CHAPTER 8

COULD THE FUTURE COST OF ENERGY CHANGE LIFE AS WE KNOW IT?

Production Costs and the Inescapable Demand for Energy

Researchers at the Post Carbon Institute (www.postcarbon.org), a nonprofit energy think tank, suggest that energy costs will increase dramatically as the supply of fossil fuels (oil, coal, and natural gas) decreases.[1] Among other things, skyrocketing energy costs would spell doom for transportation systems and the suburban neighborhoods, shopping malls, factories, and schools they serve. Energy costs are already built into the price of almost everything we buy because energy is consumed in the production, transportation, use, and disposal of most products. A spike in oil prices in the 1970s was followed by double-digit inflation rates throughout the economy. New technology will temper energy costs to a greater or lesser extent, depending on the level of investment in this technology.

At present, energy from renewable sources, such as the sun, wind, earth (geothermal), plants (biodiesel), and water (hydroelectric), costs significantly more than energy from fossil fuels. Even with the cheap stuff, 29 million households are eligible for financial help from the federal Low Income Home Energy Assistance Program

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[1] This view is shared by other groups. The U.S. Army Corps of Engineers reports that once oil production peaks, "geopolitics and market economics will result in even more significant price increases and security risks" (see www.cecer.army.mil/techreports/Westervelt_EnergyTrends_TN/Westervelt_EnergyTrends__TN.pdf). See also www.msnbc.msn.com/id/4287300/, www.peakoil.net/, and www.lifeaftertheoilcrash.net/.

(LIHEAP), and home energy costs take about 17 percent of the income of LIHEAP recipients (www.liheap.org/background.html). This chapter discusses the nature, cost structures, and market structures of this most critical of inputs.

AN INTRODUCTION TO ENERGY

Energy is the amount of physical work a system is capable of performing. *Power* is the rate of energy transfer per unit of time. The first law of thermodynamics implies that energy cannot be created, consumed, or destroyed because the amount of energy in the universe is fixed. Thus, energy "production" refers not to the creation of energy but to its conversion into a usable form, and energy "use" does not mean that energy is destroyed but that it is dissipated into heat or other unusable forms.

Most of our efforts to harness energy for commercial electricity production involve making turbines spin to create electrical currents. Nuclear fission and coal combustion create steam that turns turbines. Wind and flowing water apply direct force on turbines. You may have created electricity yourself by turning a crank or a bicycle wheel rigged for that purpose. An exception is solar energy collected by a photovoltaic cell, which converts light energy into direct-current electricity without moving a thing.

From Where Does Energy Come?

The sun is the original and ultimate source of energy, fueling the plant life that feeds other living things, as well as the ancient plant life whose fossilized remains are burned as oil, natural gas, and coal. The water wheel was invented in 350 C.E. as a way to capture energy from flowing water. Windmills were used to harness wind energy beginning about 950 C.E. James Watt used wood and coal fires to power the first modern steam engine in 1765, and to this day the standard unit of power, equal to 1/746 of a horsepower, or 1 amp times 1 volt, bears his last name. Gottlieb Daimler inaugurated the gasoline-powered automobile engine in 1884. The first nuclear power plant went on-line in 1954.

Rocky Mountain Institute founder Amory Lovins describes two paths for energy dependence. The first is a "soft path" of many renewable energy sources, such as solar panels on millions of roofs or wind turbines on thousands of "wind farms." The second is a "hard path" of relatively few centralized fossil-fuel–based producers. Although Lovins made this observation in the context of environmental concerns, the distinctions between the two paths are also useful for discussions of market structures and production costs.

In 1850, the United States obtained most of its energy from decentralized sources—the muscles of humans and animals, followed by wood, water and wind, and coal. In 2006, the United States received more than 90 percent of all its energy from large, centralized sources. Most of our energy comes from petroleum products (40 percent); natural gas (23 percent); coal (22 percent); nuclear power (8 percent); and renewable sources, including flowing water, wind, and the sun (7 percent). Electricity is a secondary source of energy because another source of energy must be harnessed to make it. The primary fuel sources for making electricity in the United States are coal (52 percent), uranium (20 percent), natural gas (16 percent), flowing water (7 percent), oil (3 percent), and other renewable sources (2 percent).

Where Does Energy Go?

Like the demand for labor, the demand for energy is derived from the demand for the services this input provides. Industry creates 32 percent of U.S. energy demand, transportation creates 30 percent, residential users create 20 percent, and commercial users create 18 percent.[2] Global growth in the number of homes, businesses, industrial plants, and vehicles leads to corresponding increases in the demand for energy.

