groups are even beginning to think about how to cut carbon emissions by 70 percent, the amount that scientists say will be needed to stabilize climate.[1]

In July 2005, the European Commission proposed a new plan to cut energy use 20 percent by 2020 and to increase the renewable share of Europe's energy supply to 12 percent by 2010. Together, these two initiatives will reduce Europe's carbon emissions by nearly one third. Among the long list of measures to boost energy efficiency in these countries are replacing old, inefficient refrigerators, switching to high-efficiency light bulbs, and insulating roofs. Reaching the renewables goal requires a rather conservative addition of 15,000 megawatts of wind power, a fivefold expansion of ethanol production, and a threefold increase in biodiesel production. The Europeans' proposed 20-percent cut in energy use by 2020 contrasts sharply with the projected growth of 10 percent under a business-as-usual scenario.[2]

The proposed plan, which is scheduled for final approval in 2006, is designed to save 60 billion euros by 2020. It is also designed to stimulate economic growth, create new jobs, and, by reducing energy outlays, enhance European competitiveness in world markets. The 25-member European Union is second only to the United States in energy consumption.[3]

In 2005 the Japanese government also announced a national campaign to dramatically boost energy efficiency in its economy, already one of the world's most efficient. It urged its people to replace older, inefficient appliances and to buy hybrid cars. The *New York Times* described this as "all part of a patriotic effort to save energy and fight global warming." It noted that the large manufacturing firms were jumping on the energy efficiency bandwagon as a way of increasing sales of their latest high-efficiency models.[4]

Beyond this initial effort, Japan has set goals for boosting appliance efficiency even further, cutting energy use of television sets by 17 percent, of personal computers by 30 percent, of air conditioners by 36 percent, and of refrigerators by a staggering 72 percent. Scientists are working on a vacuum-insulated refrigerator that will use only one eighth as much electricity as those marketed a decade ago.[5]

At the nongovernmental level, a plan developed for Canada by the David Suzuki Foundation and the Climate Action Network would halve carbon emissions by 2030 and would do it only with investments in energy efficiency that are profitable. And in early April 2003, the World Wildlife Fund released a peer-reviewed analysis by a team of scientists that proposed reducing carbon emissions from U.S. electric power generation 60 percent by 2020. This proposal centers on a shift to more energy-efficient power generation equipment, the use of more-efficient household appliances and industrial motors and other equipment, and in some situations a shift from coal to natural gas as an energy source. If implemented, it would result in national savings averaging $20 billion a year from now until 2020.[6]

In Ontario, Canada's most populous province, the ministry of energy plans to phase out the province's five large coal-fired power plants by 2009. The first, Lakeview Generating Station, was closed in April 2005; three more will close by the end of 2007, and the last will be shut down in early 2009. All three major political parties support the plan to replace coal with wind, natural gas, and efficiency gains. Jack Gibbons, director of the Ontario Clean Air Alliance, which endorses the ministry's plan, says of coal burning, "It's a nineteenth century fuel that has no place in twenty-first century Ontario."[7]

Corporations are also getting involved. U.S.-based Interface, the world's largest manufacturer of industrial carpeting, cut carbon emissions by two thirds in its Canadian affiliate during the 1990s. It did so by examining every facet of its business—from electricity consumption to trucking procedures. Founder and chairman Ray Anderson says, "Interface Canada has reduced greenhouse gas emissions by 64 percent from the peak, and made money in the process, in no small measure because our customers support environmental responsibility." The Suzuki plan to cut Canadian carbon emissions in half by 2030 was inspired by the profitability of the Interface initiative.[8]

Although stabilizing atmospheric carbon dioxide levels is a staggering challenge, it is entirely doable. With advances in wind turbine design, the evolution of gas-electric hybrid cars, advances in solar cell manufacturing, and gains in the efficiency of household appliances, we now have the basic technologies needed to shift quickly from a fossil-fuel-based to a renewable-energy-based economy. Cutting world carbon emissions in half by 2015 is entirely within range. Ambitious though this goal might seem, it is commensurate with the threat that climate change poses.

Raising Energy Productivity

The enormous potential for raising energy productivity becomes clear in comparisons of energy use among countries. Some nations in Europe have essentially the same living standard as the United States yet use scarcely half as much energy per person. But even the countries that use energy most efficiently are not close to realizing the full potential for doing so.[9]

When the Bush administration released a new energy plan in April 2001 that called for construction of 1,300 new power plants by 2020, Bill Prindle of the Washington-based Alliance to Save Energy responded by pointing out how the country could eliminate the need for those plants and save money in the process. He ticked off several steps that would reduce the demand for electricity: Improving efficiency standards for household appliances would eliminate the need for 127 power plants. More stringent residential air conditioner efficiency standards would eliminate 43 power plants. Raising commercial air conditioner standards would eliminate the need for 50 plants. Using tax credits and energy codes to improve the efficiency of new buildings would save another 170 plants. Similar steps to raise the energy efficiency of existing buildings would save 210 plants. These five measures from the longer list suggested by Prindle would not only eliminate the need for 600 power plants, they would also save money. Although these calculations were made in 2001, they are still valid simply because there has been so little progress in raising U.S. energy efficiency since then.[10]

Of course, each country will have to fashion its own plan for raising energy productivity. Nevertheless, there are a number of common components. Some are quite simple but highly effective, such as using more energy-efficient household appliances, eliminating the use of incandescent light bulbs, shifting to gas-electric hybrid cars, and redesigning urban transport systems to raise efficiency and increase mobility.

