Chapter 18

ELECTRICITY

About 700,000 megawatts (MW) of electric generating capacity is now installed in the United States. For most of this century, U.S. electricity demand has increased at roughly the same rate as the GNP. Even with aggressive conservation and efficiency efforts, and assuming that the existing 700,000 MW is maintained through refurbishment and replacement, we will need about 200,000 MW more than the present total to meet the electricity requirements of a growing U.S. economy in 2010. The Federal-State regulatory regime that governs investment decisions in electricity supply and demand will profoundly influence the types of new capacity to be built, who will build it, what technology and fuels are used, and what the full consumer and environmental consequences will be.

(*National Energy Strategy*, *Executive Summary*, 1991/1992)

The Administration believes that prudent restructuring of the electricity industry should increase competition, reduce consumers' electricity-related costs, maintain environmental protection, and enhance economic productivity.

(*Sustainable Energy Strategy*, 1995)

Electricity has often been called the ‘all-American’ energy form. It is certainly difficult to imagine an American home, and indeed a home in any industrialized nation, without dozens of electrical gadgets, equipment and appliances. In little over a hundred years, since Edison's invention of the electric light bulb and the construction of the first commercial power station (on Pearl Street in New York City), electricity has transformed our society. In Chapter 5 we saw that there is a general correlation between the prosperity of a nation (measured by its gross national product) and its electricity demand. The United States in particular is an avid consumer of electricity: with less than 5% of world's population, it accounts for almost 30% of world's demand (see Figures 5-13 and 5-14).

Electricity is today so much a part of our lives that we take it for granted. When a ‘blackout’ occurs – as it did in most of northeastern U.S. and part of Canada in November 1965, in New York City in July 1977, and most recently in Florida for Christmas 1989 – we are reminded of our dependence on it. As we approach the 21st century, increasingly preoccupied with our dependence on imported oil, little public attention is being paid to the future sources of electricity. These have become quite controversial. The cost of the pollution-control devices in power plants using fossil fuels and the safety aspects of nuclear power plants have complicated the lives of utility executives to the point that they prefer – at least for the time being – not to build any large power plants. Some consumers are actually being paid *not* to consume electricity at certain times of the day. Why is this? What is the current situation in electricity supply and demand? How long can the current ‘stalemate’ last? What are the options for the future? The answers to these questions involve very complex and debatable macroeconomic issues. Many of these issue are beyond the scope of our discussion. But in this chapter we do want to examine the most important *facts*. In contrast to the situation with residential comfort and transportation (see Chapters 19 and 20), knowledge of the facts is not sufficient for making decision that will have a major impact on the electricity industry, at least not yet. But the impending deregulation of the electric utility industry may change this (see Investigation 18-3). It should allow the reader, however, to formulate *informed* opinions about this increasingly controversial energy form, which is such a vital pillar of modern society.

A (Very) Brief Prelude: Electric Energy

Electricity is an inherent property of matter, like mass or thermal energy or entropy. The existence of positively or negatively charged particles, either at rest or in motion, was known to the ancient Greeks. Electricity's usefulness was demonstrated by Michael Faraday some twenty centuries later. Faraday's discovery that an electric current can be induced in a wire when it is rotated in a magnetic field – the principle of operation of the electric generator – led to the development of this most flexible and convenient of all energy forms. The flexibility is due to the fact that electricity can be converted very easily into other forms of energy. The conversion is usually efficient, because electricity is a low-entropy energy form, resulting from the *ordered*, directional movement of electrons through a conducting material. (An important and unfortunate exception is the conventional incandescent light bulb, as shown in Table 4-2.) Its convenience is the result of the fact that it is available at the press of a button or the flick of a switch, at the most.

Perhaps the easiest way to understand electricity is to realize that it is in many respects analogous to the intuitively more obvious gravitational energy. We know that positive and negative charges attract each other spontaneously. This is why atoms are almost indivisible: the positively charged nucleus has a very strong attraction for the negatively charged electrons. If the charges are separated, a voltage (or a potential difference) is established. This is analogous to the difference in height established when an object is raised above sea level. (It is also analogous to the difference in temperature between a hot and a cold reservoir; see Chapter 3.) The accomplishment of this charge separation is the main function of the p/n junction in a solar cell, as described in Chapter 17.

Thus, voltage (above 'ground') is analogous to height (above sea level). Its relationship to other fundamental electrical properties is given by Ohm's law, which states that voltage (V) is the product of the current (I) and the resistance (R) of the wire through which it flows:

$$\text{Voltage} = [\text{Current}]\ [\text{Resistance}]\ ,$$

or

$$V = I\ R\ .$$

Electric energy – by analogy with gravitational energy – is thus the product of electric force and distance, as summarized below:

$$\text{Gravitational (potential) energy} =$$

$$= [\text{Mass}]\ [\text{Acceleration (due to gravity)}]\ [\text{Height}] =$$

$$= [\text{Gravitational force}]\ [\text{Height}]$$

$$\text{Electric (potential) energy} =$$

$$= [\text{Electric force}]\ [\text{Voltage}]$$

The force in electricity is called the electric charge. It is related to the number of electrons flowing through a wire. Electric current is the rate of change of charge with time:

$$\text{Current} = \frac{\text{Electric force (or charge)}}{\text{Time}}$$

These arguments allow us now to formulate the relationship that is most important from a practical standpoint. We know that power (P) is energy divided by time. Therefore,

$$\text{Electric power} = \frac{\text{Electric energy}}{\text{Time}} = [\ \frac{\text{Electric force}}{\text{Time}}\ ]\ [\text{Voltage}] = [\text{Current}]\ [\text{Voltage}]$$

We know how much voltage is delivered to our homes (usually 110 volts). The various electricity-consuming devices that we use in our homes are commonly rated in units of current (usually amperes). The product of a volt (V) and an ampere (A) is a watt:

$$1 \text{ watt} = [1 \text{ ampere}]\,[1 \text{ volt}]$$

$$1 \text{ W} = (1 \text{ V})\,(1 \text{ A})$$

This expression allows us to calculate the power ‘drawn’ (from the utility company), and this – together with the knowledge of the time period over which electricity is in use – allows us to calculate the consumption and cost of electric energy.

Illustration 18-1. A computer printer (Apple LaserWriter Plus) operates on a current of 6.6 amperes (A). Calculate the daily cost of having it permanently turned on, assuming that electricity costs 10 cents per kilowatthour.

