available fuel-burning refrigeration systems. They can burn either natural gas or oil to produce chilled water for cooling. Absorption chillers are not widely used in the United States because they are not cost and/or performance competitive with current electric systems. But in Japan, where energy costs are higher and the Government favors systems that use natural gas, 80 percent of all commercial buildings are cooled with absorption chillers.

29Oak Ridge National Laboratory, op. cit., foonote 25, p. 35.

30Geller, Residential *Equipment Efficiency*, op. cit., footnote 13, p. 23.

31Oak Ridge National Laboratory, op. cit., footnote 25, p. 33.

32J.H. Gibbons, P.D. Blair, and H.S. Gwin, “Strategies for Energy Use,” *Scientific American, vol. 262, No. 3,* September 1989, p. 141.

330& Ridge National Laboratory, op. cit., footnote 25, pp. 25, 39.

‘Ibid., p. 39.

A number of successful innovations have improved the thermal efficiency of windows. As much as 25 percent of residential and 4 percent of U.S. total energy use escapes through windows.[35] Thus, the potential for reducing energy use is significant.

The introduction of two coatings technologies has improved window performance substantially. One technology applies a heat reflective coating directly on the glass, and the other applies similar coatings to a clear polyester film that is mounted inside sealed insulating glass. Low-emittance (low-e) coatings and films have increased glass insulation values up to as much as R-4.5. For example, the addition of low-e coatings to a double-pane glass increases the insulation value of a window up to as much as R-3. (A single-pane glass is roughly the equivalent of R-1; double-pane, R-2; and triple-pane, R-3.) To increase further the insulation value, a colorless inert gas, such as argon, can be added inside a sealed low-e window unit, thereby increasing the R value to R-4. Using a heat reflective coating on a clear, colorless film mounted inside a double-pane window unit can increase the R value to R-4.5.[36]

In January 1990, a window with an R-8.1 insulating value was introduced. The use of multiple-coated films mounted inside sealed insulated glass made this development possible. This window achieves almost the thermal resistance of an ordinary insulated stud wall, thus greatly reducing a major heat leakage. In addition, it reduces sound transmission much more effectively than ordinary windows (important near highways and airports) and virtually eliminates ultraviolet light, which damages fabrics. However, it is significantly more expensive. Hurd Wood Windows quotes prices for a typical 2'6" x 5' casement window as: $257 for R-2.6 clear, double-glazed; $320 for R-4.1 with a single coated film; $441 for R-8.1 double film (quadruple glaze) with inert gas. In a moderate climate, the R-8.1 window would save less than 10 dollars' worth of energy per year relative to the R-2.6 window which is not a good return for investment of $184. Thus these windows are economical only in severe climates or where the other features are valued.

Two of the most important advantages of improving window insulation performance are: 1) reducing energy costs and 2) increasing the capacity of existing heating, ventilation, and air conditioning (HVAC) systems or allowing the use of smaller HVAC systems in new construction and renovations.[37] Many new window products that incorporate these innovations are already on the market. In fact, a few large window manufacturers have standardized lowe glass products. And, DOE indicates that demand for low-e windows has increased 5 percent annually since the products were introduced in 1983.[38] Additional research is being conducted on improving the durability of the coatings and lowering their emittance and reducing condensation.

Opportunities for Improving Water Heating Efficiency

Incremental efficiency improvements have been achieved by adding insulation wraps or installing convection-inhibiting heat traps to existing water heaters. Also, more efficient conventional water heaters are commercially available at a modest increase in first cost of about $20 to $100. These more efficient water heaters provide 10- to 25-percent energy savings with a 1[1]/2- to 3-year payback.

Innovative water heaters were developed and commercialized in the 1980s. Heat-pump water heaters, for example, use about 50-percent less electricity than conventional electric water heaters. A heat-pump water heater can cost anywhere from $800 to $1,200, four times that of a conventional electric water heater.[39]

Heat-pump water heaters can be operated together with a mechanical ventilation system in houses that have low infiltration. The heat pump removes heat from the exhaust air stream during the heating season and from the incoming air stream during the cooling season and uses this heat to operate the water heater. The ventilation air streams are a very efficient

[35]Rick Bevington and Arthur H. Rosenfeld, "Energy for Buildings and Homes," *Scientific American*, vol. 263, No. 3, September 1990, p. 80.

[36]Todd W. Sitrin, "Windows for the '90s," *Public Power*, May-June 1990, vol. 48, No. 3, pp. 40-41.

[37]Ibid., p. 41.

"'Window Company Standardizes Low-E Glass," *Home Energy*, vol. 7, No. 3, May/June 1990, p. 6.

3913. Hirst, J. Clinton, H. Geller, and W. Knoner, American Council for an Energy-Efficient Economy, *Energy Efficiency in Buildings: Progress and Promise* (Washington, DC: 1986).

source of heat for the heat-pump water heater. Such systems are commonly used in Scandinavia.[40]

Highly efficient gas- or oil-fired water heating is possible by coupling a hot water tank to a high-efficiency space heating furnace. This achieves water heating efficiencies of 80 to 85 percent and saves fuel. A similar technology recently introduced is a high-efficiency integrated space and water heating system. It features electric ignition, a power burner, and flue gas condenser to provide both space and water heating at efficiency levels of 85 to 90 percent. Neither the heat-pump water heater nor the high-efficiency integrated gas-fired space and water heating system has significantly penetrated the marketplace. Low sales are attributed to high first cost and limited availability.[41]

GRI has supported the development of a gas water heater with pulse combustion and flue gas condensation (similar to the most efficient gas furnaces). It is estimated that the water heater will use 25 to 40 percent less fuel than conventional gas heaters currently produced. The estimated retail cost is about $900, roughly three times that for a standard water heater.[42]

Photo credit: Chris Calwell, courtesy of Home Energy *Magazine*

The availability of energy-efficient lighting products has increased significantly in recent years.

Opportunities for Improving Lighting Efficiency

Lighting is the second largest end-use in the commercial sector and a significant portion of total energy use. Fluorescent lights are heavily used in commercial buildings.

Fluorescent lamps are being improved through size and weight reductions. For example, switching from standard fluorescent ballasts to electronic ballasts that weigh only about four ounces can decrease energy use. Lawrence Berkeley National Laboratory developed a high-frequency, solid-state ballast that increases lamp efficiency by 20 to 25 percent.[43] Adding an optical reflector to fluorescent lamps increases useful light output by 75 to 100 percent, cutting energy use by 30 to 50 percent.[44]

Another option for improving fluorescent lighting efficiency is to develop more efficient phosphors. Phosphors currently in use are 40-percent efficient. Research is underway to develop phosphors that convert one ultraviolet photon into two visible photons, resulting in 75-percent efficiency and reducing energy use by 50 percent.[45]

In the commercial sector, a combination of options, such as replacing standard fluorescent lamps and ballasts with energy efficient types; replacing incandescent bulbs with fluorescent lighting; and installing reflectors, lighting controls, and occupancy sensors could cut electricity use for lighting by nearly 50 percent. Overall electricity use in the commercial sector could drop by about 20 percent.[46] Of course, the decision to retrofit must weigh the initial costs against the increased savings.

[40] Geller, Residential *Equipment Efficiency*, op. Cit., footnote 13, pp. 6, 19.

[41] Ibid., p. 7.

[42] Ibid., pp. 19-20.

[43] Oak Ridge National Laboratory, op. cit., footnote 25, p. 36.

[44] Geller, *Commercial Building Equipment Efficiency*, op. cit, footnote 14, P. 12.

[45] Oak Ridge National Laboratory, op. cit., footnote 25, p. 36.

[46] M.J. Wallin, S. Balakrishnan, and C. McDonald, “Commercial/Governmental Electricity Conservation Potential,” report prepared by Synergic Resources Corp. for the Public Service Commission of the District of Columbia, Washington, DC, March 1987.

The costs of retrofitting conventional lighting fixtures to more efficient ones are very site-specific. A recent lighting retrofit project conducted by the U.S. Postal Service showed a cost of $81 per lighting fixture. The retrofit included the installation of reflectors, magnetic ballasts, and new lamps.[47]

In the residential sector, energy use for lighting accounts for only about 7 percent of the total sector energy use.[48] Almost all residential lighting is provided by incandescent lamps. One way incandescent bulbs can be improved is by placing a quartz tube around the filament. The quartz tube has an optical coating that passes visible light but reflects infrared radiation. General Electric has introduced a 350-watt quartzline lamp that replaces a standard 500-watt lamp, and it is expected that this development will eventually reach households.[49]

In the early 1980s, compact fluorescent lamps were introduced to replace incandescent bulbs. Fluorescent lamps provide 3 to 5 times more light per watt of power consumed and last 5 to 10 times longer. But, they cost between $10 and $20 each. Consequently, they have been marketed primarily to the commercial and industrial sectors where lights are used more extensively. The installation of compact fluorescent light bulbs in Newark, New Jersey schools, for example, cut electricity use by 15 to 20 percent, reduced maintenance, and increased illumination levels.[50]

Because compact fluorescent lamps are larger than incandescent types, have color rendering problems, cost the consumer more, and are often difficult to find, residential market penetration is low. However, if the most heavily used incandescent bulbs were replaced with compact fluorescent, total electricity use for household lighting could drop by 30 to 40 percent.[51] Thus, the potential for energy savings is significant.

Opportunities for Improving Appliance Efficiency

Refrigerators and Freezers

In recent years, the energy efficiency of refrigerators and freezers has improved considerably. However, there is still significant potential for improvements. About two-thirds of refrigerator/freezer energy use is due to heat transfer through walls and not from door openings and food cooling.[52]

New advances in insulation products are under development. These technologies take advantage of the heat-transfer properties of a partial vacuum or trapped layers of gas to achieve higher insulation values. One type of vacuum insulation being examined uses rigid steel barriers, glass spacers, and a very low pressure or hard vacuum. Others use low-density fillers and a higher-pressure soft vacuum. Yet another concept uses no vacuum but traps gas within a number of reflective barriers.[53]

For soft vacuum insulation designs, silicon-based gels and fine powders are being tested. Aerogel insulation panels have been installed in standard refrigerators for testing by DOE. Thermalux, a California firm that manufactures aerogel panels, estimates that they would cost appliance manufacturers between $1 and $2 per square foot.[54]

Materials that have been examined for powder insulation fillers are fumed silica, precipitated silica, silica dust, perlite, glass fiber, glass wool, and fly ash. Costs for these materials vary. For example, fumed silica is expensive but performance is high. Precipitated silica, fly ash, and perlite also work well and are cheaper.[55]

The use of these new vacuum insulation designs in refrigerator/freezers could reduce their electricity consumption by 25 to 50 percent. Japanese manufacturers already incorporate first-generation, soft vacuum panels into some of their models. These panels

47Martin Nelson, Division Energy Coordinator, U.S. Postal Service, personal communication, San Diego, CA, Sept. 26, 1990.

48U.S. Energy Information Administration, Department of Energy, *Energy Conservation Multi-Year Plan, FY1989-93*, 1987.

49Geller, *Residential Equipment Efficiency*, Op. Cit., footnote 13, p. 24.

50Bevington and Rosenfeld, op. cit., footnote 35, p. 78.

51Ibid., p. 11.

52David J. Houghton, "Refrigerator Insulations for the 21st CentWY," *Public Power*, November/December 1990, p. 48.

53Ibid., p. 49.

54Ibid.