Much of the energy that is tapped by consumers literally goes up in smoke or is lost to heat or respiration. *Energy conversion efficiency* refers to the percentage of energy from a source that is converted into useful energy rather than being spent in the process of making energy useful. Wind turbines convert about 30 percent of the wind's energy into electricity. Coal-fired power plants convert 30 to 35 percent of the energy in coal into electricity. The energy conversion efficiency of standard solar cells is about 15 percent, although experimental solar cells have reached efficiency levels in excess of 30 percent.[3] If we could capture one-half of 1 percent of the energy the earth receives from the sun with 15 percent energy conversion efficiency, no other energy source would be required.

Sometimes the power goes out entirely. On August 14, 2003, an estimated 50 million people in eight U.S. states and the Canadian province of Ontario lost power, in some areas for up to 4 days. Estimates of the financial burden of this blackout in the United States approach $10 billion. Canadians lost 18.9 million work hours, and manufacturing shipments in Ontario fell by $1.9 billion. A U.S.–Canadian government investigation placed blame for the massive blackouts on the cascading effects of operators' mistakes, computer failures, rule violations, and inadequate equipment maintenance by FirstEnergy Corporation of Ohio. For many, this event was a wake-up call about the importance of energy as an input and about the vulnerability of the large, interconnected energy grids that are involved in the current structure of our energy market.

WHAT DOES ENERGY COST?

In 2006, Americans spent almost 9 percent of gross domestic product, amounting to more than $1 trillion, on energy.[4] Energy costs also include important environmental and health costs, which are addressed in Chapter 29. Here we examine the cost structure of energy production for large and small electricity producers. Several critical types of cost are explained in this context. Their meanings are summarized here for convenience:

Fixed cost: a cost that does not change as more of the product is made

Variable cost: a cost that increases as more of the product is made

Total cost: fixed costs plus variable costs

Marginal cost: the cost of making 1 more unit of the product

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[2] See www.eia.doe.gov/emeu/mer/pdf/mer.pdf, p. 23.
[3] For example, see www.spectrolab.com/com/news/news-detail.asp?id=152.
[4] See www.eia.doe.gov/emeu/steo/pub/gifs/Slide24.gif.

Average fixed cost: the total fixed cost divided by the number of units made

Average variable cost: the total variable cost divided by the number of units made

Many Small Producers

The cost structure in an energy market depends on the scale of the production facilities, which tends to be either very large or very small. The 16,000-plus wind turbines in California produce about as much energy as 1 mid-size nuclear power plant does.[5] The U.S. Department of Energy is sponsoring a Million Solar Roofs initiative, with the goal of having 1 million rooftops outfitted with solar panels in the United States by 2010. The roofs of the Zeeland Middle School in Michigan, a Harley-Davidson dealership in Hawaii, and the home of Minnesota resident Todd Volkmeier exemplify thousands of participants in this soft-path effort.

Mr. Volkmeier installed 10 165-watt solar panels on his roof. Why 10 and not 15 or 25? The answer is that diminishing marginal returns set in for panels, just as they do for workers, as explained in Chapter 7. The marginal product of another rooftop panel (that is, the additional output received by installing 1 more panel) will decrease as the roof becomes crowded and panels must be placed in less sunny spots, and it will fall to 0 when there is no more open space for another panel.

Let's consider the cost picture for energy producers, such as Mr. Volkmeier. The $2,500 cost of the equipment—the energy inverter that makes the solar energy usable by household appliances, the wiring, and the battery pack for storing energy—is a *fixed cost* because the expenditure on these items does not change as more capacity is produced. In order to produce more energy in a given period with a given amount of sunlight, more panels must be added. Because solar panels are the input that is varied in order to produce more electricity, their cost is a *variable cost*, which amounts to $600 per panel. The *total cost* is the sum of the total variable cost and the total fixed cost for a given amount of output. Mr. Volkmeier's total cost was $2,500 + (10 × $600) = $8,500.

The determination of the best number of panels for Mr. Volkmeier requires a closer look at marginal cost and marginal benefit. We know that, in general, *marginal cost* is the cost to producers of 1 more unit of a good. The marginal benefit for producers is the *marginal revenue*—the additional revenue they take in from 1 more unit. As explained in Chapter 1, if something is worth doing, it should be done until the marginal benefit no longer exceeds the marginal cost, and that holds true for producers as well: If it is worthwhile to produce a good or service, it should be produced until marginal cost equals marginal revenue.

Marginal cost is closely tied to marginal product, although the two measures move in opposite directions. As explained in Chapter 7, the marginal product of labor generally increases and then decreases. In such cases, marginal cost falls and then rises. The explanation is straightforward: As marginal product increases for the first few workers, it takes fewer additional workers to make another unit of output, so the mar-

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[5] See www.gracelinks.org/energy/wind/.

ginal cost of making that additional output falls. As the marginal product of workers falls, it takes more workers and thus more wage payments to make more units, and marginal cost increases. Likewise, as the marginal product of solar panels decreases as a result of roof crowding, it takes more additional panels to increase energy capacity by a given amount, and the marginal cost of energy capacity increases.