Solution.

$$\text{Cost (per day)}, \frac{\$}{\text{day}} = \left(\frac{\text{Cost}}{\text{kWh}}\right)\left(\frac{\text{kWh}}{\text{day}}\right)$$

Now, the number of kWh per day shown above is nothing else but the power needed by the printer, and this in turn is the product of voltage and current. Therefore, we have:

$$\text{Cost} = \left(\frac{\$0.10}{\text{kWh}}\right)(110 \text{ V})\,(6.6 \text{ A}) = \left(\frac{\$0.10}{\text{kWh}}\right)(0.726 \text{ kW})\left(\frac{24 \text{ h}}{1 \text{ day}}\right) = \$1.74/\text{day}$$

The Electric Power Plant

At this point we must remind the reader that nothing in life comes for free. It takes a lot of energy to produce electricity. About 70% of this energy is supplied in the form of chemical energy of fossil fuels, as shown in Figure 18-1. About 90% is supplied by first converting chemical or nuclear energy to heat, then heat to work, and finally work to electricity (see Figure 4-5). In Chapter 4 we discussed the thermodynamic limitations associated with the conversion of heat to work. The data shown in Figures 5-13 and 5-14 illustrate the large energy losses (nature's ‘tax’) involved. Of the 30.7 quads of thermal energy used for electricity generation in the U.S. (see Figure 5-14), 20.8 quads (20,800,000,000,000,000 BTU) are wasted. If petroleum alone were used to generate all the electricity in the world, 48 million barrels would be used every day (see Figure 5-13); as much as 33 million barrels per day – twice as much energy as the entire U.S. petroleum consumption – would be wasted.

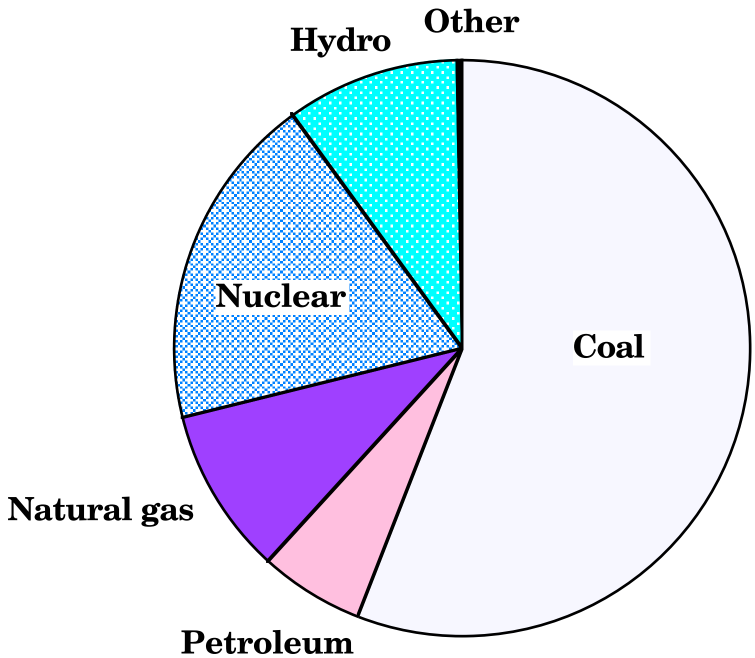


FIGURE 18-1
Today's mix of energy resources used to generate electricity in the U.S.
[Source: Energy Information Administration.]

How to increase the efficiency of an electric power plant is thus an issue of major concern. A higher efficiency obviously saves fuel and money. It also reduces pollution and decreases the potential greenhouse effect by reducing the amount of carbon dioxide released. Because of the large quantities of fuel consumed, even small improvements are important. This is shown in Illustration 18-2.

A typical efficiency of a coal-fired power plant is about 35%. This number is not likely to increase further, because of thermodynamic limitations. One of the ways to achieve a higher overall efficiency in a power plant is to ‘squeeze’ more energy out of the “spent working fluid” coming out of a turbine, by converting it into additional useful work. In Chapter 10 we mentioned the technology of integrated gasification-combined-cycle (IGCC), as one of the possible new uses of coal that also achieves higher efficiencies. This is illustrated in Figure 18-2. Indeed, in this process, which combines a gas-fired turbine with a steam turbine – and is thus called a *combined cycle* – the energy of the hot products of combustion from the gas turbine is used to make steam for

Illustration 18-2. An electric power plant processes every hour 255 tons of coal (13,200 BTU/lb; $50/ton) to produce 760 megawatts of electricity. Calculate its efficiency. If the efficiency could be improved by 10% over the existing one, how much coal, money and emitted carbon dioxide could be saved?

Solution.

$$\text{Efficiency} = \frac{\text{Useful energy output}}{\text{Total energy input}}$$

Useful energy output = Electric energy = 760 MW = $7.6\text{x}10^8$ J/s

Total energy input = Chemical energy of coal =

$$= 255\ \frac{\text{tons}}{\text{hour}} = (255\ \frac{\text{tons}}{\text{hour}})\ (\frac{2200\ \text{lb}}{1\ \text{ton}})\ (\frac{13200\ \text{BTU}}{1\ \text{lb}}) = 7.4\text{x}10^9\ \frac{\text{BTU}}{\text{h}} =$$

$$= (7.4\text{x}10^9\ \frac{\text{BTU}}{\text{h}})\ (\frac{1055\ \text{J}}{1\ \text{BTU}})\ (\frac{1\ \text{h}}{3600\ \text{s}}) = 2.2\text{x}10^9\ \text{J/s}$$

Therefore,

$$\text{Efficiency} = \frac{7.6\text{x}10^8\ \text{J/s}}{2.2\text{x}10^9\ \text{J/s}} = 0.35$$

A 10% improvement means that the new efficiency is (0.35)(1.10) = 0.385, or 38.5%. In this case, the output of the plant does not change, so the new input (X) decreases. This is calculated as follows:

$$\text{Efficiency} = 0.385 = \frac{7.6\text{x}10^8\ \text{J/s}}{\text{X}}\ ; \quad \text{therefore,} \quad \text{X} = 1.97\text{x}10^9\ \text{J/s}$$