55Ibid.

have measured insulating values of R-16 to R-20 per inch of thickness. However, some concerns about panel insulation durability and maintenance have been raised. These concerns will have to be addressed before these products are used extensively in the United States.[56]

The Solar Energy Research Institute (SERI) and the Lawrence Berkeley Laboratory (LBL) have pursued different approaches to vacuum insulation. SERI has built a number of prototype panels that incorporate steel outer layers and glass spacers. The prototype panels, called compact vacuum insulation (CVI), are estimated to cost refrigerator/freezer manufacturers between $1 and $4 per square foot. Because the panel is very thin, the interior volume of a refrigerator/fkeezer could be increased. Appliance industry estimates indicate that additional volume could be worth $45 to $50 per cubic foot, and could help offset the high cost of the insulation. Thus far, manufacturers have shown little interest in CVI.[57]

LBL has been developing superinsulated gas-filled panels that resemble windows more than refrigerator/freezer insulation panels. The estimated cost to the appliance manufacturer is $0.40 to $1.50 per board foot. The panels use a number of sheets of low-e plastic separated by air gaps, which are loosely filled with very thin, crumpled low-e plastic material. The entire panel is filled with low conductivity gas and sealed. LBL has applied for a patent.[58]

Another promising option is to shift from one to two refrigeration systems. This improves thermodynamic efficiency and results in less dehydration of food in the refrigerator compartment. Refrigerator-freezers with dual refrigeration systems are manufactured in Europe.[59]

The use of electronic variable speed controls is another way to improve the efficiency of refrigeration systems. Electronic variable speed controls, which modulate cooling output, can produce electricity savings of about 20 percent.[60]

Cooking and Laundry

There have been a number of promising developments in cooking technology and clothes drying. For example, a high-efficiency electric oven, called the biradiant oven, was developed and demonstrated in the 1970s. Its features include highly reflective walls and two heating elements that operate at relatively low temperatures. Tests show that the biradiant oven uses about 60-percent less electricity than conventional ovens. Manufacturers have shown little interest in producing the biradiant oven even though it appears to be technically and economically viable.[61]

Another development, the infrared-jet impingement burner for gas stove tops, promises fuel savings of 15 to 25 percent. This burner utilizes a high degree of radiative heat transfer from a ceramic flame holder. Other advantages of the infrared jet impingement burner are a reduction in nitrogen oxide and carbon monoxide emissions, uniform heating, fast response, and ease of cleaning. GRI field-tested the burner and is continuing to reduce production cost and increase lifetime.[62]

Some promising advances in clothes dryers are on the horizon. A heat-pump clothes dryer has been developed, and tests show electricity savings of 50 to 60 percent relative to a conventional clothes dryer. (Larger-scale heat pump dryers at-e used for drying lumber and food products.) The heat-pump clothes dryer has a drain pipe rather than an exhaust vent, which is advantageous in apartment buildings. A major disadvantage is its cost. The estimated retail price of the dryer is $600 to $700, about twice that of a conventional electric dryer. The payback on the extra first cost is about 8 years. Commercialization and marketing are expected to begin in the near future.[63]

Microwave clothes dryers are also under development. However, there are problems with high water retention when drying larger loads.

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56 Geller, *Residential Equipment Efficiency*, op. Cit., footnote 13, P. 18.

57 Houghton, op. cit., footnote 52, p. 50.

58 Ibid.

59 Geller, *Residential Equipment Efficiency*, Op. Cit., footnote 13, p. 17.

@ibid.

61 Ibid., p. 24.

62 Ibid., pp. 24-25.

63 Ibid., p. 26.

Opportunities for Improving Energy Management and Control Systems

Energy management and control systems are used to monitor and adjust heating and air conditioning, lighting, and other energy-using appliances, primarily in commercial buildings. Energy management and control systems are diverse and vary from a simple thermostatic control to complex pneumatic control systems with many sensors, microprocessors, and other components.

Behavioral changes, particularly changes in indoor air temperatures, are an important element in building energy management programs. The EIA, which has been tracking indoor air temperatures since 1981, reports that winter indoor air temperatures dropped during the 1973-84 period. This drop was an important factor in the decline in U.S. residential energy use during this time.[64]

Improvements in control technologies and sensors, and diagnostic equipment could result in energy savings as high as 10 to 15 percent of total U.S. energy use. The commercial sector offers the greatest potential for savings.[65]

Strides have also been made in the residential sector. Automated control systems comparable to those used in commercial buildings are now being installed in houses. These "smart" houses, as they are commonly called, are being promoted by a number of manufacturers, utilities, the Electric Power Research Institute, and the National Association of Home Builders. For example, the Southern California Edison Co. and a number of local builders initiated a House of the Future pilot project. New homes are equipped with automated systems and controls and a number of energy-saving technologies, such as compact fluorescent light bulbs, energy efficient appliances, and occupancy sensors.[66]

Over the years, advances in energy management and control have been continual. Nevertheless, some opportunities still have not been realized. For example, there is a lack of reliable, low-cost meters for measuring oil and natural gas use in buildings. Also, humidity sensors need further development.[67]

OPPORTUNITIES FOR ENERGY EFFICIENCY IMPROVEMENTS IN THE INDUSTRIAL SECTOR[68]

The industrial sector is both diverse and large. It uses energy for probably a wider variety of purposes than does any other sector of the economy. Energy is used for direct heat, steam generation, machinery operation, and feedstocks. The most intensive industrial processes involve the direct application of heat to break and rearrange molecular bonds through chemical reactions. Processes such as smelting, cement manufacture, and petroleum refining typically involve large amounts of heat.

Since it peaked in 1970, industrial energy use per unit of output (energy intensity) has been declining due to a number of factors: efficiency improvements, innovative process changes and the application of new technologies, changes in the product mix (level and demand for products), and the price of energy. Many of the energy efficiency gains realized over the last decade have been the result of good business practices.

Most firms regard energy efficiency in the context of a larger strategic planning process. Investments are evaluated and ranked according to a variety of factors: product demand, competition, cost of capital, labor, and energy. Thus, energy-related projects are not treated differently from other potential investments and must contribute to the corporate goals of increased profitability and enhanced competitive position. This view has important policy implications for reducing energy demand. Incentives aimed at decreasing energy demand growth must compete with other strategic factors and therefore have to be substantial to make a significant impact.

OTA found that the best way to improve energy efficiency in the industrial sector is to promote general corporate investment. Lowering interest rates would increase capital availability and allow

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64 Steven Meyers, "Energy Consumption and Structure of the U.S. Residential Sector: Changes Between 1970 and 1985," *Annual Review of Energy 1987*, vol. 12, 1987, pp. 92-93.

65 Oak Ridge National Laboratory, op. cit., foomote 25, p. 28.

66 Bevington and Rosenfeld, op. cit., footnote 35, p. 82.

67 Oak Ridge National Laboratory, op. cit., footnote 25, p. 28.

68 For a more indepth discussion of industrial energy use, see OTA report *Industrial* Energy use, Op. Cit., footnote 8.

more projects to be undertaken. Industries that believe energy prices will continue to rise have a strong impetus to use capital for more energy efficient equipment. However, it should be noted that growth in product demand is essential if investment is to take place, even with lower interest rates. The OTA report *Industrial Energy Use* provides a more indepth discussion of corporations' investment behavior.

While the industrial sector has made impressive strides in reducing energy use, opportunities for further gains in energy efficiency have by no means been exhausted. A number of promising developments in crosscutting technologies are discussed below. They include computer control systems and sensors, waste heat recovery, cogeneration, catalysts, separation processes, combustion, and electric motors. Also, opportunities for improving energy efficiency in four of the most energy-intensive industries-pulp and paper, petroleum refining, chemicals, and steel industries-follows.

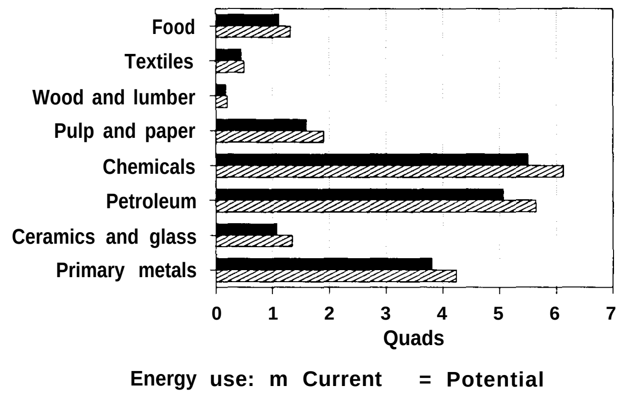
Computer Control and Sensors

Computer control systems and sensors are added to existing equipment, such as a boiler, to improve the performance, or to an industrial process to monitor the production line for wastage and quality control. In a production line, computerized process control systems can be used to optimize such things as paper thickness, polymer color, or petroleum viscosity. Almost any energy-using process can be made more efficient if specific parameters at each point in the process can be measured and conditions optimized. Figure 2-2 shows the potential for energy savings associated with improved sensor technology for several industries. Potential savings in the range of 5 to 20 percent can be achieved for each of the industries. In addition, improved sensors have the potential for reducing total industrial energy use by 10 percent.[69]

Waste Heat Recovery

Whenever fuel is burned, the products of combustion are a potential source of waste heat. Therefore the recovery of waste heat has enormous potential for saving energy. Waste heat recovery systems can improve the overall energy efficiency by recovering heat from combustion gases in a steam boiler or from excess thermal energy from a process stream product. A great deal of waste heat recovery has been taking place, especially since 1974.

Figure 2-2—Potential Energy Savings With Improved Sensor Technology



SOURCE: U.S. Department of Energy, the DOE Industrial Energy Conservation Program, Research and Development in Sensor Technology, DOE/NBM-7012450, April 1987, p. 4.

Traditional approaches to heat recovery include transferring heat from a high-temperature, waste heat source (combustion gases) to a more useful medium, e.g., steam, for low-temperature use; or upgrading thermal energy to a level that can be useful as a heat source. Heat exchangers are used for the former approach and vapor recompression and heat pumps are used for the latter.

New approaches to waste heat recovery have been broadened to include improved monitoring and control to optimize conversion and distribution of energy. A 1985 survey indicated that waste heat recovery could reduce energy inputs by 5 percent in petroleum refineries. In the chemicals industries, existing waste heat recovery programs have reduced energy usage per pound of product by 43 percent since 1974.[70]

[69] Oak Ridge National Laboratory, *Energy Technology R&D: What Could Make a Difference?* vol. 2, Part 3, "Cross-Cutting Science and Technology," ORNL-6541/V2/P3, December 1989, p. 11.

[70] Oak Ridge National Laboratory, op. cit., footnote 25, pp. 71,76.

[71] A more detailed discussion of cogeneration and its potential impacts can be found in *Industrial and Commercial Cogeneration* U.S. Congress, Office of Technology Assessment, OTA-E-192 (Washington, DC: U.S. Government Printing Office, February 1983).

Cogeneration[71]

Cogeneration is defined as the production of both electrical or mechanical power and thermal energy from a single energy source. In industrial cogeneration systems, fuel is frost burned to produce steam. The steam is then used to produce mechanical energy at the turbine shaft, where it can be used directly, but more often is used to turn the shaft of a generator, thereby producing electricity. The steam that leaves the turbine still has sufficient thermal energy to provide heating and mechanical drive throughout a plant.

The principal technical advantage of a cogeneration system is its ability to improve fuel efficiency. A cogeneration facility uses more fuel to produce both electric and thermal energy. However, the total fuel used to produce both energy types is less than the total fuel required to produce the same amount of power and heat in separate systems. A cogenerator will achieve overall fuel efficiencies 10 to 30 percent higher than separate conventional energy conversion systems.

Major industrial cogenerators are the pulp and paper, chemicals, steel, and petroleum refining industries. The pulp and paper industry has been a leader in cogeneration because it has large amounts of burnable wastes (bark, scraps, forest residues unsuitable for pulp) that can supply energy needed for plant requirements. The industry considers power production an integral part of the manufacturing process.

In the 1980s, a favorable economic and regulatory climate encouraged the growth of cogeneration in the industrial sector. Since the passage of the Public Utility Regulatory Policies Act (PURPA) in 1978, the amount of electricity received by utilities from nonutility sources has grown dramatically. According to the Edison Electric Institute, electricity sales to utilities from nonutility sources increased from 6,034 gigawatt-hours (GWh) in 1979 to 93,677 GWh in 1989. The latter figure represents 3 percent of the total electricity available to the utility industry for distribution.[72]

Estimates of current and projected nonutility capacity vary considerably, however, so it is difficult to measure the growth of this industry with precision. Although there is no definite count of nonutility capacity in the United States, the Edison Electric Institute estimated that 40,267 megawatts (MW) of nonutility capacity was in operation at the end of 1989. Cogeneration accounted for 29,216 MW, or about 73 percent of the total.[73]

Estimates of future capacity growth also vary. Several estimates suggest that roughly 38,000 MW of capacity will be online by 1995. By the year 2000, other studies estimate that nonutility capacity will be as high as 80,000 MW.[74]

In the 1980s, a favorable economic and regulatory climate encouraged the growth of cogeneration in the industrial sector.

Advanced turbines have attracted renewed attention for cogeneration applications because they can save energy and provide fuel flexibility. Over time, turbine efficiency and size have increased considerably as new turbine technologies and advanced materials allowed for hotter combustion temperatures.[75] Many of the advances in design and high temperature materials for turbines result from military R&D for improved jet engines.

In addition to hotter combustion temperatures, capturing the energy of the hot exhaust gases to make useful steam offers further options to improve efficiency. A process receiving increased attention is the steam-injected gas turbine (STIG). In the STIG, steam is injected into the turbine's combustor. The result is greater power and electrical efficiency. For example, in turbine units based on General Electric's LM-5000 (which is derived from the engine used in the Boeing 747, some DC-1 OS, and the Airbus A300), steam injection allows an increase in power from 33.1 MW to 52.5 MW and increases efficiency from 33 to 40 percent.[76] STIG units have been used in cogeneration applications, allowing for greater flexibility and efficiency when the industrial process has variable steam requirements. Intercooling, a further enhancement to STIGS, may further increase

72Edison Electric Institute, *1989 Capacity and* Generation *of Non-Utility Sources of Energy*, Washington, DC, April 1991, p. 29.