Although there was an impressive round of efficiency gains in household appliances after the oil price jumps during the 1970s, the world generally lost interest as oil prices declined after 1980. Rising oil and natural gas prices are rekindling interest in this issue. Fortuitously, engineering advances since then have brought another wave of efficiency gains, such as those mentioned for Japan, that promise to substantially reduce electricity use. If national governments raise appliance efficiency standards to fully exploit the latest technologies, it would sharply cut carbon emissions worldwide.

One simple energy-saving step is to replace all remaining incandescent light bulbs with compact fluorescent lamps (CFLs), which use only one third as much electricity and last 10 times as long. In the United States, where 20 percent of all electricity is used for lighting, if each household replaced the still widely used incandescents with compact fluorescents, electricity for lighting would be easily cut in half. The combination of greater longevity and lower electricity use greatly outweighs the higher costs of the CFLs, yielding a risk-free investment return of some 25–40 percent a year. Worldwide, replacing incandescent light bulbs with CFLs in, say, the next three years would facilitate the closing of hundreds of climate-disrupting coal-fired power plants.[11]

A second obvious area for raising energy efficiency is automobiles. If over the next decade the United States, for example, were to shift from the current fleet of cars powered with gasoline engines to gas-electric hybrids with the fuel efficiency of the Toyota Prius, gasoline use could easily be cut in half. Sales of hybrid cars, introduced into the U.S. market in 1999, reached an estimated 88,000 in 2004. Higher gasoline prices and mounting climate change worries are driving sales upward. With U.S. auto manufacturers coming onto the market with several new models, hybrid vehicle sales are projected to exceed 1 million by 2008.[12]

Another attractive way to raise energy efficiency is to redesign urban transport systems, moving from the existing system centered on single-occupant automobiles to a more diverse bicycle- and pedestrian-friendly system that would include well-developed light-rail subway systems complemented with buses. Such a system would increase mobility, reduce energy use and air pollution, and provide more opportunities for exercise, a win-win-win situation. Taking automobiles off the street would facilitate the conversion of parking lots into parks, creating more friendly cities.

Harnessing the Wind

World wind-generating capacity, growing at 29 percent a year, has jumped from less than 5,000 megawatts in 1995 to more than 47,000 megawatts in 2004, a ninefold increase. (See Figure 10–1.) Wind's annual growth rate of 29 percent compares with 1.7 percent for oil, 2.5 percent for natural gas, 2.3 percent for coal, and 1.9 percent for nuclear power. There are six reasons why wind is growing so fast. It is abundant, cheap, inexhaustible, widely distributed, clean, and climate-benign. No other energy source has all these attributes.[13]

Europe is leading the world into the age of wind energy. Germany, which overtook the United States in 1997, leads the world with 16,600 megawatts of generating capacity. Spain, a rising wind power in southern Europe, overtook the United States in 2004. Denmark, which now gets an impressive 20 percent of its electricity from wind, is also the world's leading manufacturer and exporter of wind turbines.[14]

In its 2005 projections, the Global Wind Energy Council showed Europe's wind-generating capacity expanding from 34,500 megawatts in 2004 to 75,000 megawatts in 2010 and

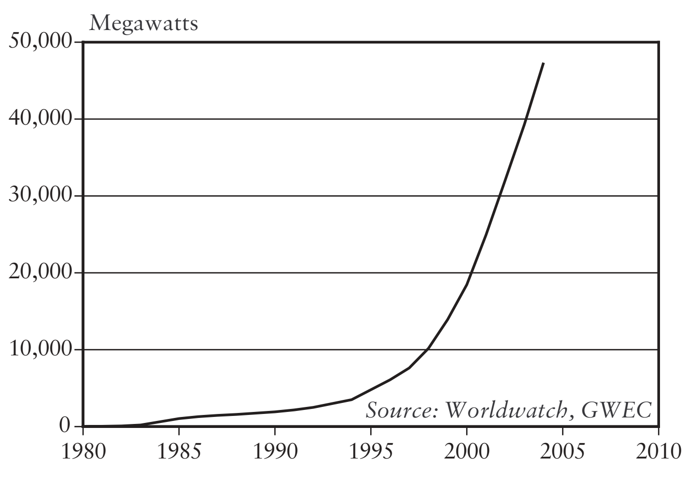

Figure 10–1. *World Wind Energy Generating Capacity, 1980–2004*

230,000 megawatts in 2020. By 2020, just 15 years from now, wind-generated electricity is projected to satisfy the residential needs of 195 million consumers, half of Europe's population.[15]