Translated into tons per hour, the new coal input is obtained as follows:

$$(1.97\text{x}10^9\ \frac{\text{J}}{\text{s}})\ (\frac{1\ \text{BTU}}{1055\ \text{J}})\ (\frac{3600\ \text{s}}{1\ \text{h}})\ (\frac{1\ \text{lb}}{13200\ \text{BTU}})\ (\frac{1\ \text{ton}}{2200\ \text{lb}}) = 232\ \text{tons/hour}$$

This is 10% less than 255 tons/hour in the 10% less efficient plant. The daily cost savings, for the 23 tons/hour coal savings, are:

$$\text{Cost savings} = (\frac{23\ \text{tons}}{\text{hour}})\ (\frac{\$50}{\text{ton}})\ (\frac{24\ \text{h}}{1\ \text{day}}) = \$28{,}000/\text{day}$$

If we assume that one ton of this coal produces about 3 tons of carbon dioxide (see Table 11-3), the emissions of CO_2 would decrease by about 69 tons per hour (or as much as 600,000 tons per year).

the steam turbine. This can raise the overall efficiency significantly. Based on thermodynamic analysis that we need not go into, the system efficiency (remember Chapter 4) of these two turbines placed in series (see Figure 18-2) is obtained as follows:

$$E_{system} = E_{gas\ turbine} + E_{steam\ turbine} - [E_{gas\ turbine}]\ [E_{steam\ turbine}]$$

For example, if the efficiencies of the two turbines are 38% and 20%, the overall efficiency of the plant is 50.4%. Furthermore, all the hot gases are sent to heat exchangers and are thus used to produce additional steam. This highly efficient combination of electricity generation and steam production at the same location is called *cogeneration.*

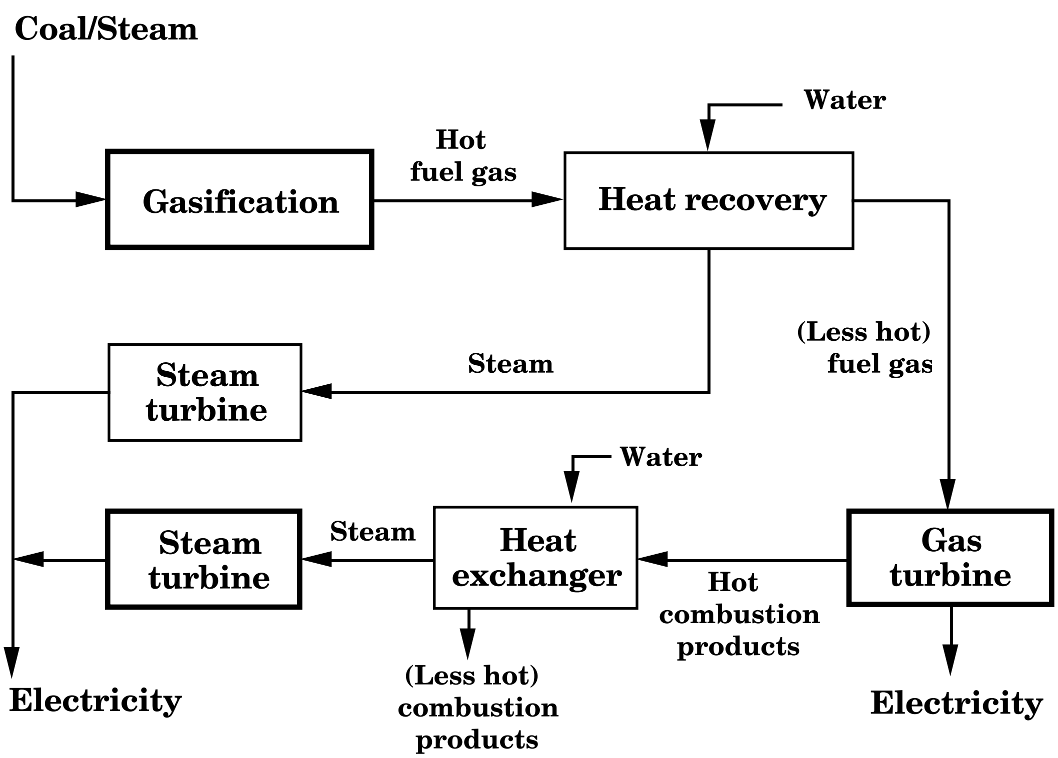


FIGURE 18-2
Schematic representation of an integrated gasification-combined-cycle (IGCC) power plant.

Electricity Supply and Demand

Electricity accounts for almost 40% of the energy consumed in the United States (see Figure 5-14). Its growth in the postwar period, until the petroleum crises of the 1970s, has been phenomenal. This is documented in Figure 18-3. Note the logarithmic scale of the y-axis, indicative of exponential growth. Essentially, two straight lines are observed. Before the Arab oil embargo – see Chapter 21 – the doubling time was less than 10 years, giving a rate of growth of about 7% per year; after the oil embargo, the doubling time has been about 20 years, and the more recent annual rate of growth has been about 2.5%. Before the oil embargo (from 1945 to 1973) the demand for electricity grew much faster than the GNP. Since the early 1970s, both have been growing at about the same rate.

The slowdown in the growth of electricity consumption has not met with disapproval of the electric utility managers. In fact, as we mentioned earlier in this chapter and as we shall illustrate below, they are doing their best to postpone the day when new large power plants will be needed. To understand this, it is necessary to appreciate the difference between installed capacity and electricity consumption (or generation), shown in Figure 18-3.