73Ibid., p. 1.

74U.S. Congress, Office of Technology Assessment, *Electric Power Wheeling and Dealing: Technological Considerations for Increasing Competition*, OTA-E-4(I9 (Washington, DC: U.S. Government Printing Office, May 1989), pp. 46-47.

75"Utility Turbopower for the 1990S," *EPRI Journal*, April/May 1988, pp. 5-13.

76R. Williams, E. Larson, "Aeroderivative Turbines for Stationary Power," Center for Energy and Environmental Studies, Princeton, May 1988.

power and efficiency to nearly 50 percent. Technology transfer from future improvements in jet engines could further raise efficiency to over 50 percent.[77]

Turbines that can use coal or biomass gasification as fuel could be a promising technology for cogeneration applications.

Separation

Separation of two or more components in a mixture is one of the most energy-intensive processes in the industrial sector. Separations account for about 20 percent of industrial energy use. Separation of liquids is commonly accomplished through the distillation process, one of the most energy-intensive separation technologies. Other separation technologies include cryogenics, pressure swing adsorption, and mercury or asbestos diaphragm electrolytic processes.

Distillation retrofit projects offer significant potential for energy savings. For example, a small increase in the number of trays in a distillation column can reduce energy use. Also, improvements in distillation control technologies will not only enhance product quality but lower energy consumption as well. It is estimated that improvements in the distillation process can reduce energy consumption by 10 percent.[78] Further reductions in energy use are possible by using other currently available processes: the use of membranes for reverse osmosis and microfiltration, or supercritical fluid (solvent) extraction.

Membrane technology is based upon the principle that components in gaseous or liquid mixtures permeate membranes at different rates because of their molecular characteristics. Solvent extraction uses fluids with a high affinity for one component of a chemical mixture, but immiscible with the remaining components. Both technologies are used by the chemicals industry. In 1984, OTA noted that the use of solvent extraction in a synthetic fiber plant saved an estimated 40,000 barrels of oil equivalent annually.[79] Membrane separation technology is expected to capture a number of other markets, including food and beverage processing.

Catalytic Reaction

Another crosscutting technology is catalytic reaction. Catalysts are used in many industries to facilitate chemical reactions. The petroleum refining and chemicals industries rely heavily on catalysts to perform a variety of functions, including raising gasoline octane level, removing impurities, and converting low-grade hydrocarbons to higher value products.

Opportunities exist for improving energy efficiency through catalytic reaction. By increasing chemical reaction rates, lower temperatures and pressures can be used, which in turn reduce heating and compression requirements.

The discovery and use of new synthetic zeolites in catalytic processes also have contributed to energy efficiency gains in both the petroleum refining and chemicals industries. These industries have spent considerable time and effort in identifying and developing unique zeolites for use in synfuels production, petrochemical manufacture, and nitrogen oxide (NO_x) abatement.[80]

Also, energy efficiency can be improved by using catalytic reaction to recover organic acids in pulp and paper industry waste streams and in processed urban waste. Typically, these wastes are dumped because there is no method for extracting the acids unless the streams are first concentrated. A catalytic process could convert the organic acids to hydrocarbons, which can be easily separated from water.[81]

Combustion

Combustion of fossil fuels is one of the principal uses of energy in the industrial sector. The Oak Ridge National Laboratory (ORNL) estimates that more than 50 percent of industrial energy is burned in boilers and process heaters. The combustion process itself is very efficient, but inefficiencies arise in the extraction and use of the thermal energy.

77 Ibid.

78 Oak Ridge National Laboratory, op. cit., footnote 25, p. 70.

79 For additional information on oil replacement capability in the industrial sector, see U.S. Congress, Office of Technology Assessment, *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability*, OTA-E-243 (Washington, DC: U.S Government Printing Office, September 1984).

80 Oak Ridge National Laboratory, op. cit., footnote 25, p. 67.

81 Ibid.

A number of opportunities exist to improve energy efficiency.

The pulsed gas or condensing furnace is a demonstrated improvement in the combustion process. The furnace uses a pulsed combustion technique to induce a draft. This technique has been applied primarily to space heating systems, but there maybe other applications for this technology in industry. In addition, advances in cogeneration systems for industrial and large commercial applications have the potential to increase thermal utilization efficiencies and reduce first cost.

Foremost among new technologies is atmospheric fluidized-bed combustion (AFBC). It is commercially available for industrial applications and has the potential to be widely used in cogeneration operations. Its major advantages include fuel efficiency, pollution control, and its small size. AFBC plants currently in use by cogenerators appear to be able to produce electricity at lower costs than other conventional coal plants. However, this technology is not without technology concerns. Difficulties with fuel and sorbent feeding systems are two of the most troublesome problems. According to ORNL, the AFBC, when perfected, is likely to be the coal-burning technology of choice for many industrial applications because pollution control is relatively easy to accomplish.

In addition, combustion control systems have been extensively applied to industrial operations and are expected to play an even greater role in the future. For example, in the combustion process, a given quantity of fuel requires a freed and easily measured quantity of air. Having an excess quantity of air or fuel results in either unused air being heated or incomplete combustion of the fuel. A computer control system could optimize the fuel:air ratio by controlling the rate at which each is introduced into the combustion chamber.

Electric Motors

Electric motors are the workhorses of the industrial sector. They power pumps, fans, and compressors, and drive heating and ventilation systems. In the industrial sector, motors use 65 to 70 percent of industrial electricity.[82] Pumps alone account for about 31 percent of total electricity used by electric motors in the United States.[83] Thus, there is a significant potential for energy savings.

Standard electric motor efficiency generally ranges from 80 to 90 percent. By increasing the iron and copper content of the core and windings, respectively, energy efficiencies can be improved to beyond 95 percent. This incremental increase may not seem significant at first blush, but even small increases in electric motor efficiency could translate into considerable savings. Electric motor capital costs are only a small fraction of their operating costs.[84] A typical large industrial motor uses electricity that costs 10 to 20 times its capital cost per year. Thus, even a 1 percent gain in efficiency could translate into significant savings.[85]

Crucial to achieving greater energy efficiencies with electric drive is the ability to control motor speed. Typically, pumps and fans need to vary speed to accommodate changing process needs. This is often done by operating the pump or fan at full speed and then throttling speed with a partly closed valve or damper. When this method is used, enormous energy losses are realized. According to one estimate, industrial and commercial pumps, fans, and compressors have average annual energy losses of 20 to 25 percent.[86] The adjustable-speed drive, which is commercially available, can improve efficiency by 10 to 40 percent.[87]

New high-efficiency motors can reduce magnetic, resistance, and mechanical losses by more than 50 percent, compared to the electric motor of a decade ago. The use of higher quality materials and innovative design have made these improvements possible. Together, high-efficiency motors and adjustable-

[82] Arnold P. Fickett, Clark W. Gellings, and Amory B. Lovins, "Efficient Use of Electricity," *Scientific American*, vol. 263, No. 3, September 1990, p. 67.

[83] Oak Ridge National Laboratory, op. cit., footnote 25, p. 68.

[84] U.S. Congress, Office of Technology Assessment, *Industrial Energy Use*, op. cit., footnote 8, p. 50.

[85] Fickett et al., op. cit., footnote 82, p. 67.

[86] Sam F. Baldwin, "Energy Efficient Motor Drive Systems," *Electricity: Efficient End-Use and New Generation Technologies and Their Planning Implications*, Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.) (Lund, Sweden: Lund University Press, 1989), p. 33.

[87] Fickett et al., op. cit., footnote 82, p. 68.

Table 2-7—Estimated Energy Used To Produce Paper and Paperboard Products (in million Btu per ton produced)

Product	From 100% virgin wood	From mixed recycled paper		Change due to recycling (percentage)
	Energy use	Minimum virgin fiber content (percentage)	Energy use	
Paper products:				
Newsprint	44.33	0	34.76	–21 .6
Printing paper	67.72	16	43.43	-35.9
Packaging paper	47.07	70	43.48	-7.6
Tissue paper	68.52	0	29.46	-57.0
Paperboard products:				
Liner board	14.46	75	36.28	+150.9
Corrugated board	37.22	0	36.28	-2.5
Box board	25.97	0	36.25	+39.6
Food service board	29.19	100	N/A	—
Other paper board	17.65	0	36.32	+105.8
Construction board	31.71	65	32.24	+1.7

SOURCE: T. Gunn and B. Hannon, "Energy Conservation and Recycling in the Paper Industry," *Resources* and *Energy* 5:243-260, 1983.

speed drives account for about half of the total potential energy savings in U.S. motors.[88]

Significant energy savings can also be realized by better matching motor size to the load, improved maintenance, and the use of controls to regulate, among other things, the electricity supplied to the motor and the torque transmitted to the machine.[89]

Pulp and Paper Industry

The pulp and paper industry is a major energy user. In 1985 (the most recent year for which data are available), the industry used 2.21 quads, making it the fourth largest energy user of primary energy in the industrial sector. A number of opportunities exist to improve efficiency. Several of the cross-cutting technologies discussed earlier can offer significant energy savings. For example, the use of computer control systems and sensors to optimize the combination of heat and chemicals can cut energy costs and improve pulp quality. In one mill, sensors and controls reduced steam requirements by 19 percent.[90]

Technologies that integrate fermentation into the conventional pulping process can also offer energy savings. They include biopulping, chemical pulping with fermentation and black liquor phase separation, and ethanol organosolv pulping. A substantial amount of research is still needed for each of these processes.

Recycling waste paper may provide further energy savings. Recycled waste paper, or secondary fiber, can be used to make various paper and paperboard products. Using recycled fiber for some paper products, like newsprint, printing paper and tissue, may require less energy. Savings can result from reducing energy demand in the process of making paper from waste paper and from a reduction in need to harvest and transport timber. However, savings could be offset by the energy needed to collect, transport, and de-ink the waste paper.[91] Based on studies done in the early 1980s, estimates of energy used to produce paper and paperboard products are shown in table 2-7.

According to the U.S. Environmental Protection Agency (EPA), paper and paperboard recovery totaled 18.4 million tons in 1988, a recovery rate of 25.6 percent. This compares to a recovery rate of 16.7 percent in 1970.[92] Paper and paperboard mills are the major consumers of secondary fiber.

[88]Ibid.

[89]Ibid.

[90]Marc H. Ross and Daniel Steinmeyer, "Energy for Industry," *Scientific American,* vol. 263, No. 3, September 1990, p. 94.

[91]For a more in-depth discussion of recycling technology and markets, see U.S. Congress, Office of Technology Assessment, *Facing America's Trash: What Next for Municipal Solid Waste?* OTA-O-424 (Washington, DC: U.S. Government Printing Office, October 1989).

[92]U.S. Environmental Protection Agency, *Characterization of Municipal Solid Waste in the United States: 1990 Update*, EPA/530-SW-90-042, June 1990, pp. ES-7, 11.

[93]Much of the information in this section is *drawn* from the OTA report, Industrial *Energy Use*, Op. Cit., footnote 8, pp. 99-100.