Let's track Mr. Volkmeier's marginal cost as he decides how many solar panels to install. Given the capacity of individual panels, in this example we will consider 165-watt increments in energy capacity. As long as there is unobstructed, sun-facing space on the roof, the marginal cost of adding 165 watts of energy capacity is $600—the cost of 1 panel—or $600/165 = $3.64 per watt. If the best available space requires that additional panels obstruct one-half of an existing panel, then it takes 2 additional panels to add 165 watts of capacity, bringing the marginal cost to $1,200 for 165 watts, or $7.27 per watt. If the best remaining roof space only gets one-third of the amount of sun necessary to bring a panel to its productive capacity, it will take 3 panels to increase Mr. Volkmeier's capacity by 165 watts, and the marginal cost is $1,800 for 165 watts, or $10.90 per watt. Finally, if the only place to put another panel is on top of an existing panel, the marginal cost of energy capacity becomes infinite: There is no amount that can be spent on additional panels to increase capacity.

Average fixed cost is total fixed cost divided by the quantity of output. To find the average fixed cost of producing 165 watts of capacity, we divide the total fixed cost of $2,500 by 165 and find $15.15. As output increases, average fixed cost invariably decreases because the same total fixed cost is divided by a larger and larger quantity. For example, the average fixed costs of producing capacities of 330, 825, and 1,100 watts are $7.57, $3.03, and $2.27, respectively. When a capacity of 250,000 watts is being produced, the average fixed cost is 1 cent.

Average variable cost is the cost of the variable input (panels) divided by the quantity of output (watts). Suppose that the first 4 panels have prime locations in the sun, the next 4 create 50 percent obstruction for other panels, the 4 after that must go on the side with one-third as much sun, and additional panels provide no net gain. The average variable cost of producing 330 watts is (2 × $600)/330 = $3.64. The production of 825 watts requires 4 panels at full capacity plus 2 panels at half capacity, so the average variable cost is (6 × $600)/825 = $4.36. The production of 1,100 watts requires 4 panels at full capacity, 4 panels at half capacity, and 2 panels at one-third capacity, for an average variable cost of (10 × $600)/1,100 = $5.45.

Producers compare average total cost with price to determine whether profits or losses are in store. Average total cost is the sum of average fixed cost and average variable cost. It can also be found by dividing total cost by the quantity of output. Because

WATTS	MARGINAL COST	AVERAGE FIXED COST	AVERAGE VARIABLE COST	AVERAGE TOTAL COST
330	$ 3.64	$7.57	$3.64	$11.21
825	$ 7.27	$3.03	$4.36	$ 7.39
1,100	$10.90	$2.27	$5.45	$ 7.72

the total cost of producing 330 watts is ($2,500 + [2 × $600]) = $3,700, the average total cost is $3,700/330 = $11.21. Likewise, the average total cost of producing 825 and 1,100 watts is $7.39 and $7.72, respectively.

The accompanying table summarizes the marginal and average cost levels. Notice that as output increases, the average total cost decreases and then increases. Average total cost will generally fall as output increases at small levels of production because decreases in average fixed cost are initially dramatic (for example, going from 1 watt to 2 watts cuts the average fixed costs down from $2,500 to $1,250), and these decreases are larger than the increases in average variable cost. At higher output levels, average fixed cost decreases more gradually than average variable cost increases, and average total cost begins to rise at precisely the quantity at which marginal cost rises above average total cost.

With millions of small producers of identical units of energy, the energy market would resemble the perfectly competitive model that Adam Smith described as being efficient, as discussed in Chapter 6. In such a market, it would be impossible for any one producer to maintain a price for energy in excess of average cost because competitors would be willing and available to sell energy for a price as low as average cost. However, the energy market in the United States does not, in fact, resemble the competitive model.

Few Large Producers

Eleven hundred coal-fired power plants and 103 nuclear reactors provide 72 percent of the United States's electricity needs. In 2004, Colorado regulators approved plans for the state's first new coal-fired power plant in 23 years. This addition to the Comanche Generating Station in Pueblo will cost an estimated $1.3 billion and produce 750 megawatts (a megawatt is 1 million watts). The Watts Bar Nuclear Power Plant in Tennessee, the most recent reactor to go on-line in the United States, began operation in 1996 with a capacity of 1,138 megawatts after a painful 23 years of construction delays at a cost of $8 billion.[6]

Although there is diminishing marginal product from coal and uranium, the overarching cost of these types of operations is the cost of building the power plants themselves. The enormous fixed cost of these facilities makes the cost structure of coal-fired and nuclear energy producers different from that of soft-path producers. Consider the average cost of nuclear power. The average fixed cost of the first million watts produced at the Watts Bar plant is $8 billion/1 million = $8,000 per watt. In contrast, variable costs and marginal costs are relatively small. The fuel cost in coal production is about two-thirds of the variable cost; the remaining one-third is for things such as labor and plant maintenance. Uranium fuel represents one-third to one-half of the variable cost of nuclear power. As Ron Hagen[7] of the U.S. Department of Energy commented, "This is important, because if you want to operate in a market, what matters is marginal cost; how much will it cost to sell extra power?"