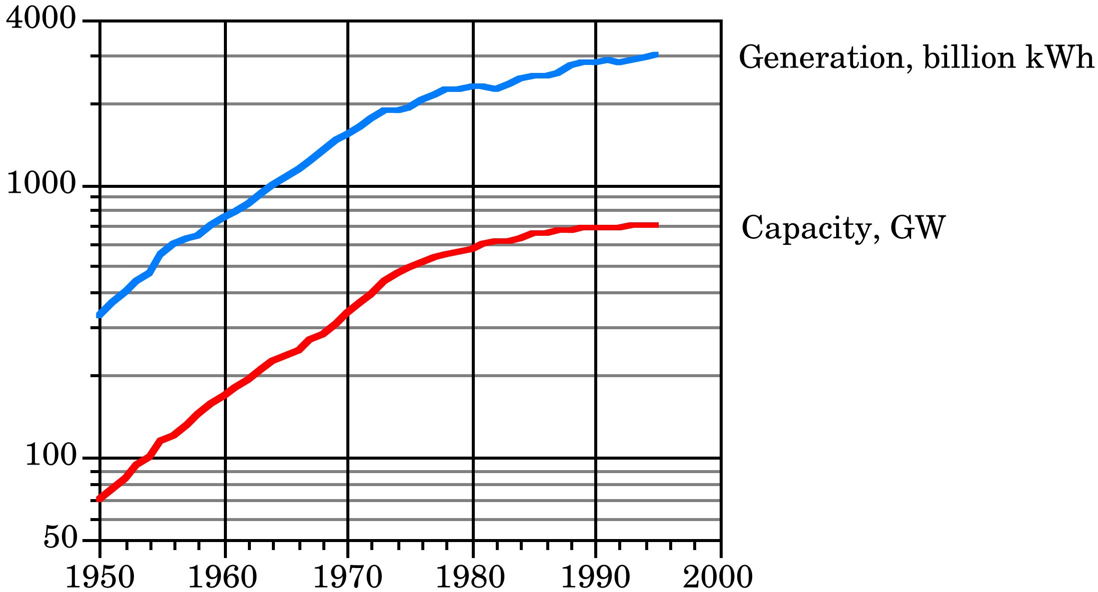


FIGURE 18-3. Consumption (generation) of electric energy and installed capacity in the United States in the last forty five years. [Source: Energy Information Administration.] Note that consumption is synonymous with generation only when imports and exports are negligible.

In the early 1990s, the installed capacity in the U.S. was 700 gigawatts, equivalent to seven hundred 1000-MW plants. If all these plants had operated at full capacity throughout the year, the generation of electricity would have been:

$$700 \text{ GW} = (700\text{x}10^6 \text{ kW}) \left(\frac{8760 \text{ h}}{1 \text{ year}}\right) = 6{,}132 \text{ x } 10^9 \text{ kWh/year}$$

This number is much larger than the 3000 billion kWh of electricity generated in 1995. This would seem to be in contradiction with simple economics (and common sense). Why is there so much overcapacity? Typical statistical information illustrated in Figure 18-4 provides the answer.

FIGURE 18-4. Illustration of daily and weekly variations in electricity consumption (and generation). [Adapted from Fowler, op. cit.]

Baseload electricity is that amount which is needed 24 hours a day, 365 days a year. It is typically produced using equipment that cannot be turned on and off very easily nor very quickly, such as nuclear reactors and large coal-fired boilers. The operational costs are relatively low for these units and the overall cost of electricity production in them can be as low as one cent per kWh (see Chapter 21).

Peak load electricity is that amount which is needed during short daily periods of peak consumption, like between 7 and 9 A.M. and between 5 and 8 P.M., when the residential consumption is very high. It is produced using equipment that can be turned on and off in a matter of minutes, such as gas turbines and diesel engines. The operational costs can be very high here and the cost of producing electricity during these hours can be as high as 10-15 cents per kWh.

Intermediate load, as the term implies and as shown in Figure 18-4, refers to electricity-generating equipment that is operational during most of the day but can be turned off – if necessary – during the night. Reserve equipment is on stand-by. It is used during periods of unusually high demand (such as very cold or very hot weather) or as replacement for other equipment that needs maintenance or repair. If it is not economical to keep it idle, it can also be used to store electricity (for example, by pumping water uphill in hydroelectric power plants). This storage of electricity is not something that can be done easily, however. It is perhaps the only disadvantage of electricity as an energy form.

This highly variable demand represents a challenge for utility executives, to minimize the excess capacity and to make sure at the same time that peak loads can be satisfied. Construction of large and expensive baseload power plants – the so-called "hard path" to our energy future in the terminology of Amory Lovins – does not seem to be the right choice any more (see, for example, NYT of 2/10/87, p. D1). And in fact, a closer look at Figure 18-3 indicates that no new generating capacity has been added in the past five years. It takes a long time to build and obtain license for nuclear power plants, and this can make them very expensive; coal-fired plants – the other principal option – now require stricter pollution controls (see Chapter 11) and can also become expensive. On the other hand, if electricity consumption continues to grow at 2-3% per year, additional 270 GW of installed capacity will be needed within the next twenty years.

Figure 18-5 illustrates the recent preferences of U.S. electric utility managers. A welcome decline in petroleum use is seen. The only significant growth continues to be in electricity generated by coal-fired and nuclear power plants. The decisions made today will not be seen on this graph until the 21st century.

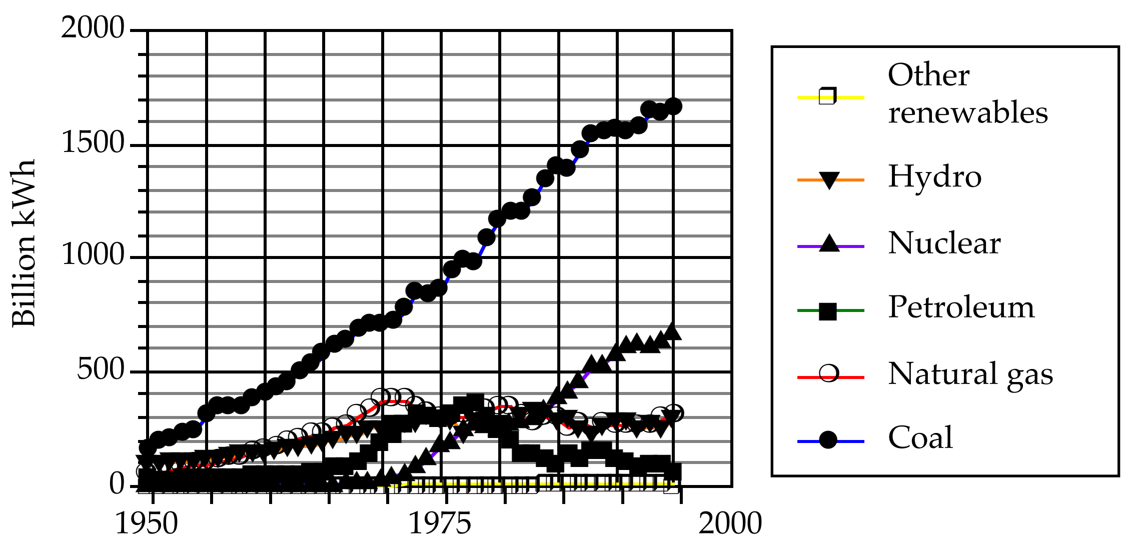


FIGURE 18-5. Historical trends in the U.S. generation of electricity by source. [Source: Energy Information Administration.]