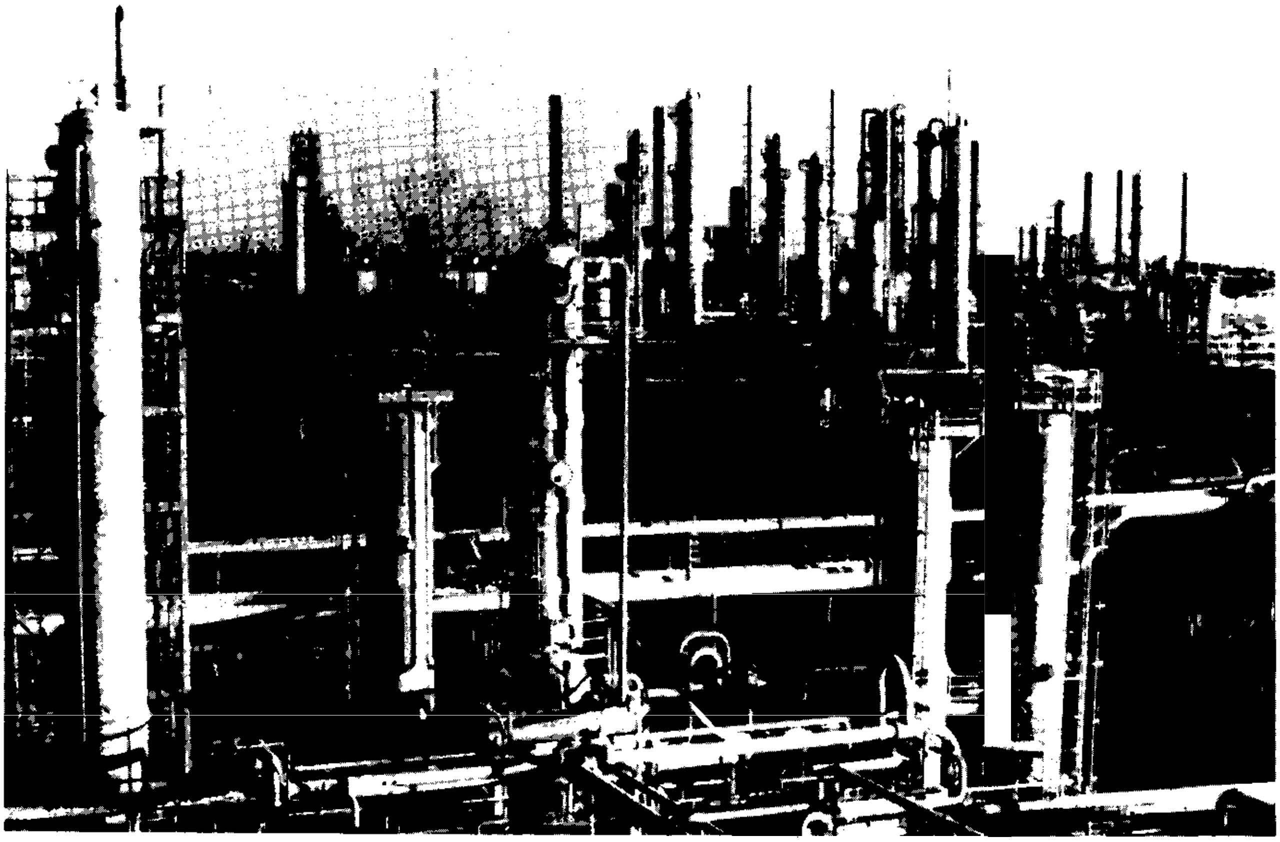


Photo credit: American Petroleum Institute and Exxon Corp.

A large petroleum refinery complex.

Petroleum Refining Industry[93]

A number of energy efficiency opportunities have been identified in the petroleum refining industry. The most productive options appear to be in the areas of improved combustion, the recovery of low-grade heat, and the use of process modifications.

The greatest single loss of energy in a refinery occurs during the final cooling of process streams. Where feasible, heated streams first could be used to heat other process streams, thus reducing the energy needed to cool. However, opportunities for recovering significant amounts of low-level heat are unlikely to be found in existing plants but in new facilities that are designed to optimize heat recovery. Opportunities focus on how to recover heat in the 200 to 250 degrees Fahrenheit range and improve heat exchange by better matching the heat source and heat sink. A 1985 survey indicated that improved heat exchange could reduce refinery energy use by about 9 percent. The survey also noted that process modifications could save up to 11 percent of energy use.[94]

Process heaters and steam boilers also offer opportunities for reducing energy use. Options include improving combustion by using stack gas analyzers and combustion control instrumentation; reducing stack gas temperatures by using air preheater to heat incoming combustion air; and installing convection sections at the heater outlets to heat incoming feed or to generate steam.

Continued improvements in computer control systems and sensors offer energy-savings benefits as well. In addition to reducing energy use, these

[94] R.O. Pelham and R.D. Moriarity, "Survey Plants for Energy Savings,' *Hydrocarbon Process*, vol. 64, No. 7, pp. 51-56; reported in Oak Ridge National Laboratory report, op. cit., footnote 25, p. 76.

systems improve performance, increase output, and optimize product specifications. A number of energy management control systems are available today. One control system company estimates that energy savings of 5 to 10 percent can be realized in the petroleum refining industry.[95]

Steel Industry

While the energy intensity of steelmaking has decreased over the years, steelmaking is still one of the most energy-intensive industries. The steel industry includes blast furnace-based integrated mills; nonintegrated minimills; and independent producers of wire, bars, and pipes who purchase and process semifinished steel.

All stages of steel production use energy to alter the chemical composition of the metal or to work the metal into useful forms and shapes. The industry has a number of options to save energy. These include the electric-arc furnace and continuous casting. The electric-arc furnace saves energy by allowing the substitution of scrap metal for iron ore. This method uses about 50-percent less energy than the blast furnace or basic oxygen furnace methods.

Continuous casting saves energy by eliminating the need for ingot stripping, heating, and primary rolling. Continuous casting reduces energy use by about 50 percent, as compared to ingot casting. Also, the yield is much greater than from ingot casting because less metal must be returned to the steelmaking process in the form of waste and unfilled ingot molds. Continuous casting increased from 12 percent in 1977 to 53 percent in 1986.[96] High product quality and yield and reductions in production costs are responsible for the increase.

A new steelmaking process—thin slab casting—is attracting the attention of the industry worldwide. This innovative process has the potential to reduce energy use and production time considerably. For example, the final slabs, which are only one-tenth of an inch thick, can be made in only 3 hours instead of as long as a week using conventional procedures. Steel industry analysts indicate that the process could change production methods throughout the industry. The first commercial use of thin slab casting in the United States is done at the NUCOR, Inc. plant in Indiana.[97]

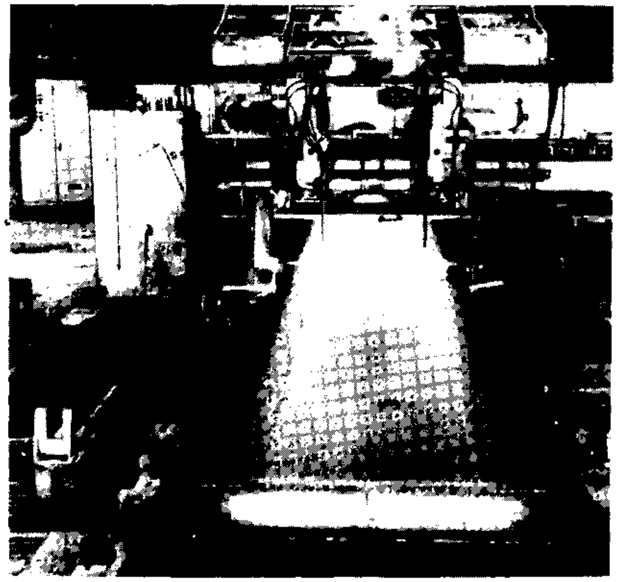


Photo credit: American Iron and Steel Institute

Steel slab emerging from a continuous slab caster.

Also, the innovative direct and ore-to-powder steelmaking processes could offer substantial energy savings. The direct steelmaking process replaces the coke-oven/blast furnace steps with one continuous process. The key to its success is effectively transferring heat from postcombustion to the bath. Another advantage of the direct steelmaking process is that it can use either iron ore or scrap. ORNL estimates that the process can reduce energy use by 20 to 30 percent and yield production rates that are two to three times higher than those of a blast furnace.[98]

The ore-to-powder steelmaking process eliminates the ore-melting process with magnetic separation and chemical leaching. ORNL estimates that this method may reduce energy use by 40 percent and decrease capital costs. The need for highly refined magnetic separation may be a technical barrier to using this method.[99]

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[95] Oak Ridge National Laboratory, op. cit., footnote 25, p. 78.

[96] Ibid., p. 86.

[97] "Making Steel Faster and Cheaper," *The New York Times*, Business Technology, Feb. 27, 1991, pp. D-6, D-7.

[98] Oak Ridge National Laboratory, op. cit., footnote 25, p. 88.

[99] Ibid.

Table 2-8-Technologies for Improving Energy Efficiency in the Steel Industry

Investment option	Energy efficiency-improving characteristics
Dry-quenching of coke	Recovers waste heat of hot coke from ovens; saves coke; reduces environmental pollution because coke is quenched in a closed system.
Coke-oven gas desulfurization	Natural gas substitute. Some loss of calorific value, but improved product quality.
Blast furnace top-gas turbine	Recovers waste energy by cogeneration. Only possible with the best high-pressure furnaces.
External desulfurization of hot metal	Saves coke by allowing lower slag volume and hot metal temperature in the blast furnace. Some energy used in desulfurization.
High-pressure blast furnace	Lowers coke consumption.
Electric-arc furnace (EAF)	Allows for increased use of scrap, thereby lowering overall energy requirements for steel production.
Water-cooled panel, EAF	Allows for higher productivity and net energy savings in melting when refractory consumption is considered.
Oxyfuel burners, EAF	Saves electrical energy and reduces melting time. Total energy consumption maybe increased.
Open hearth, shrouded, fuel-oxygen lances	Reduces fuel requirements in the open hearth. May prolong useful life of open hearth.
Basic oxygen furnace (BOF) gas collection	Recovers calorific value of carbon monoxide with net energy savings.
Scrap preheating, BOF	Allows for greater use of scrap, thereby saving energy in ironmaking.
Secondary, ladle refining, EAF	Saves electrical energy by removing refining function from EAF.
Closed system ladle preheating	Saves natural gas used for preheating ladles.
Continuous casting	Increases yield, thereby decreasing overall energy requirements; saves fuel gas in ingot reheating.
Thin slab casting	Has the potential to reduce energy use and production time.
Continuous slab reheaters	Saves clean fuel gas through increased efficiency.
Continuous annealing and reheating systems	Saves clean fuel gas through increased efficiency.
Direct rolling	Saves clean fuel gas through the elimination of slab reheating.
Indication heating of slabs/coils.	Allows fuel switching to electricity, conserves total energy, and increases yield.
Steam-coal injection into the blast furnace	Allows fuel switching from more expensive gas or oil. Technology should be available in 5 years.

SOURCE: Office of Technology Assessment, 1991.

A number of other opportunities are summarized in table 2-8. Many of these options require retrofitting existing equipment. Some of the energy-savings opportunities will result in additional benefits such as a reduction in environmental impacts and an improvement in product quality.

Chemicals Industry[100]

Of the four industries examined, the chemicals industry is by far the most complex. It produces several thousand products and uses the most energy of the four industries. Table 2-9 shows six of the most energy-intensive processes in chemical manufacturing.

Dramatic improvements in energy use can result from changes in physical separation. According to OTA, incremental improvements in the distillation process have achieved 25-percent energy savings in many plants.

Alternative approaches to conventional distillation include vacuum distillation, freeze crystallization, and liquid-liquid (solvent) extraction. The increased cost-effectiveness of turbocompressors and advances in vacuum pumps and cryogenic technology have vastly increased the relative attractiveness of both vacuum distillation and crystallization. The most appealing characteristic of freeze crystallization as a separation technique is that the process requires less energy. About 150 Btus are needed to freeze a pound of water compared to about 1,000 Btus to boil water in the conventional distillation process.

The most promising of the alternative approaches to conventional distillation appears to be liquid-liquid extraction, which uses a solvent with a high

[100] Much of the information in this section is drawn from the OTA report, *Industrial Energy Use*, Op. Cit., footnote 8, pp. 115.

Table 2-9--Energy-Intensive Processes in Chemical Manufacturing

Electrolysis includes all industrial electrolytic processes in which electricity is used in direct chemical conversion.

Fuel-heated reaction for processes that require some type of heat to force a chemical reaction to take place can be subdivided into low- and high-temperature operations. Energy sources include steam (except for high-temperature reaction), natural gas, residual oil, distillate oil, and even fluidized-bed coal combustion. Where precise temperature regulation is required, natural gas and distillate fuel oil are used.

Distillation processes include those that require physical separation of end products from both feedstocks and byproducts by evaporation and condensation.

Refrigeration includes processes that compress and expand a refrigerant, such as ammonia or a fluorocarbon, for the purpose of cooling feedstocks or products below ambient temperatures.

Evaporation includes those processes that use passive-evaporation cooling. In general, the evaporated water is lost to the atmosphere, and the heat energy is unrecoverable.

Machine drive is used by many chemical industry processes to pump, compress, or move feedstock and end product materials. Machine drive arises from electric motors, steam turbines, or gas turbines. A subcategory of machine drive processes-mixing and blending (especially in polymerization processes)--can be very energy intensive due to the high viscosity of the materials.

SOURCE: Office of Technology Assessment, 1991.

affinity for one component of a mixture but immiscible with the remaining components. One company reported that this technology saved an estimated 40,000 barrels of oil equivalent annually.

Also, the use of membrane separation technology in the chemicals industry is growing. The technology has been used to replace other more costly separation technologies such as cryogenics, pressure swing adsorption, and mercury or asbestos diaphragm electrolytic processes. One of its major advantages is that membrane separation systems can improve product quality.