The fixed costs of coal and nuclear power are prohibitive for any modest level of production. A competitive market divided among many coal or nuclear power pro-

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[6] See www.energybulletin.net/5950.html.

[7] See http://archive.salon.com/tech/feature/2001/12/10/nukes/index2.html.

ducers could not survive because none of the plants would sell enough energy to cover fixed costs. The only way for such a plant to break even is to serve a large region and to sell mass quantities of electricity. When high fixed costs effectively eliminate access to the market by competing firms, the result is a *natural monopoly*—a single firm that is more efficient than any number of competitive firms would be. Water utilities are also natural monopolies because the enormous cost of a water system infrastructure causes average fixed cost to eclipse marginal and average variable costs; the solutions described in the next section apply similarly to water suppliers.

IS ENERGY REGULATION A GOOD IDEA?

Our reliance on natural monopolies for power raises the prospects for regulation to achieve both monopoly production and moderated prices simultaneously. As explained in Chapter 7, competition keeps prices in check, whereas a monopoly can garner lasting profits at the expense of consumers. The importance of energy to production, transportation, food supplies, and winter heating, among other essentials, makes price moderation a concern of government legislators. Given that a monopoly will exist naturally, regulation can limit prices and increase output. By restricting prices to the level of average cost, lawmakers can ensure that consumers pay the smallest amount possible without sending the power utility into debt.

Regulations must be applied and removed with care. In the summer of 2000, people in California began to experience an electricity shortage after power plants in that state were deregulated and sold to private energy wholesalers. The wholesale price of power was uncapped, but limits remained on retail prices. Thus, the power utilities purchased power from the deregulated wholesalers and sold it to customers at regulated retail prices. As cold snaps and heat waves increased electricity demand, production was constrained by plant closings and by increased temperatures that caused more precipitation to fall as rain rather than snow, leaving less snowmelt to fuel hydroelectric power stations.

Increased demand and decreased supply caused the wholesale energy prices in California to exceed the regulated retail prices. The inability to pass higher costs on to consumers resulted in electricity shortages and multibillion-dollar debt among the power utilities. The state experienced *brownouts* (periods of low voltage in power lines that cause lights to dim and equipment to malfunction) and *blackouts* (complete power outages as a result of overburdened power grids). Factories and stores closed; traffic signals faltered. In the end, it was necessary to increase retail electricity prices across the state by 12 to 55 percent.

CONCLUSION

Energy can be produced centrally by natural monopolies using fossil fuels or uranium, or locally by small producers of energy from alternative sources. There has been considerable interest and growth in alternative fuels during the past several decades, but, pollution costs aside, fossil fuels are still far less expensive and provide the large majority of energy in the United States. Dwindling stocks of oil and coal, dilemmas over the safe and secure storage of nuclear waste, ethical interests in conserving energy resources for future generations, and the demands of worldwide development force users to grapple with the spectrum of energy options. The high fixed costs of hard-path solutions invite monopolistic market structures and contentious regulations. Looking ahead, improvements in alternative energy technology could lower the costs of decentralized soft-path sources, such as wind and solar, and change both the structure of energy markets and the price of power.

DISCUSSION STARTERS

1. The Castle River Wind Farm in Alberta, Canada, operates 67 wind turbines and produces 125 million kilowatt-hours of electricity—enough to serve 20,000 homes. Why do you suppose the company erected 67 turbines, rather than, say, 50 or 100?
2. According to warnings from the Post Carbon Institute, fossil-fuel supplies will bring about "relocalization"—a return to communities with local economies, housing, schools, and amenities. Other people expect that technological advances will lower the cost of alternative fuels to the vicinity of fossil-fuel costs. How much reliance do you believe can be placed on high-tech solutions to the energy problem?
3. Which of the following power sources are most likely to come from natural monopolies? Which could be set up either as centralized power sources or as decentralized, soft-path sources? What are the advantages and disadvantages of each type of setup?
   a. wind turbines
   b. hydroelectric power generation along a river
   c. coal
   d. oil
   e. solar
   f. nuclear
4. Of the six types of costs discussed in this chapter, which type is the most important to the decision as to how much of a good or service to produce? Why?
5. Draw supply-and-demand curves on a graph to illustrate what you think happened in the alternative energy market as a result of skyrocketing retail energy prices in California.