The trend seen in Figure 18-5 explains the decrease in the inflation-adjusted price of electricity shown in Figure 18-6. Baseload electricity generated by coal-fired and nuclear power plants is typically the least expensive of all. It will be interesting to observe in the coming decades how the environmental benefits of renewable sources and natural gas will be factored into these prices and how that will affect the decisions of electric utility managers. The political decisions made today (see Chapter 21) will determine the outcome of this obvious conflict between technical, economic and environmental interests.

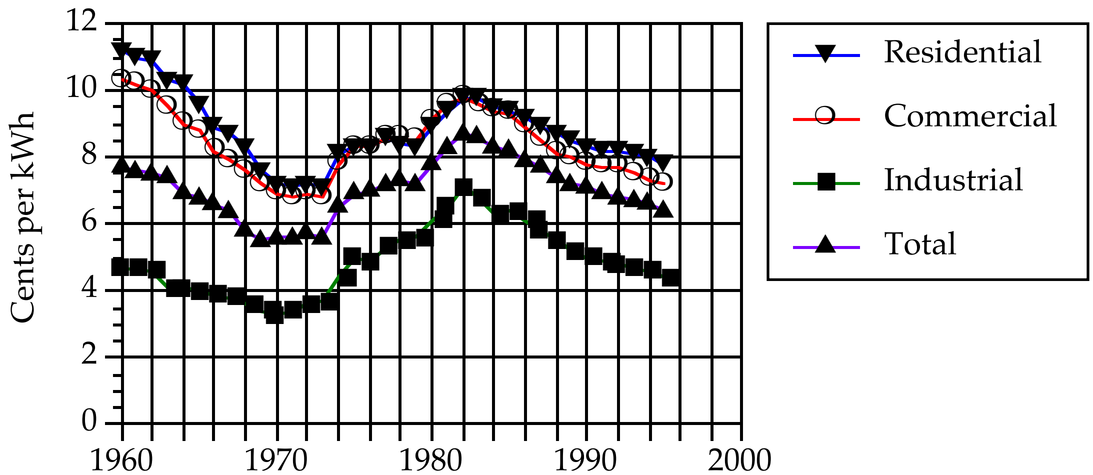
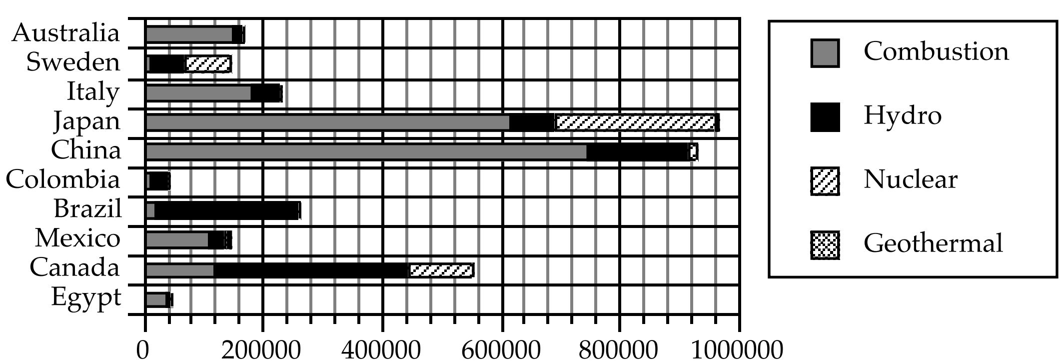


FIGURE 18-6. Retail prices of electricity in the U.S. in the last 35 years (in 1992 dollars). [Source: Energy Information Administration.]

Finally, Figure 18-7 summarizes how the world is generating its electricity today. Everybody except South America relies heavily on fossil fuels. Nuclear energy is very important in Europe, while hydroelectricity is dominant in South America. A sample of 'representative' countries is given below. (The units are the same as in Figure 18-7.)



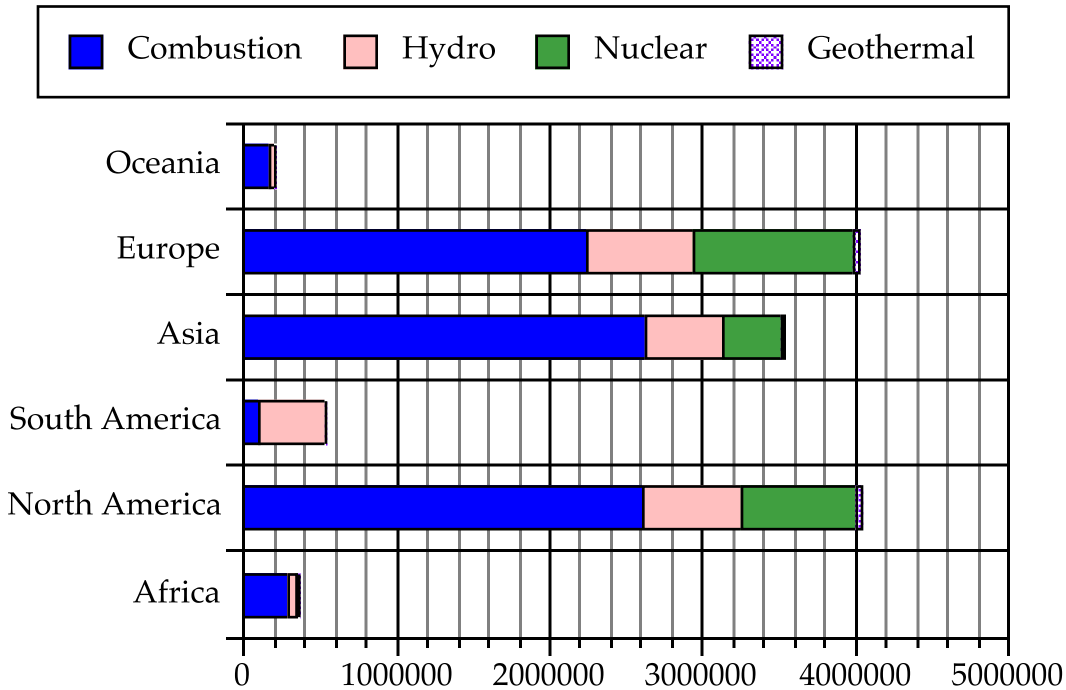


FIGURE 18-7. Production of electricity in the world in 1994 (in million kilowatthours). [Source: 1994 Energy Statistics Yearbook, United Nations.]