Continued improvements in energy management and advances in computer control systems and sensors will contribute to reducing energy use in the chemicals industry. ORNL estimated that the development of a full component of sensors could reduce energy use by 10 to 15 percent in both the chemicals and pulp and paper industries.[101]

OPPORTUNITIES FOR ENERGY EFFICIENCY IMPROVEMENTS IN THE TRANSPORTATION SECTOR

Since the early 1970s, efficiency improvements in the transportation sector have been dramatic. The retirement of older, less efficient vehicles and the introduction of new, more efficient models have been responsible for these improvements.

The fuel efficiency of the new car fleet doubled between 1974 and 1989. The average fuel efficiency of the light-duty fleet should continue to rise over the next decade, but the rate of improvement will be slowed by a leveling off of further efficiency improvements in new vehicles. In the current OTA "business as usual" scenario, new car fleet economy for 2001 is 33 mpg.[102]

The energy intensity of commercial air travel has been cut by more than one-half since 1970, as a result of more efficient aircraft and operations. However, efficiency improvements in heavy truck transport has been less dramatic than those achieved by passenger cars.

In recent years, concerns about urban smog have renewed interest in alternative fuels. Energy security concerns have further stimulated interest in these fuels. Alternative fuels of primary interest for the U.S. light-duty fleet are methanol, ethanol, compressed or liquefied natural gas, hydrogen, and electricity. The advantages and disadvantages of these fuels are discussed later.

Automobile Efficiency

OTA has concluded that the fuel economy of the new car fleet could range from 29.2 to 30.3 mpg in 1995. With no fuel economy standards or other new policies that could alter fuel economy, such as gasoline taxes, and no significant changes in market forces, domestically manufactured new car fleet economy will be about 28.3 mpg. Total new car fleet economy will be about 29.2 mpg, assuming a 35-percent import share. OTA believes that the industry could realistically meet a higher level—30.3 mpg—for 1995.

Significant.ly higher levels of fuel efficiency in the long term (by 2010) can be achieved without drastic

[101] Oak Ridge National Laboratory, op. cit., footnote 25, p. 69.

[102] U.S. Congress, Office of Technology Assessment, *Improving Automobile Fuel Economy: New &a&r&, New Approaches,* forthcoming report.

shifts in size and performance, using only technologies that are generally expected to be commercialized shortly after the turn of the century. A fleet fuel economy of 45 mpg is possible. Some of the technology changes needed to achieve this fuel economy level include extensive use of aluminum and fiberglass reinforced plastics, 5-speed automatic transmissions, improved packaging, low-rolling resistance tires, and engine improvements, such as weight reduction of reciprocating engine components, low-friction pistons and rings, five-valve designs, and intake valve control.

By 2010 even higher levels of fuel efficiency are possible if significant technological advances are commercially available in the 2000-10 timeframe. For example, a fleet fuel economy of about 55 mpg can be attained if maximum weight and drag reduction and packaging efficiency benefits are fully exploited. Also, the direct-injection diesel engine and turbocharging must capture 20 percent of the small car market to realize this level of fuel efficiency.

Electric vehicles can make a major contribution to efficiency gains as well as urban air quality, but only if storage technology is improved to address consumer acceptance and cost considerations. A forthcoming OTA report, *Improving Automobile Fuel Economy: New Standards, New Approaches,* discusses indepth the potential for long-term automotive fuel efficiency.

Table 2-10 lists a number of technologies whose introduction or wider use offer the potential to improve fleet fuel efficiency. In addition, there are a number of technologies at various stages of development that appear to show promise of achieving large efficiency gains. For example, new designs of a two-stroke engine for automobile applications may be capable of achieving fuel economy gains of 11 to 14 percent over conventional four-stroke engines. However, questions remain about the ability of the engine to comply with emissions standards. The advanced two-stroke engine employs direct injection of fuel and forced air scavenging. Due to forced air scavenging, the exhaust stream is lean, and the technology (three-way catalysts) for reducing NO_x emissions is not yet available. This problem may be solved with better control of airflow, and it appears possible that with further development the engine can meet future NO, standards.[103]

Other engine designs said to hold considerable promise include direct-injection diesels and low-heat rejection engines (also called adiabatic diesels). The direct injection (DI) diesel has seen limited passenger car application in Europe. The DI diesel was rated by Volkswagen and Mercedes Benz as being 12 to 15 percent more efficient than the indirect injection (prechamber) diesel. Previous problems meeting nitrogen oxide and particulate emissions standards have been solved. Audi plans on introducing a direct injection diesel in the United States.[104] Stricter emissions requirements could pose a problem, however.

Adiabatic diesels eliminate the cooling system required by current engines and insulate cylinders and pistons to retain thermal energy within the combustion chamber and exhaust system. The ability of this and other diesel engines to meet more stringent emissions standards is in some doubt.

Heavy-Truck Efficiency

Opportunities for heavy-truck fuel efficiency gains include better aerodynamics, reduced rolling resistance, and the development of adiabatic diesels. In a conventional diesel engine, about 25 percent of the fuel energy is lost as waste heat to the cooling and lubricating of fluids, and another 35 percent is lost as waste heat in exhaust gases. The adiabatic engines offer the greatest potential for improving efficiency of freight transport. It may be capable of achieving 40 to 50 percent decreases in energy lost to waste heat.[105]

The ceramic gas turbine has also be identified as a potentially attractive heavy-duty engine because of its anticipated fuel efficiency and flexibility.

Aircraft Efficiency

Passenger travel by commercial jet aircraft has more than tripled since 1970. At the same time, energy use increased only by about 43 percent. Higher load factors, improved engine efficiencies

[103] Energy and Environmental Analysis, "An Assessment of Potential Passenger Car Fuel Economy Objectives for 2010,' contractor report prepared for the U.S. Environmental Protection Agency, February 1991, pp. 4-21,4-22.

[104] Ibid., p. 4-24.

[105] Oak Ridge National Laboratory, op. cit., footnote 25, p. 3.

Table 2-10--Reported Efficiency Improvements for Developed or Near-Term Technology

	Percent improvements over 1987 base[a]		
Technology	EEA estimates (% F/E benefit)	Industry estimates (% F/E benefit)	Comment[b]
Front-wheel drive	10.0	0.5-1.0	Over 1970s rear wheel drive vehicles
Drag reduction	2.3	2.0	Per 10 percent coefficient of drag reduction
4-speed auto transmission	4.5	3.0	Widely used in 1988
Torque converter lock-up	3.0	1.5-2.0	WIdely used in 1988
5-speed auto transmission	2.5	0.1-2.0	Over 4-speed automatic transmission
Electronic transmission control	0.5	0.5	For automatic transmission only
Continuously variable transmission (CVT) only.	3.5	1.0-2.5	Over 4-speed automatic transmission oars only
Accessories	-0.5	1.0	Varies between 0.3 and 0.7 depending on market class
oil (5W-30)	0.5	0.2	Already used in some large oars
Advanced tires	0.5	1.0	—
Engine improvement			
Fuel injection			
—Throttle-body fuel injection	3.0	3.0	Widely used
—Multipoint fuel injection (over throttle body injection)	3.0	1.0-3.0	Widely used
Overhead camshaft	6.0	1.0-3.5	Over old overhead valve design
Roller cam followers	2.0	3.0	Widely used in domestic oars
Low-friction pistons/rings	2.0	2.0	Except for specific engines already incorporating technology
4 valves per cylinder engine	5.0	1.0-3.5	At constant performance
4 cylinder replacing 6[d]	8.0	(-2.0)-0.5	At constant performance
6 cylinder replacing 8[d]	8.0	1.0-3.5	At constant performance
Intake valve control	6.0	1.5-3.0	Synergistic effects with 5-speed auto/CVT

[a]The list of technology benefits cannot be summed to provide an overall benefit.

[b]Ford Motor Co.'s explanations for the significant differences between EEA and industry estimates:

Front-wheel drive—Ford's analyses and data indicate that front-wheel drive provides a small potential for fuel economy improvement because of a slight reduction in vehicle weight (60 pounds) for mid-size and smaller cars. Ford rear-wheel drive models introduced since the late 1970s are 660 pounds lighter than their predecessors. There are no technological reasons for a net efficiency gain with front-wheel drive.

4 valve over 2 valve engine—Based on U.S. Environmental Protection Agency data, Ford indicates that the average fuel economy improvement is 3 percent for equal performance engines which have incorporated 4-valve designs. The 10:1 compression ratio assumed by EEA may not be appropriate for all vehicles.

4 cylinder replacing 6 cylinder; 6 cylinder replacing 8 cylinder-Reducing the number of cylinders will reduce engine friction but increase lugging speeds. As a result, 4-cylinder engines tend to have higher idling speeds and thus lower fuel economies than 6-cylinder engines; 6-cylinder engines have slightly higher lugging speeds than 8-cylinder engines. Thus, no substantial fuel economy effect is realized by replacing 8 cylinders with 6.

Intake valve control-Systems that provide 6 percent fuel economy benefits are not suitable for typical engines because they severely compromise wide-open throttle performance.

[c]Because newly designed engines all have multiple improvements, the efficiency benefits representad by individual changes are not easily separated.

[d]1987 Distribution: 20.5 percent-V-8; 29.5 percent—V-6; 50 percent-4 cylinder)

KEY: EEA = Energy and Environmental Analysis. F/E = Fuel efficiency.

SOURCES: Energy and Environmental Analysis, "AnAssessment of Potential Passenger Car Fuel Economy Objectives for 2010," contractor report prepared for the U.S. Environmental Protection Agency, February 1991; and the Ford Motor Co.

and aerodynamics doubled seat-mile per gallon efficiencies.[106]

Aircraft efficiency will continue to improve as newer, more efficient planes replace the older, less efficient ones. For example, the Boeing 747-400 and the 737-500 are 10 to 20 percent more efficient than the equipment they replaced. Also, advances in engine technology, aerodynamics, controls, and structural materials for frames and high-temperature materials for engine components will be required to achieve improvements in fuel efficiency in the future.

Engines

The ultrahigh-bypass turbofan engine achieves greater thrust per pound of fuel used by sending as little as 15 percent of the air entering the engine shroud through the combustor. The remainder passes around the core and is accelerated by turbine engine-driven fans.

Ducted ultrahigh-bypass engines have yielded efficiency improvements of 10 to 20 percent. Unducted, or propfans, using advanced propeller designs, can achieve 20 to 30 percent efficiency

[106]Ibid., p. 5.

improvements over current high-bypass turbofan engines. However, these advanced engines cost twice as much as current-generation high-bypass engines.[107]

Improvements in engine efficiency are dependent on the development of high-temperature materials, such as metal matrix and ceramic matrix composites. These materials will allow higher turbine inlet temperatures, reduce the need for airfoil cooling, permit higher pressure ratios, and reduce engine weight. Because these ceramic materials are subject to brittleness and sensitive to flaws, they are currently not being used. To achieve advanced engines' efficiency gains, research will have to focus on high-temperature materials.

Aerodynamics and Aircraft Weight

Further reductions in aerodynamic drag and airframe weight are needed to achieve future energy efficiency improvements. Advances in computer hardware and software programs will enable engineers to optimize aircraft design. In addition, controlling air flow to minimize turbulence is necessary to improve efficiency. Some promising concepts include using suction on key wing surfaces to smooth airflow and changing wing shapes to adapt to changes in speed, altitude, and weight. Perhaps the most promising concepts involve putting grooves in the portion of the wing in front of the spar, through which air is vacuumed to reduce turbulence, with ultrasmooth wing surfaces behind to maximize the area of naturally laminar flow. It is expected that some of these wing concepts will be introduced in the early 1990s. Two of Airbus' new models will include variable-camber wings that adapt their profiles automatically during flight to match changes in weight, speed, and altitude.[108]

In addition, composite materials have the potential for reducing frame weight by 30 percent with equal or better structural strength. Today, composite materials are used only for a limited number of components such as vertical fins and the horizontal surfaces of sailplanes. It is possible that future advances could enable planes to be constructed of 80-percent composites by the 21st century.[109]

Alternative Fuels[110]

Alternative fuels of primary interest for the U.S. light-duty fleet are:

- reformulated gasoline,
- alcohol fuels-methanol and ethanol,
- compressed or liquefied natural gas (CNG or LNG),
- hydrogen, and
- electricity.

Interest in these fuels is based on their potential to address environmental and energy security concerns. The use of alternative fuels as a substitute for gasoline is being promoted by EPA, the California Energy Commission, and others as a way to address these concerns.

Much is already known about alternative fuels. Not surprisingly, each of these fuels has disadvantages as well as advantages. Aside from fuel cost, the major barrier that most alternative fuels must overcome is the need to compete with the highly developed technology and massive infrastructure that exists to support the production, distribution, and use of gasoline as the primary fleet fuel. Concerns about the performance and range of vehicles that use alternative fuels are also barriers to introduction and public acceptance. Nevertheless, each of the suggested alternative fuels has one or more features, e.g., high-octane, low emissions potential, that imply some important advantage over gasoline in powering vehicles. Table 2-11 presents some of the tradeoffs among the alternative fuels relative to gasoline.

