crises stimulated both economic and political action. Eight years later, the discipline of the OPEC coalition cracked and oil prices sank. They did not rise to the heights achieved in the 1970s until early in the twenty-first century (see Fig. 7.9).

Throughout most of this period of turmoil and adjustment in world oil markets, U.S. production has dwindled. Kenneth Deffeyes, a geologist at Princeton University, is one of many experts who have concluded that the reason for this decline is that no more cheap oil can be obtained here.[3] The United States was the first nation to produce petroleum commercially, in 1859, and America has been the object of intense exploration activity ever since. So it may not be surprising that production has begun declining here first, too.

What is unsettling is that oil production has also peaked elsewhere. Deffeyes and many other geologists and energy analysts argue that the all-time peak in oil production may have occurred in the first decade of the twenty-first century. Remember the bet between Paul Ehrlich and Julian Simon that we discussed in Chapter 6, however. It is hard to pin down when we are running out of a finite resource, because markets are volatile and people are clever. New technologies and new energy sources such as wind power will enter energy markets. The economic logic is clear. As cheap energy declines, higher prices will make sources and technologies that are now unprofitable worthwhile. Yet there is no doubting our reliance on petroleum today, as shown in Figure 7.8, and it is worth wondering how smoothly energy consumers and governments will make the transitions that lie ahead.

The situation is similar with natural gas, which is found together with oil. But there is a far greater known reserve of coal. In addition, coal is distributed differently in Earth's crust, and the largest reserves are in China and the United States. The problem with coal is a different one, as noted earlier—burning coal releases more carbon dioxide per unit of energy than any other fossil fuel. China and the United States are also the largest contributors to global warming. Moreover, mining and burning coal generates large quantities of other pollutants that cause harm to humans and ecosystems unless controlled effectively; this has proven hard to do in many places.

TACKLING THE GRAND CHALLENGE OF CLIMATE CHANGE

Faced with the emerging evidence of climate change, nations are beginning to respond. This will be a long, painful adjustment—one that will unfold during much of your life and may even involve your career. There is much opportunity, as a result, for constructive change, from individuals to firms to governments and the wider global society.

The emissions of greenhouse gases are the exhalations of the industrial economy of the world: fossil fuels have created the world without edges. Oil, natural gas, and coal account for nearly all of the additions to the atmosphere. So thinking about how to reduce those emissions leads directly to deep changes, not only to the gasoline used in cars—the one form of energy Americans monitor closely because they so frequently fuel their vehicles—but also to manufacturing, transportation, and the heating and cooling of our living, shopping, and work spaces. Nearly all of our energy is generated and handled with machines such as furnaces and electric power plants that are costly to build and that last for decades. Even in a rich nation, we cannot afford to change overnight. In practical terms, the United States has yet to begin the process of change. And in China, a large new coal plant was being opened at the rate of one a week during the first decade of this century.

Not only will it be costly and difficult to reduce greenhouse gas emissions, the attempt to do so must overcome the fact that the atmosphere is a commons, one that may be damaged if the shepherds put too many animals on the pasture, to use the metaphor of Chapter 3.

Greenhouse gases emitted anywhere on Earth go into the atmosphere, where they circulate over the entire planet. This is why measuring CO_2 on a mountaintop in Hawaii (Fig. 7.2) can detect coal-burning electric power plants outside Shanghai, natural gas flared in Kazakhstan, and truck exhaust in Mexico. Among the shepherds with flocks on the pastures that are the world's atmosphere, some have sheep that eat a lot more grass than others. An American emits carbon more than twice as fast as a Japanese (see Box 7.2, page 173). As with other commons, it is not easy to secure agreement on who should go first and how severe the reductions should be.

Yet it is far from impossible for humans to control climate change. Although the world economy is deeply dependent on fossil fuels today, the cost of making large reductions in greenhouse gases is surprisingly affordable. Global consulting firm McKinsey & Company published an analysis in 2009 (see Fig. 7.13) that reaffirms the conclusions of other economic studies:

> Our analysis finds that there is *potential* by 2030 to reduce [greenhouse gas] emissions by 35 percent compared with 1990 levels, or by 70 percent compared with the levels we would see in 2030 if the world collectively made little attempt to curb current and future emissions. This would be sufficient to have a good chance of holding global warming below the 2 degrees Celsius threshold [deemed prudent by scientists].
>
> Capturing enough of this potential to stay below the 2 degrees Celsius threshold will be highly challenging, however. . . . A 10-year delay in taking abatement action would make it virtually impossible to keep global warming below 2 degrees Celsius.