Demand-side Management

Demand-side management is an old economic concept, even for public utilities. Telephone companies have had a lot of success with it. For electric utilities it is a new concept whose time has come. Rather than providing additional supply, the utilities are increasingly asking their customers not to use electricity during peak hours. They are also beginning to charge us different rates at different times of the day, like telephone companies.

To illustrate the perhaps surprising statements in the first paragraph on page iv and this new demand management strategy of electric utility companies, we reproduce below a part of the “Enlightened Energy Test,” which appeared as an advertisement by Con Edison, a New York-based electric utility.

(1) About one-third of our area's electricity is made by burning oil. How much of it has to be burned to light one ordinary 75-watt light bulb for a year?

(a) One ounce; (b) two quarts; (c) eleven gallons; (d) one pint

(2) Burning the oil that would be required to light one ordinary 75-watt light bulb for a year releases into the air how many pounds of gases that might contribute to environmental problems?

(a) 275 pounds; (b) five pounds; (c) twelve pounds; (d) one pound

(3) It makes sense to use compact fluorescent light bulbs rather than ordinary light bulbs because:
(a) they use 75% less electricity;
(b) they last ten times as long;
(c) they provide the same soft light;
(d) all of the above

(4) Does it use more electricity to turn a light switch on and off than to leave it on?

(a) Yes, a lot; (b) yes, a little bit; (c) no; (d) it depends on the kind of light

(5) When shopping for an energy-efficient air conditioner, look for:
(a) an Energy Efficiency Rating of 9.5 or higher;
(b) the proper BTU size;
(c) the biggest one you can find;
(d) both (a) and (b)

For answers to these questions – and the reader should by now know at least some of them – see the NYT of March 20, 1991, p. A25. Times have changed indeed, when an electric company pays for a full-page newspaper advertisement not to promote a new product but to ask consumers about conservation or, as they put it, if we are "energywise or otherwise."

Demand-side management has worked for the electric utilities, as documented in Figure 18-8. Substantial peak load reductions have been achieved in this decade.

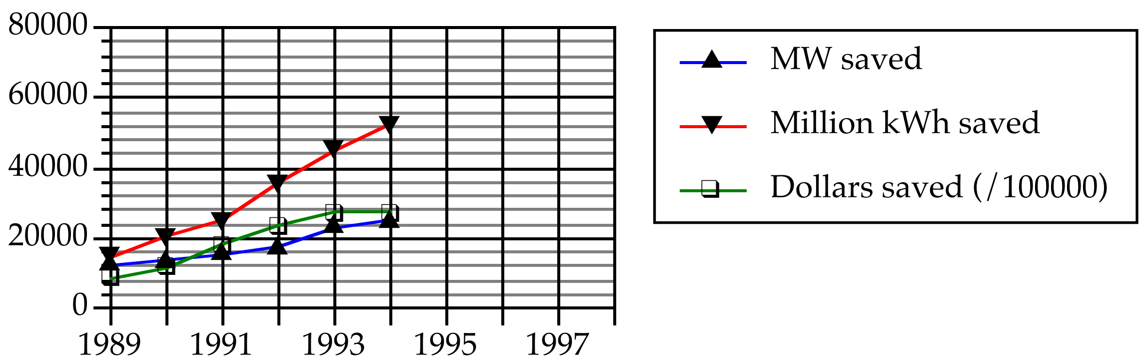


FIGURE 18-8. Effects of demand-side management programs of U.S. electric utilities. [Source: Energy Information Administration.]

Reading the Press: NIMBY

We have referred to the NIMBY ("not in my backyard") syndrome previously, in connection with the use of nuclear reactors in power plants. That times are changing for the electric utilities, and that challenging times lie ahead, can be illustrated by reproducing the following article from *The New York Times*, September 10, 1990, p. B1. Even coal-fired power plants are now in some trouble because of greater environmental concerns of the public. The article is six years old, New York has a new governor, the other politicians mentioned in the article may have changed jobs as well, but the energy issues are exactly the same today as they were then.

COAL PLANT PROPOSAL UPSETS NEW YORK'S NEIGHBORS

(by Elizabeth Kolbert, Special to *The New York Times*)

HALFMOON, N.Y., Sept. 8 – It used to be that the fight against acid rain united New York and other Northeastern states like allies in wartime. Together they railed against dirty Midwestern power plants, filed lawsuits against the Federal Government and mourned the fate of their slowly dying lakes.

Today, a coal-burning plant proposed for this small town 15 miles north of Albany is sorely testing this alliance. New York State officials have indicated that they plan to approve the plant, whose emissions, carried east by the prevailing winds, would spill over the Berkshires in Massachusetts and the Green Mountains in Vermont. The officials say that the plant would not have a serious impact on air quality because of its sophisticated pollution control.

"Have to Practice What We Preach"

But officials in neighboring states disagree, and are accusing New York of exporting its air pollution in much the same manner as the Midwestern states they have all condemned.

"We in the Northeast have to practice what we preach," Gov. Madeleine M. Kunin of Vermont said. "This is not the right time to launch a project that's going to hurt our environment."

The plant, proposed by a company called Inter-Power of New York, Inc. has become a campaign issue in Massachusetts, where all five candidates in this month's gubernatorial primary have come out against it. In the Berkshire region, where the impact of the plant would be the greatest, opposition to Inter-Power has become practically a prerequisite for running for office.

In New York, too, the plant has been protested by dozens of politicians and civic groups, including, in a surprising twist, the local industrial development agency.

But Gov. Mario M. Cuomo has remained silent on the issue, saying the plant's future is a matter best left to state regulators to decide. Through a spokesman, Mr. Cuomo has said that he was sure that the regulators would be 'scrupulous' in insuring that the plant qualified as "clean technology."

The far-flung opposition to the plant has become a potential embarrassment to Mr. Cuomo, whose re-election campaign stresses his commitment to a clean environment. Critics of the plant charge that the Governor, so forceful when it comes to Midwestern polluters, has failed to show the same firmness in dealing with problems closer to home.

"You can't set a dual standard: one for the rest of the world and one for your state," said Ken Dufty, president of the Concerned Citizens for the Environment, a New York-based group formed to fight Inter-Power. "I think the Governor needs to be made accountable for that."