The technologies for producing alternative fuels are still developing and changing. Ongoing research and development programs are attempting to address technical problems and reduce overall costs. For example, the success of ongoing research on low-cost manufacture of ethanol from wood waste would radically improve ethanol's environmental and economic attractiveness. The outcome of this and other research initiatives is still uncertain.

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[107] Ibid., p. 6.

[108] Ibid., p. 7.

[109] Ibid.

[110] Much of the information in this section is drawn from U.S. Congress, Office of Technology Assessment, *Replacing Gasoline: Alternative Fuels for Light-Duty Vehicles, OTA-E-364* (Washington, *DC:* U.S. Government Printing Office, September 1990).

Reformulated Gasoline

Reformulated gasoline is gasoline that has been reblended specifically to reduce exhaust and evaporative emissions and/or to reduce the photochemical reactivity of these emissions. It is appealing because it requires no vehicle adjustments or new infrastructure, aside from modifications to existing refineries. Although reformulated gasoline is now being sold in many locations in the United States, these gasolines

Table 2-1 l—Pros and Cons of Alternative Fuels

Fuel	Advantages	Disadvantages
Methanol	• Familiar liquid fuel. • Vehicle development relatively advanced. . Organic emissions (ozone precursors) will have lower reactivity than gasoline emissions. • Lower emissions of toxic pollutants, except formaldehyde. • Engine efficiency should be greater. • Abundant natural gas feedstock. • Less flammable than gasoline. • Can be made from coal or wood (as can gasoline), though at higher cost. • Flexfuel "transition" vehicle available.	• Range as much as one-half less, or larger fuel tanks. • Would likely be imported from overseas. • Formaldehyde emissions a potential problem, especially at higher mileage, requires improved controls. • More toxic than gasoline. • Ml 00 has nonvisible flame, explosive in enclosed tanks. • Costs likely somewhat higher than gasoline, especially during transition period. • Cold starts a problem for M1OO. • Greenhouse problem if made from coal.
Ethanol	• Familiar liquid fuel. • Organic emissions will have lower reactivity than gasoline emissions (but higher than methanol). • Lower emissions of toxic pollutants. • Engine efficiency should be greater. • Produced from domestic sources. • Flexfuel "transition" vehicle available. • Lower carbon monoxide with gasohol (1 O percent ethanol blend). • Enzyme-based production from wood being developed.	• Much higher cost than gasoline. • Food/fuel competition at high production levels. • Supply is limited, especially if made from mm. • Range as much as one-third less, or larger fuel tanks. • Cold starts a problem for E1OO.
Natural gas	• Though imported, likely North American source for moderate supply (1 mmbd or more gasoline displaced). • Excellent emission characteristics except for potential of somewhat higher nitrogen oxide emissions. • Gas is abundant worldwide. • Modest greenhouse advantage. • Can be made from coal.	• Dedicated vehicles have remaining development needs. • Retail fuel distribution system must be built. • Range quite limited, need large fuel tanks with added costs, reduced space (liquefied natural gas (LNG) range not as limited, comparable to methanol; LNG disadvantages include fuel handling problems and related safety issues). • Dual fuel "transition" vehicle has moderate performance, space penalties. • Slower refueling. • Greenhouse problem if made from coal.
Electric	• Fuel is domestically produced and widely available. • Minimal vehicular emissions. • Fuel capacity available (for nighttime recharging). • Big greenhouse advantage if powered by nuclear or solar. . Wide variety of feedstocks in regular commercial use.	• Range, power very limited. • Much battery development required. • Slow refueling. • Batteries are heavy, bulky, have high replacement costs. • Vehicle space conditioning difficult. • Potential battery disposal problem. • Emissions for power generation can be significant.
Hydrogen	• Excellent emission characteristics, minimal hydrocarbons. • Would be domestically produced. • Big greenhouse advantage if derived from photovoltaic energy. • Possible fuel cell use.	• Range very limited, need heavy, bulky fuel storage. • Vehicle and total costs high. • Extensive research and development effort required. . Needs new infrastructure.
Reformulated gasoline.. . . .	• No infrastructure change except refineries. • Probable small to moderate emission reduction. • Engine modifications not required. • May be available for use by entire fled, not just new vehicles.	• Emission benefits remain highly uncertain. • Costs uncertain, but will be significant. • No energy security or greenhouse advantage.

SOURCE: Office of Technology Assessment, 1991, have been rushed into the market in advance of research results, and their formulations may change as ongoing research begins to identify optimal gasoline formulae.

Methanol

Methanol, which is commonly known as wood alcohol, is a light volatile flammable alcohol usually made from natural gas but can be manufactured from coal and biomass. It has an energy content of about half that of gasoline (i.e., the fuel tank has to be twice as big for the same range), an octane level of 101.5, and a much lower vapor pressure than gasoline.

The advantages of methanol include its potential to reduce urban ozone, particularly in cities that have significant smog, and its high-octane level, which allows higher (or leaner) engine air-fuel and compression ratios. Engines that operate at leaner air-fuel and higher compression ratios are more fuel efficient.

One of its disadvantages is its potentially high price in relation to current gasoline prices. The economic competitiveness of methanol continues to be a source of controversy. Estimates of methanol costs have ranged from competitive with gasoline to much higher than gasoline. OTA concludes that methanol will most likely be more expensive than gasoline in the early stages of an alternative fuels program. Without government guarantees, methanol's gasoline-equivalent price is likely to be at least $1.50/gallon. During the initial period, government guarantees could bring the cost down to as low as /$1.20/gallon if natural gas feedstock costs were very low. Costs of manufacturing methanol from coal will be much higher. A recent report by the National Research Council estimates methanol-from-coal's crude oil equivalent price to be over $50/barrel, and methanol from wood, over $70/barrel.[111]

Another disadvantage of methanol is its low vapor pressure, which is problematic for cold weather starts. Also, methanol is more toxic than gasoline. It is absorbed through the skin more quickly than gasoline, but prolonged or frequent contact is necessary for acute symptoms to appear.[112]

Methanol is the most "ready" of the alternative fuels. Methanol for chemical use has been produced for many decades and thus production technology is well known. Recent attention has focused on the potential for using methanol as an automotive fuel, either 100 percent methanol or mixed with up to 15-percent gasoline. Vehicle technology capable of burning a gasoline/methanol blend has been demonstrated and could be produced in a few years. Work is continuing on improving the efficiency, driveability, and emissions characteristics of methanol-burning engines.

A number of cities and States have expressed interest in methanol use. California, for example, has a program to stimulate the development of a fleet of methanol-capable vehicles. Moreover, Congress has passed measures to stimulate development and sales of methanol-powered vehicles, and is considering legislation to develop alternative-fueled fleets in cities suffering from ozone problems.

Ethanol

Ethanol is a grain alcohol that is produced by fermenting starch and sugar crops. It has an energy content of about two-thirds that of gasoline and, like methanol, an octane level of 101.5, and a much lower vapor pressure than gasoline. Because of its high octane level, an ethanol-powered vehicle will outperform an equivalent gasoline vehicle and provide some improvement in energy efficiency.

Ethanol made from food crops would be the most expensive of the major alcohol fuels. Even so, it has managed to gain support because of its potential contribution to the agricultural economy. Every year, nearly 1 billion gallons of ethanol are added to U.S. gasoline stocks to create gasohol. The addition of small quantities of ethanol to gasoline is viewed primarily as a means to reduce carbon monoxide emissions; the use of 100-percent ethanol is viewed as a means to reduce concentrations of ozone in urban areas.

Improvements in the current production system are needed to enhance ethanol's prospects for use in transportation. SERI and others are conducting R&D on ethanol-from-biomass production processes and have achieved important advances. SERI

[111] Committee on Production Technologies for Liquid Transportation Fuels, National Research Council, "Fuels To Drive @T Future" (Washington, DC: National Academy Press, 1990).

[112] P.A. Machiele, "A Perspective on the Flammability, Toxicity, and Environmental Safety Distinctions Between Methanol and Convention Fuels,'" American Institute of Chemical Engineers 1989 Summer National Meeting, Philadelphia, PA, Aug. 22, 1989.

recently formed a cooperative partnership with the New Energy Co. of South Bend, Indiana, to commercialize the process developed by SERI. SERI hopes to be able to produce ethanol-horn-biomass for no more than $25/barrel of oil equivalent by the end of the decade.[113]

Currently, ethanol production is profitable because the Federal Government and about one-third of the States subsidize ethanol use by partly exempting gasohol (a 90-percent gasoline/10-percent ethanol blend) from gasoline taxes. The current Federal Government subsidy amounts to $0.60/gallon. Under certain market conditions, ethanol production may reduce Federal crop subsidies and generate secondary economic benefits to the Nation. However, it also may generate large secondary costs by promoting crop expansion onto vulnerable, erosive lands.

Natural Gas

Either compressed or liquefied natural gas can serve as an alternative fuel for vehicles. There are about 700,000 CNG vehicles in use worldwide, with the largest group in Italy. Generally, natural gas-powered vehicles are gasoline vehicles retrofitted to use either gasoline or natural gas. At current prices, dual-fueled vehicles are not cost competitive with gasoline-powered ones in most uses, and they will not become so unless oil prices rise sharply while gas prices stay low or gasoline is heavily taxed.

Most of these dual-fueled vehicles have less power and some driveability problems when powered by natural gas. The power loss and drivability problems are due to the design and/or installation of the retrofit components. Improvements in power and driveability can be realized with more sophisticated retrofit kits or in factory-built, dual-fueled vehicles. Nevertheless, dual-fueled vehicles will have a difficult time competing with gasoline vehicles or vehicles fueled with other, higher energy density fuels.

Single-fueled vehicles optimized for natural gas use are likely to be more attractive in terms of performance and somewhat more attractive in terms of cost. The cost of pressurized storage will make the vehicles more expensive (about $700 to $800 more) than a similar gasoline-powered vehicle. A natural gas-powered, single-fuel vehicle should be capable of similar power, similar or higher efficiency, and substantially lower carbon dioxide (CO_z) emissions but somewhat higher NO_x emissions than an equivalent gasoline-powered vehicle. Natural gas-powered vehicles have the potential to leak methane, which is the prime constituent of natural gas. Methane is a more powerful greenhouse gas per molecule than CO_z. In addition, the range of natural gas-fueled vehicles will continue to be unattractive compared to gasoline-fueled vehicles.

The Ford Motor Co. has done extensive work with CNG vehicles, including light-duty car and trucks, as well as heavy-duty trucks.

Hydrogen

Hydrogen, which is the lightest gas, has a very low energy per unit of volume because it is so light, but it has the highest energy content per pound of any fuel. It can be used in a fuel cell and in internal combustion engines. Hydrogen is available from a number of sources. It can be produced from hydrocarbons or from water by several processes: 1) coal gasification; 2) combining natural gas and steam (steam reforming); 3) applying high temperatures, with or without chemicals, to water (thermal and thermochemical decomposition); 4) adding an electrolyte and applying a current to water (conventional electrolysis; potential sources of the electricity are discussed in chapter 3), or by electrolyzing steam rather than water (high-temperature steam electrolysis), or by using light with a chlorophyll-type chemical to split out the hydrogen (photolysis) from water. Currently, steam reforming of natural gas is the least expensive production method.

Hydrogen's primary appeal is its cleanliness and, ultimately, its enormous resource base (water). A hydrogen-powered vehicle should emit virtually no hydrocarbons, particulate, sulfur dioxide, CO_z or carbon monoxide, and only moderate NO_x emissions. Disadvantages of using hydrogen include its high cost, and low energy density (one-sixth that of gasoline), and the need for onboard vehicle storage. Onboard storage can be either in the form of heavy and bulky hydrid systems that will adversely affect range and performance, or in bulky cryogenic systems that will reduce available vehicle space. Both are expensive.

[113] "SERI Signs First Cooperative R&D Agreement," *New Technology Week*, vol. *5, No. 19, May 6, 1991*, p. 8.

The thermal efficiency of a hydrogen-powered engine should be at least 15 percent higher than an equivalent gasoline engine, and even higher in a fuel cell. As with other fuels, engine efficiency, performance, and emissions are interdependent, and maximizing one may increase or decrease the others. For example, operating very lean will increase efficiency but decrease power and driveability.