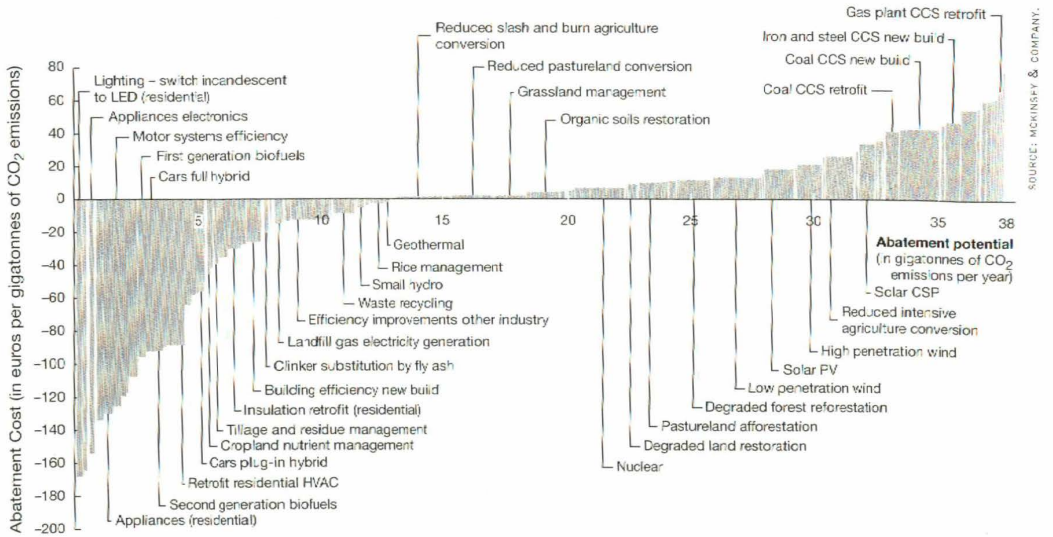

FIGURE 7.13
The estimated costs of different alternatives for reducing greenhouse gas emissions by 2030. This figure provides a large range of technical alternatives, including more efficient residential appliances and the deployment of solar photovoltaic (PV) technology (solar cells). An important point here is that many of the "costs" are below zero—that is, adopting such options would save money. This is true, for example, when a new energy-efficient refrigerator lowers electricity consumption enough to more than pay for its higher cost. (CCS = carbon capture and storage; CSP = carbon sequestration program.)

What would such an effort cost? We find that, if the most economically rational abatement opportunities are pursued to their full potential—clearly an optimistic assumption—the total worldwide cost could be €200 to 350 billion annually by 2030. This is less than 1 percent of forecasted global GDP in 2030.[4]

The McKinsey study is notable, in part, because it represents a statement from a leading voice in the business world. The costs of *failing* to control greenhouse gas emissions, meanwhile, were estimated by the British Chancellor of the Exchequer (roughly equivalent to the U.S. Secretary of the Treasury) to be between 5 and 20 percent of the world economy. That larger number comes close to the economic losses of the Great Depression of the 1930s. There is now significant awareness among large corporations that climate change is not only real but that the responses to climate contain business opportunities as well as threats.

INTERNATIONAL TREATIES

Politicians have been deliberating these matters for some time. In 1992 a Framework Convention on Climate Change was opened by the United Nations. This is a **treaty** that has been ratified by 189 nations so far, including the United States. The word "framework" means that the signatory nations agree to discuss a problem, but have not necessarily adopted any actions to respond to that problem. In effect, the framework convention is an agreement that identifies a commons to be governed and articulates principles to guide governance.

In 1997, a concrete step was taken under the framework—a treaty known as the Kyoto Protocol. The Kyoto Protocol came into force in 2004 with an expiration date of 2012. The Kyoto Protocol is a commitment by most industrialized countries to decrease their emissions of greenhouse gases, just as if some of the herders with larger flocks agreed to limit the number of animals they put into the pasture. These large herders are called Annex B countries. The Annex B countries agreed to commitments to reduce their greenhouse gas emissions below the level they were releasing in 1990. The developing countries that signed on to the Kyoto Protocol were exempt from reductions. Because they are developing nations, China and India were included in this exemption. This so unsettled critics in the United States, it eventually became the world's only developed nation *not* to ratify the Protocol.

In 2009, representatives of many nations gathered in Copenhagen, Denmark, to craft a successor to the Kyoto Protocol. They failed. The logic of the commons had proved too powerful. The search for a practical way to govern the global atmosphere continues in the international community.

The Kyoto Protocol is, so far, the high-water mark of international agreements to respond to climate change. But even this treaty would not have halted climate change, even in the long run. Because CO_2 can stay in the atmosphere for several hundred years, the effects of today's elevated levels of greenhouse gases will take time to work their way through Earth's biological and geological architecture. What the treaty targets would do, if met, is slow down the rate at which humans put additional greenhouse gases into the atmosphere—not halt them. But as the McKinsey analysis (see Fig. 7.13) demonstrates, the economic burden of slowing warming to an environmentally manageable level is affordable. This burden can only be lifted, however, by a world ready to deal with its grandest commons. This has yet to happen.

Of course, no climate policy being considered today would return the atmosphere to its composition before the Industrial Revolution. We are adding more and more animals to the pasture. Climate remains a grand challenge.

This is a very large opportunity for readers of this book, however. It is an opportunity in every professional field, from law to medicine to engineering. It