The winds that blow pollution from the coal-fired power plants of the Mid-west toward the Northeast are the same winds that would scatter the Inter-Power plant's emissions over a broad swath of New England, and the issues that the proposed plant raises are the same ones that have long troubled relations between the regions.

Reject or Embrace Coal?

Should the nation turn away from coal, as many Northeast officials have argued, because it produces large quantities of pollutants like sulfur dioxide, which are the precursors of acid rain? Or is coal, one of the nation's most abundant energy sources, an integral part of the country's future, as officials in the Midwest – and now in New York – have said?

The disputed 220-megawatt power plant is proposed for desolate industrial stretch of the Hudson river's west bank, beside a General Electric Company plant that has been fined for spilling solvents and other toxins into the river. The plant would sell some power to General Electric, and under Federal law, the local utility company, Niagara Mohawk, would have to buy the rest. While the plant is of moderate size for a power station, it is unusually large for a co-generating plant.

The question of whether the plant is needed is a matter of contention. Niagara Mohawk executives have testified that the company will not need new power until 1999, and plant opponents argue that energy conservation and other forms of power could easily meet the utility's needs by then.

But state officials argue that the power is needed sooner, and the Inter-Power plant has already received favorable reviews from several state agencies, including the Department of Environmental Conservation. The final say rests with the state's Board on Electric Generation Siting and the Environment, all of whose members have been appointed by Governor Cuomo. The board will decide whether it will be generated without adverse environmental impact.

"We're So Darn Clean"

Like Midwestern officials before them, New York's environmental officials argue that their regulations are strict enough to insure that the Inter-Power plant does not harm the region's air quality. In addition, state officials note, the plant is in keeping with the state's newly adopted energy plan, which calls for several new coal-fired plants to be built using pollution controls similar to Inter-Power's.

Inter-Power officials say that the image of the plant has been unfairly tarnished by the older and dirtier coal-fired plants in operation in the state. "You want to get facilities like ours on line because we're so darn clean," John D'Alessandro, a spokesman for the Latham-based company, said.

But opponents like Mr. Dufty of Inter-Power argue that building new coal-fired plants, even with sophisticated pollution controls, is folly at a time of deep concern over acid raid.

By changing the chemical composition of the water, acid rain can, over time, transform thriving lakes and streams into the aquatic equivalent of deserts. Foes of the Inter-Power plant note that just this week, a Federal study confirmed that emissions of sulfur dioxide and nitrogen oxides, many of them originating at coal-fired power plants in the Midwest, are major contributors to the acid rain that has been damaging Northeastern lakes.

According to Inter-Power's estimates, the proposed coal-fired plant would each year emit 2,337 tons of sulfur dioxide, a major ingredient of acid rain. Some older coal-burning plants emit twice as much sulfur dioxide to produce the same amount of energy. A plant burning natural gas, which many opponents of Inter-Power have advocated, would produce less than one-sixth of the amount of the Inter-Power plant.

The Inter-Power plant would emit roughly 2 million tons of carbon dioxide, which many scientists have labeled a factor in another environmental problem: global warming. A comparable gas-fired plant would emit roughly one-quarter that amount.

Illustration 18-3. The key point of contention in this controversy over the coal-fired power plant is seen to be one number: 2337 tons of sulfur dioxide per year for a 220 megawatt plant. Calculate the sulfur content of the coal to be used if it has a (typical) heating value of 13,200 BTU/lb and if the efficiency of the proposed plant is 35%. Could you find a better coal?

Solution.

In Illustration 18-2 we saw that a 760 MW plant (having the same efficiency, 35%) consumes 255 tons of coal per hour. So a 220 MW plant would consume 220/760, or 29% of 255 tons, that is about 74 tons of coal (of the same heating value) per hour. That translates into about 650,000 tons of coal per year (assuming that the plant is operational 100% of the time, or 8760 hours per year).

In Illustration 11-3 we saw that 2 tons of sulfur dioxide are produced for every ton of sulfur in the coal. So 2337 tons of sulfur dioxide are produced from 1168 tons of sulfur in the coal considered for the Halfmoon plant. This in turn means that this coal has 1168/520000 = 0.2% sulfur. If the plant in fact has a typical load factor of 70% (it is operational seventy percent of the time), the sulfur content in this coal would be 0.25%. Now, being in all likelihood from the eastern U.S., this coal has a very low sulfur content (see Table 7-3). It is, therefore, not likely that the company officials can switch to a better coal to minimize further the potential pollution problem.

Inter-Power officials say that foes of the plant are being unrealistic in arguing it should be converted to natural gas, because no pipeline exists. "People have to look at this project within the realm of the real," said Mr. D'Alessandro, the company spokesman.

Events in the Mideast, Mr. D'Alessandro added, underscore the importance of coal. "Coal is a domestic resource," he said. "This is an opportunity to put us on the right path not just environmentally, but economically."

INTERNET INFO	For the most recent developments in the electric power industry, see the Web site of the Electric Power Research Institute, at www.epri.com.

REVIEW QUESTIONS

18-1. From the bar graph on p. 345, determine roughly what fraction of electricity is produced by nuclear reactors in Australia and China, and what fraction is produced by hydro-energy in Japan and Canada. Compare these values with the situation in the U.S.

18-2. The NYT of 5/22/88 carries an article with the following title: "The Promise of Wind Awaits a New Energy Crisis." One of its statements is that "16,000 [wind] turbines provide about 1 percent of California's electric power, enough for more than 300,000 homes, and enough to cut air pollution from burning coal and other fuels by 200,000 tons a year." Show that these numbers make (or do not make?!) sense. (Assume that an 'average' household consumes between 15,000 and 20,000 kWh per year; see Chapter 19.)

18-3. The NYT of 2/14/89 has a report on an unconventional biomass-based electric power plant in California ("Cow Manure Fuels a California Power Plant"). The plant produces 15 megawatts of electricity, "enough for 15,000-20,000 homes, using 800 to 900 tons of [cow] manure daily." How does this analysis compare with the one in the previous problem.

18-4. A personal computer typically consumes 200-300 watts of electric power. In 1993 IBM introduced 'green' PCs that require less than 60 watts. They were reported to consume, on average, $15-worth of electricity per year (see NYT of 5/23/93, "No Pie in the Sky: I.B.M.'s New 'Green' Machine"). Estimate the assumed daily use of one of these computers.

18-5. In the NYT of 10/30/92, the following electricity generating capacities and actual quantities generated are reported for a number of large hydroelectric power plants around the world. Determine their capacity utilization factors and comment on their values.