The development of a hydrogen-fueled fleet is still in the early stages of research. Work needs to be done on storage and delivery systems, large-scale production systems, and engines. The production system with the largest resource base--coal gasification-may be the closest to becoming fully commercial. (The Lurgi gasifier is fully commercial and some others are arguably commercial.) However, coal gasification will create substantial negative impacts from CO_z emissions. The Cool Water integrated coal gasification combined cycle plant has performed extremely well, and the next generation technology is expected to achieve substantial improvements in cost and efficiency. The Japanese and West Germans have strong hydrogen vehicle development programs, but they have produced only a small number of prototype vehicles. Major uncertainties remain about the configuration and performance of a hydrogen engine. Also, a breakthrough in storage technology may be needed, and work needs to be done on pipeline transport because pure hydrogen will damage certain steels. Inhibiting agents to be added to hydrogen must be found, or a separate pipeline infrastructure must be built.

Electricity

The use of electricity as a fuel has several advantages: available and adequate supply infrastructure, with the exception of home charging stations, and virtually no vehicular emissions. The latter advantage can be particularly important in polluted areas. Pollutants that are emitted at generating stations that must be operated to charge the batteries often play only a minor role in urban air quality, but do contribute to problems associated with long-range pollution transport, particularly acid rain and degradation of visibility. OTA has concluded that a fleet of several tens of millions of vehicles could be supported by existing generating capacity, assuming that vehicles would be recharged at night when electricity demand from most other uses is low.

Disadvantages of electric vehicles (EVS) using current technology, in particular lead-acid batteries, include limited range, performance and capacity. Most EVs built to date have required recharging at about 100 miles or less. They are also expensive to buy and may require a special charger. DOE estimates the cost for a home recharging station to be $400 to $600.

Improving the prospects for electric vehicles in the marketplace will depend on extending their range considerably and upgrading performance in a variety of traffic situations. This can be accomplished by improving battery and powertrain technologies. The outlook for significant improvements in commercial battery technology appears promising, but uncertainties remain about costs and the environmental implications of disposing and recycling associated with battery production. The advanced batteries necessary for successful EV penetration in the urban market are too far away from mass production to allow reliable cost estimates to be made. A number of advanced battery types show promise. These include nickel/iron, nickel/cadmium, zinc/bromide, lithium/iron sulfide, sodium/sulfur, and metal-air.

Some analysts consider the nickel/iron battery very promising for the next generation of electric vehicles because it has demonstrated long lifecycle and ruggedness. This battery type, however, produces large quantities of hydrogen during recharge, uses a lot of water, and is relatively inefficient. Leading European battery developers have halted developmental work on nickel/iron batteries. The high-temperature sodium/sulfur battery offers much higher energy and power densities than lead/acid and nickel/iron types. Also, it has no water requirement, does not produce hydrogen when recharging, and has very high charging efficiencies. In the long term, the metal air battery holds some promise. This battery type has high power density and can be recharged rapidly by replacing the metal anodes, adding water, and removing byproducts. However, metal-air batteries are the farthest from commercial readiness.

A consortium was recently formed to accelerate research on EV batteries. The consortium consists of the three U.S. automakers, the Electric Power Research Institute (EPRI), and several utilities. The members have proposed a 4-year, $300-million R&D project that will focus on reducing or holding

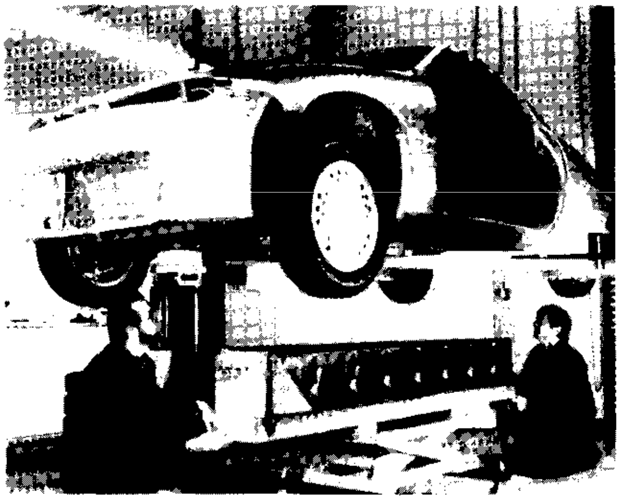

Photo credit: General Motors Corp.

General Motors' prototype electric vehicle, the Impact. The Impact's battery pack, shown being installed, takes up the center portion of the vehicle. The current range of the vehicle is over 100 miles between charges. With improved batteries-a key hurdle facing this technology-both range and efficiency would increase.

the line on battery costs, reducing weight, and increasing power capacity. DOE will provide 50 percent of the funding and participate in the project, although it is not a member of the consortium.[114]

Over the years, interest in EVs has fluctuated, but recent concerns about air quality have put this technology back on the R&D agendas of U.S. automakers. In January 1990, General Motors introduced the Impact, its most recent electric-powered car design. According to General Motors, the Impact has a range of 120 miles at average highway speeds of 55 mph. Battery charging can be done by simply plugging in an onboard charger and will require about 2 hours to complete. General Motors has not announced production plans, and cost information is not available.[115]

In addition, EPRI and the Chrysler Corp. recently announced plans to develop an electric-powered minivan suitable for passenger or light-service work. The Chrysler electric-powered minivan will have a top speed of 65 miles per hour and will be able to go 120 miles between charging. It will use a nickel/iron battery with an onboard charging unit. Chrysler hopes to begin production and marketing by 1994.[116] EPRI and General Motors also have a similar ongoing project. Production of the General Motors electric-powered van has just begun.[117]

Also, hybrid electric vehicles have been attracting attention as a way to exploit the respective advantages of gasoline and electricity. For example, in one type of hybrid, an electric motor provides the motive power, and a small gasoline-powered engine is used as an electric generator to provide the range. In another type of hybrid, a small gasoline-powered engine provides the motive power with an electric motor providing additional power. Yet another hybrid is the fuel cell-powered electric vehicle. A fuel cell is used to charge the battery and an electric motor provides the motive power. The fuel cell can operate on hydrogen or reformulated methanol.

Fuel cell hybrids are at an early stage of development. Concerns about fuel cell cost and weight and low power density represent important market barriers that will have to be addressed before the use of vehicle fuel cell systems is a viable option.

OTHER FACTORS THAT AFFECT ENERGY USE

Environmental Concerns

Recent concerns about environmental problems such as air pollution, ozone depletion, and the greenhouse effect could influence how buildings use energy and how buildings get energy. For example, the recently signed international agreement, the Montreal Protocol,[118] set out a schedule for reducing production and consumption of many chlorofluorocarbons (CFCs), the major source of ozone depletion. The Montreal Protocol requires participating countries with high CFC use per capita (greater than 0.3 kilograms) to reduce production and consumption of the most common CFCS-CFC-11 and

[114] "The United States Advanced Battery Consortium Has Filed Notices," *Inside Energy/With Federal Lands, Mar.* 11,1991, p. 10; and "DOE Plans Increase in Commitment to Electric Vehicle Battery R&D," Jan. 14, 1991, pp.5-6.

[115] General Motors Corp., *Impact — Technical Highlights,* Jan. 3, 1990.

[116] "EPRI Inks Contract With Chrysler To Build Electric-Powered Minivan," *Electric Utility Week,* Jan. 14, 1991, p. 7.

[117] Ibid.

[118] In response to growing international concerns about CFCs destroying stratospheric ozone, 47 nations reached agreement on a set of CFC control measures in September 1987. A significantly stronger version was adopted in June 1990.

CFC-12-by 20 percent of 1986 levels in the next 3 years, and to achieve a 50-percent reduction by 1997, and a 100-percent phaseout by the year 2000.

CFCs are used primarily in refrigeration systems, including automobile air conditioners, refrigerators, and centrifugal chillers, and in building insulation foams. In the United States, refrigeration accounts for 80,000 tons of CFCs used per year, or about 22 percent of the total. A typical refrigerator contains about 1/2 pound of CFC in its cooling systems and 2½ pounds in its foam insulation.[119] CFCs are released during the manufacturing process, servicing and disposal of air-conditioners and refrigerators. Some CFCs used in insulating foams are also released during the manufacturing process, but most remain in the foam and slowly leak out over time. Therefore, a large reservoir of CFCs exist within buildings.

Alternatives to CFC insulation and refrigerants are available, and others are being developed. The chemicals industry is developing manufacturing processes for these products. In addition, alternative building designs and construction techniques can reduce the need for air-conditioning and supplemental insulation. Also, using air-conditioning technologies based on waste heat or solar energy can exploit alternative ways to maintain comfortable temperatures in buildings.

In the transportation sector, concern about urban smog and the greenhouse effect may have an impact on vehicle energy efficiency. The new more stringent emission standards, especially for NO_x will force manufacturers to tradeoff cost, fuel efficiency, and emissions. Historically, manufacturers have pursued a variety of strategies to achieve previous standards. For example, to meet the 1981 emissions standards, many Japanese manufacturers chose to use oxidation catalyst technology and accepted an efficiency loss of 6 to 8 percent; General Motors met the same standard with "closed loop" electronic fuel control systems with three-way catalysts that incurred no efficiency loss. The effect of the new NO_x standard (0.4 grams/mile) on fuel efficiency is not clear-cut. One OTA contractor, Energy and Environmental Analysis, Inc., estimated the potential fuel economy penalty (or gain foregone) to be about 1 percent, with significant variation possible, depending on how the manufacturers choose to trade off efficiency and costs.[120] Another OTA contractor, Sierra Research, indicates that automakers need not sacrifice efficiency if they are willing to add more catalysts, at a cost of about $100.

Environmental and, most recently, energy security concerns have renewed an interest in alternative transportation fuels as a way of reducing ozone levels in urban areas and decreasing U.S. reliance on foreign oil supplies. The oil crises of the 1970s spurred a number of Federal initiatives to supplement or replace gasoline with alternative fuels produced from domestic coal and oil shale. These initiatives, which were generally not viewed as successful, were largely abandoned in the early 1980s.

In September 1990, the California Air Resources Board approved a smog control plan that is expected to reduce hydrocarbon emissions by 28 percent, nitrogen oxide by 18 percent, and carbon monoxide by 8 percent by the year 2000. The plan phases in progressively cleaner vehicles, which could include compressed natural gas vehicles and 'flexible-fuel' cars, and requires the production of electric vehicles. A number of other States are considering similar standards, which are stricter than the recently passed clean air standards.

Appliance Efficiency Standards

Appliance efficiency standards will also have an impact on energy efficiency. The Federal Government and several States have enacted minimum efficiency standards for residential appliances. Although NAECA does not set standards as high as can be achieved by the best currently available technology, it does require that standards be reviewed and allows for raising them. Standards for refrigerators, freezers, and small gas furnaces have been promulgated. Standards for other appliances are being developed.

In the 1970s, California took the lead by adopting efficiency standards for a wide range of products, including refrigerators, freezers, air conditioners, and heat pumps. Even tougher standards were adopted by the California Energy Commission in the mid-1980s. In 1987, the National Appliance Energy Conservation Act of 1987 (NAECA) set minimum

[119] Houghton, op. cit., footnote 52.

[120] K.G. Duleep, Director of Engineering at the Energy and Environmental Analysis, Inc., personal communication.

Table 2-12-Cumulative Energy Impacts of the National Appliance Energy Conservation Amendments of 1988, 1990 to 2015

Department of Energy region	Base case		Savings			
	Electricity (TWh)	All fuels (quads)	Electricity (TWh)	All fuels (quads)	Electricity (%)	Savings all fuels (%)
New England	1,261	18.1	13	0.1	1.0	0.7
New York/New Jersey	1,833	28.6	27	0.3	1.5	1.0
Mid Atlantic	3,464	30.9	69	0.2	2.0	0.8
South Atlantic	9,112	21.8	320	0.1	3.5	0.4
Midwest	5,234	63.1	110	0.5	2.1	0.8
Southwest	4,022	23.1	135	0.2	3.4	0.8
Central	1,584	14.3	38	0.1	2.4	0.7
North Central	1,312	13.3	20	0.1	1.5	0.7
West	3,423	26.9	61		1.8	
Northwest	2,087	5.8	29	0.3/(0.0)	1.4	(0.3)
Total	33,332	245.8	822	1.9	2.5	0.8

SOURCE: Lawrence Berkeley Laboratory, "The Regional and Economic Impacts of the National Appliance Energy Conservation Act of 1987," Berkeley, CA, June 1988.

efficiency (or maximum consumption) standards for many appliances[121] and will result in the least efficient appliances being taken off the market. The standards, which apply at the point of manufacture, vary according to product type and size.

The initial Federal standards are relatively stringent. For example, of all classes of refrigerators, refrigerator-freezers, and freezers, only 7 models out of 2,114 listed in the Association of Home Appliance Manufacturers directory meet the 1993 standards. Most models will have to be improved or redesigned over the next 2 years. Thus, the standards could have a significant impact on residential energy use in the future. The American Council for an Energy Efficient Economy estimated that by 2000, the standards will reduce U.S. residential energy use by about 0.9 quads/year and peak summer demand by 21,000 MW.[122]

LBL also estimated the impacts of the appliance standards on energy use. Table 2-12 shows the energy impacts by region by the year 2015. A reduction in electricity use is the primary benefit of the standards. According to LBL, the standards will save 2.8 quads of electricity; the percentage savings for all other fuels are relatively modest compared to those for electricity. The largest absolute and percentage electricity savings will occur in the South Atlantic and Southwest regions. The large savings in these regions can be attributed to the relatively greater cooling loads found in these climates and thus the prevalence of air conditioning.[123]

Other impacts of the standards include a slight shift away from central air and heat pumps in favor of room air conditioners. LBL notes that the interaction of a number of factors, including equipment costs, climate, and consumer preferences, are responsible for the shift. In addition, electric water heaters sales are expected to increase at the expense of other types of water heating equipment. The projected increase in electric water heater sales results from the higher cost of efficient nonelectric water heaters, according to LBL. Both shifts are small-about 1 to 3 percent. LBL notes that the national appliance standards will produce a net savings benefit of $25 billion.[124]

Building Energy Codes

Standardized building energy codes that define thermal characteristics have the potential to improve energy efficiency by preventing the least efficient buildings from being constructed. Currently there is little support from States and localities and the construction industry. In the 1970s there was some interest in a standardized code for new buildings.

[121] Thirteen product types are included: 1) refrigerators, refrigerator-freezers, and freezers; 2) room air Condition_; 3) central air conditioners and central air conditioning heat pumps; 4) water heaters; 5) furnaces; 6) dishwashers; 7) clothes washers; 8) clothes dryers; 9) direct heating equipment; 10) kitchen ranges and ovens; 11) pool heaters; 12) television sets; and 13) fluorescent lamp ballasts.

[122] Geller, op. cit., footnote 13, p. 30.

[123] Joseph H. Eto et al., Lawrence Berkeley Laboratory, *The Regional Energy and Economic Impacts of the National Appliance Energy Conservation Act of 1987*, June 1988, pp. 15, 16, and 19.

[124] Ibid.

Congress enacted legislation in 1976 requiring the development of the Building Energy Performance Standards, a mandatory national code based on performance standards. However, before the building energy performance standards were finalized in 1983, the law was modified to be mandatory only for Federal buildings.

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) also promulgates standards. ASHRAE standards, which typically require a 3-year payback period, are regularly updated. Compliance is voluntary; most States adopt but poorly enforce the ASHRAE standards. The Federal buildings standards are nearly identical to ASHRAE's new Series-90, but they, too, are seldom enforced.

ASHRAE previously released standards in 1975 and 1980. The 1980 standard was estimated to result in energy reductions in commercial buildings of 12 to 29 percent compared to buildings constructed in the late 1970s. Modifications to lighting contributed about half of the total savings. The new ASHRAE standard is expected to provide 20- to 25-percent energy savings in commercial buildings over the previous ASHRAE code. It is important to note, however, that the average energy efficiency of new buildings in most States exceeds the 1980 ASHRAE standards.

Some States, especially on the west coast, require tighter standards and enforce them. Other States are considering novel approaches to encouraging energy efficiency. For example, the State of Massachusetts is considering hookup fees and rebates to encourage energy efficiency in new commercial buildings. Commercial buildings (50,000 square feet or larger) that will use more electricity per square foot than average would be charged a stiff utility hookup fee. Buildings designed to use less electricity than average will receive a rebate. The fees collected from the owners of the less-energy efficient buildings are rebated to the energy efficient building owners.i[n]

Standards are equally important for existing buildings. Some cities in California have recently enacted conservation ordinances for existing residential and commercial buildings. These ordinances stipulate that a building must be upgraded to minimum standards before the title is transferred.[126]

Corporate Average Fuel Efficient (CAFE) Standards

The purpose of the CAFE standards is to boost fuel efficiency beyond what the manufacturers believe the market alone warrants. From 1973 to 1987, automobile fuel efficiency gains were impressive. The current CAFE standards establish a uniform efficiency target of 27.5 mpg that must be achieved by all manufacturers regardless of the mix of vehicles in their fleets. The efficiency target, however, is subject to revision, pending ongoing U.S. Department of Transportation rulemaking. The current standard places a more difficult technological burden on companies that sell a mix of vehicle sizes than on companies selling small vehicles only. Automakers who focus on small cars will have more flexibility than the "full line" manufacturers to introduce features that are attractive to consumers but are fuel inefficient. OTA indicates that a higher fuel economy level could be achieved if all automakers were required to improve efficiency to the maximum extent possible.

Electric Utility Programs—Demand-Side Management

Demand-side management programs can result in greater investments in energy efficient equipment and building shell improvements. Utilities in all regions of the country are using demand-side management programs to reduce load and to possibly defer the need for future generating capacity additions. In addition, State public utility commissions and energy offices have supported these programs. EPRI forecasts that by the year 2000 demand-side management programs could reduce summer peak demand by 6.7 percent (45 GW) and annual electric use by 3 percent.[127]

Demand-side management programs include activities undertaken by a utility or customer to influence electricity use. Activities undertaken by utilities include rate programs (time of use or time of day), interruptible rates, real-time pricing, no de-

[125] Bevington and Rosenfeld, op. Cit., footnote 35, pp. 85-86.

[126] Ibid.

[127] Electric Power Research Institute, "Impact of Demand-Side Management on Future Customer Electricity Demand: An Update," EPRI CU-6953, September 1990, p. v.

mand charge under certain conditions, and use of "smart' demand meters. The time of use rate is the most frequently used.[128]

A growing number of utilities offer financial incentives to commercial, industrial, and residential building owners who invest in energy efficient equipment, such as appliances, space conditioning systems, lighting products, and motors. Rebates were the most popular form of financial incentive. Most utilities use minimum efficiency levels as the unit of measure for the rebates.

A national survey completed in 1986-87 found that about 35 to 50 percent of the Nation's utilities have some type of energy efficiency rebate program. The most frequently stated purpose of the rebate program was to promote energy efficiency, followed by peak load reduction. According to the survey, commercial and industrial rebate programs reduced, on average, peak demand by 13.6 MW per year. Residential rebate programs reported peak demand savings, on average of 9.7 MW per year. The average peak demand reduction for all programs was 21 MW per year.[129]

Another survey, conducted by ORNL, found that many utilities increasingly recognize the commercial buildings sector as a significant source of untapped savings in energy and corresponding peak demand. Rebate programs for commercial buildings are likely to expand and proliferate in the future because of the potential cost and energy savings of such initiatives, according to ORNL.

And, there are indications that utilities are willing to go beyond financial incentives to encourage investment in energy efficiency. For example, Pacific Gas and Electric (PG&E), with help from the Natural Resources Defense Council (NRDC), developed a $2 billion, 10-year program aimed at promoting energy efficiency. The program includes a state-of-the-art facility for demonstrating and developing energy efficient technologies, which is expected to open in late 1991, a research study to identify economical ways to improve energy efficiency, consumer education programs, and, of course, financial incentives. PG&E's goal is to cut peak demand growth by 75 percent (2,500 MW) for the 1990-2000 period.[130]

Under this innovative program, PG&E shareholders and customers are expected to benefit. After efficiency measures are installed, dollar savings are estimated. For every dollar saved, shareholders will received 15 cents. Customers will receive 85 percent of the savings through rate reductions. However, customers will pay slightly higher rates in the short term to cover the costs of the program.[131]

Oil Supply and Price Uncertainties[132]

Short-term or even long-term interruptions in the availability of Middle Eastern crude oil always remain a possibility. Oil supply interruptions and the accompanying increases in oil prices weaken the U.S. economy, increase inflation, and decrease personal disposable income. After the Iraqi invasion of Kuwait in early August 1990, crude oil prices jumped from about $18/barrel to a high of more than $40/barrel and then back down again. The initial hike in oil prices contributed to the U.S. recession. There was also some concern at the time that escalating oil prices would trigger a global recession.

While the demand for petroleum is generally sensitive to price, other factors can also influence consumption. Existing plant and equipment and the potential for sizable shifts in fuel preference can limit the ability to save oil. Also, personal disposable income and demographic changes can also have an impact on oil use. Thus, there is considerable uncertainty about the rate of investment in energy saving equipment during an oil disruption. In fact,

[128] J.O. Kolb and M.S. Hubbard, "A Review of Utility Conservation programs for the commercial Building Sector," ORNL/CON-220, Oak Ridge National Laboratory, Oak Ridge, TN, 1988, p. 26.

[129] "A Compendium of Utility-Sponsored Energy Efficiency Rebate Programs,' report prepared by the Consumer Energy Council of American Research Foundation and the American Council for an Energy Efficient Economy for the Electric Power Research Institute, EPRI EM-5579, Palo Alto, CA, December 1987.

[130] Testimony of Greg M. Rueger, Senior Vice president and General Manager, Electric Supply, Pacific Gas and Electric, before the U.S. Senate Committee on Energy and Natural Resources, Regarding Titles III and IV of the National Energy Security Act of 1991, Concerning Energy Efficiency and Renewable Energy, Feb. 26, 1991; and "PG&E Launches $2-Billion Energy SavingProgram," *LosAngeles Times*, Business Section, Mar. 14, 1991, p. D1.

[131] Ibid.

[132] For a detailed discussion of U.S. vulnerability t. oil disruptions, see U.S. Congress, Office of Technology Assessment, *U.S. Vulnerability to an Oil Import Curtailment*, OTA-E-243 (Washington, DC: U.S. Government Printing Office, September 1984), and a forthcoming update.

the strain of high oil prices on personal disposal income may actually minimize investment in more energy efficiency equipment. For example, residential and commercial oil users may be unable to invest in new heating and hot water equipment at a time when their heating bills are straining their finances. Or, consumers may defer the purchase of new, more efficient automobiles.

In any event, the increasing U.S. reliance on foreign oil supplies, particularly the insecure sources of supply in the Middle East, and the potential for large increases in oil prices should be strong incentives to evaluate the energy efficiency progress that has been made to date and to continue to look for energy-saving opportunities. During the Arab oil embargo of 1973-74, crude oil prices quadrupled, and more than doubled again during the Iranian crisis of 1978-80. These disruptions and the resultant increases in oil prices changed U.S. thinking about the importance of energy. Historically, the U.S. simply shifted from one supply source to another as declining supplies or other concerns shifted consumer preferences. Little research attention and policy concern were given to energy conservation until after the 1973 oil embargo. However, rising oil prices and the specter of insufficient supplies that followed 1973 set in motion a flurry of research, demonstration, and development programs, government initiatives, and private commitment to pay attention to the cost of energy and to lower that cost through improved efficiency in design and process. Federal spending for conservation R&D, for example, increased from about $3 million in fiscal year 1974 to $406 million in fiscal year 1980 (1982 constant dollars),[133] but has since declined. The result of all of these efforts was that the U.S. economy became considerably more energy efficient, across all sectors.

Fuel Switching

Fuel switching away from oil was another response to the oil disruptions of the 1970s. It became an important way of restoring services formerly supplied by oil and enhancing the reliability of fuel supplies. Many energy users in the industrial and utility sectors now have the capability to switch between alternative fuel sources quickly-often with only a twist of a knob-to take advantage of relative differences in fuel prices and availability. Today, there are more than 100,000 dual-fuel units in the United States. About two-thirds can burn gas continuously.

Typically, utilities switch from oil to gas when gas prices are lower and vice versa. For example, in 1979 and 1987, utilities switched to natural gas because prices were lower. And, in 1986 the reverse was true.

Additions to fuel switching capability will depend on a number of factors, including seasonal and regional demand, availability of supplies, price considerations, and technical constraints. Much fuel switching capability has already been realized. Since the mid-1970s, many oil-fired generating plants have been converted to gas- or coal-fired units. Those that have not been converted generally include units that are too small to justify conversion, or cannot be converted because of environmental or financial constraints, or lack coal-burning handling and storage capability. In addition, inadequate fuel supplies or storage may preclude switching on an immediate or continuous basis.

Given these considerations, DOE estimates that natural gas could at a minimum replace about 85,000 barrels of oil per day immediately.[134] The DOE estimate could be higher when several new pipeline projects come on line. The projects are being developed to supply domestic and Canadian gas to the northeast and California. Also, acid rain legislation will make natural gas a more attractive fuel option for reducing sulfur emissions.

[133] Congressional Research Service, *Energy Conservation: Technical Efficiency and Program Electiveness,* IB85 *130,* updated Jan. 10,1991, attached tables.

[134] U.S. Energy Information Administration, Department of Energy, *Electric Power Monthly,* "PetroleumF uel-Switching Capability in the Electric Utility Industry," September 1990.