Plant	Capacity, MW	Electricity produced, billion kWh/yr
Itaipu (Paraguay-Brazil)	12,600	77
Grand Coulee (USA)	9700	20
Guri (Venezuela)	9000	50
Krasnoyarsk (ex-USSR)	6100	30
Churchill Falls (Canada)	5200	30
Paulo Afonso (Brazil)	4500	18
Assuan (Egypt)	2100	10

18-6. Using Figure 18-7 show that the world electricity generating capacity is equivalent roughly to that of 2000 1000-MW power plants.

18-7. Indicate whether the following statements are true or false:
(a) Baseload electricity is available 24 hours a day, 365 days a year.
(b) Nuclear energy is used today to generate more than 10% of U.S. electricity.
(c) The electric power consumed by an appliance is equal to the ratio of the current and the voltage.
(d) The electricity consumption data on p. 345 and in Figure 18-7 show that Brazil consumes more than 40% of South America's electricity.
(e) Canada and Mexico together consume less than 20% of North America's electricity.
(f) In Figure 18-8 a capacity utilization factor of less than 30% is assumed for 1994.
(g) In Figure 18-8 a peak electricity cost of more than 10 cents per kWh was assumed for 1994.

INVESTIGATIONS

18-1. Amory Lovins has coined the term ‘negawatts’. What does it mean? How does it apply to electricity consumption? See NYT of 4/20/93 (“Utilities Should Seek ‘Nega-Watts,’ Says an Enemy of Fossil Fuel Use”). Explore also the Web site of the Rocky Mountains Institute, http://www.rmi.org.

18-2. Electric utilities that are burning coal, especially high-sulfur coal, have been in quite a squeeze since the Clean Air Act amendments of 1990 (see Chapter 21). Some of them are coming up with ingenious solutions. The case of Osage, Iowa (“the energy conservation capital of the U.S.”) has been well publicized. Find out about the example of A.E.P., Ohio, in NYT of 7/26/92.
(a) Summarize the steps taken by this utility in an attempt to “paint itself green.”
(b) It is important these days that the electric utilities project a pro-environment image. Explore the Web to find out how some of them do it. See, for example, www.coned.com and NYT of 1/26/97 (Con Edison: “The Company You Know. The People You Trust”).

18-3. The electric utility industry is gearing up for the same kind of deregulation that the telephone industry went through some time ago. Find out more about this process and its expected benefits. Are there any potential problems? See NYT of 5/9/93 (“Utilities Brace for a Buyer's Market in Electricity”), 8/8/94 (“Electric Utilities Brace for an End to Monopolies”), 4/5/96 (“Utilities Rewrite the Rate Card”), 4/16/96 (“Market Place: Utility shareholders face a new hurdle as deregulation nears”), and 8/4/96 (“The Baby Bulbs: The End of the Last Great Monopoly”); BW of 6/24/96 (“Future shock: a lower electric bill”); *Economist* of 1/6/96 (“Electricity deregulation: A nasty shock”).

18-4. Find out what happened to the coal-burning power plant project in Halfmoon, New York (pp. 348-351). Call up Inter-Power of New York, Inc. Maybe they even have a Web site... You then want to call the office of the Governor of Vermont, to hear their side of the story. Finally, talk to the Concerned Citizens for the Environment in New York City to see how successful they were.

18-5. There has been some controversy recently about the link between cancer and exposure to high-voltage power transmission lines. Find out more about this issue. See NYT of 11/1/96 (“Panel Sees No Proof Of Health Hazards From Power Lines”), 11/13/96 (“Power Line Paranoia”) and 11/18/96 (“Power Lines and Cancer”); and USNWR of 11/11/96 (“For Power Lines, Almost an Acquittal”).

18-6. Find out about the prices of electricity around the world. See *Economist* of 4/13/96 (“Short Circuit”), 11/11/95 (“Energy in Japan: Electric shocker”) and 6/3/95 (“European electricity: Battle for power”). Do we seem to be paying more or less than people in Japan and the European Union? See also Figure 18-6.

18-7. California has a lower per capita electricity consumption than the rest of the country (about 7000 vs. 11,000 kWh). Why is that? The following article in the NYT of 5/25/95 may contain part of the answer: “California Moves to Form Agency to Buy Power.” See also *Forbes* of 8/1/94 (“Mandate power”).

18-8. As electric utility deregulation moves into high gear, independent power producers will compete with the utilities. Find out how ‘strong’ these IPP's are at the moment, in terms of their electricity generating capacity. See NYT of 3/17/95 (“In Power Industry, Changes Batter Independents”). Compare these capacities with the information in Figure 18-3.

18-9. Hydroelectricity costs tend to be low (see pp. 329-330). Find out how electricity customers in the Northwest benefit from this. See NYT of 3/3/95 (“Northwest benefits From Cheap Electricity”).

18-10. Much controversy exists regarding the effects of impending electricity deregulation on alternatives such as wind, solar, geothermal, etc. Will deregulation hurt or help? For some insight into this complex issue, see NYT of 2/3/95 ("A Makeover for Electric Utilities").

18-11. Electric utilities are taking advantage of their right to trade pollution rights (see Chapter 11 and Investigation 21-6). Find out about a concrete example in NYT of 11/18/94 ("For Utilities, New Clean-Air Plan: A Swap May Lead To a Global Effort").

18-12. In these days of impending electric industry deregulation, and emerging competition, it is increasingly important for the utilities to market their products. Find out how the Southern Company does it, at http://www.southernco.com. Detroit Edison company has also been in the news, for publishing a 36-page catalog featuring more than 250 energy-related innovations. Explore the Web to find out more about this and other such initiatives.

18-13. A concrete example of the deregulation that's probably coming to a neighborhood near you was described recently in *Newsweek* of 9/9/96 ("Monopoly Unplugged"). Since May 1996, 17 thousand households in New Hampshire have been able to choose among 30 electricity suppliers. Summarize some of their experiences and the key facts mentioned in this article.

18-14. The Sacramento Municipal Utility District and David Freeman, its general manager, have also been in the news. Their challenge was to replace the Rancho Seco nuclear power plant, which the local community voted to close down in late 1980s. Find out how they met this challenge. See NYT of 9/27/92 ("An Energy Prophet Who Guessed Right"). Get an update by visiting their Web site at http://www.smud.org.