After developing most of its existing 34,500 megawatts of capacity on land, Europe is now tapping offshore wind as well. A 2004 assessment of the region's offshore potential by the Garrad Hassan wind energy consulting group concluded that if governments move aggressively to develop their vast offshore resources, wind could be supplying all of Europe's residential electricity by 2020.[16]

The United Kingdom, moving fast to develop its offshore wind capacity, accepted bids in April 2001 for sites designed to produce 1,500 megawatts of wind-generating capacity. In December 2003, the government took bids for 15 additional offshore sites with a generating capacity that could exceed 7,000 megawatts. Requiring an investment of over $12 billion, these offshore wind farms could satisfy the residential electricity needs of 10 million of the country's 60 million people. At the end of 2004, the United Kingdom had an offshore generating capacity of 124 megawatts, with an additional 180 megawatts under construction.[17]

The push to develop wind in Europe is spurred by concerns about climate change. The record heat wave in Europe in August 2003 that scorched crops and claimed 49,000 lives has accelerated the replacement of climate-disrupting coal with clean energy sources. Other countries that are turning to wind in a major way include Canada, Brazil, Argentina, Australia, India, and China.[18]

One of wind's great appeals is its abundance. When the U.S. Department of Energy released its first wind resource inventory in 1991, it noted that three wind-rich states—North Dakota, Kansas, and Texas—had enough harnessable wind energy to satisfy national electricity needs. Those who had thought of wind as a marginal source of energy obviously were surprised by this finding.[19]

In retrospect, we now know that this was a gross underestimate of the wind potential because it was based on the technologies of 1991. Advances in wind turbine design since then enable turbines to operate at lower wind speeds, to convert wind into electricity more efficiently, and to harness a much larger wind regime. In 1991, wind turbines may have averaged scarcely 40 meters in height. Today, new turbines are 100 meters tall, perhaps tripling the harvestable wind. We now know that the United States has enough harnessable wind energy to meet not only national *electricity* needs, but national *energy* needs.[20]

When the wind industry began in California in the early 1980s, wind-generated electricity cost 38¢ per kilowatt-hour. Since then it has dropped to 4¢ or below at prime wind sites. And some U.S. long-term supply contracts have been signed for 3¢ per kilowatt-hour. Wind farms at prime sites may be generating electricity at 2¢ per kilowatt-hour by 2010, making it one of the world's cheapest sources of electricity.[21]

Low-cost electricity from wind can be used to electrolyze water to produce hydrogen, which provides a way of both storing and transporting wind energy. At night, when the demand for electricity drops, the hydrogen generators can be turned on to build up reserves. Once in storage, hydrogen can be used to fuel power plants. Wind-generated hydrogen can thus become a backup for wind power, with hydrogen-powered electricity generation kicking in when wind power ebbs. Wind-generated hydrogen can also serve as an alternative to natural gas, especially if rising prices make gas prohibitively costly for electricity generation.

The principal cost for wind-generated electricity is the upfront capital outlay for initial construction. Since wind is a free fuel, the only ongoing cost is for turbine maintenance. Given the recent volatility of natural gas prices, the stability of wind power prices is particularly appealing. With the near certainty of even higher costs of natural gas in the future, natural-gas-fired plants may one day be used only as a backup for wind-generated electricity.

The United States is lagging in developing wind energy simply because the wind production tax credit (PTC) of 1.5¢ per kilowatt-hour, which was adopted in 1992 to establish parity with subsidies to fossil fuel, has lapsed three times in five years. Uncertainty about the tax credit has disrupted planning throughout the wind power industry. With the two-year extension of the PTC in mid-2005, however, through the end of 2007, growth in wind power investments is escalating rapidly.[22]

Given wind's enormous potential and the associated benefits of climate stabilization, it is time to consider an all-out effort to develop wind resources. Instead of doubling every 30 months or so, perhaps we should be doubling wind electric generation each year for the next several years, much as the number of computers linked to the Internet doubled each year from 1985 to 1995. Costs would then drop precipitously, giving electricity generated from wind an even greater advantage over fossil fuels.[23]

Energy consultant Harry Braun points out that since wind turbines are similar to automobiles in the sense that each has an electrical generator, a gearbox, an electronic control system, and a brake, they can be mass-produced on assembly lines. Indeed, the slack in the U.S. automobile industry is sufficient to produce a million wind turbines per year. The lower cost associated with mass production could drop the cost of wind-generated electricity below 2¢ per kilowatt-hour. Assembly-line production of wind turbines at "wartime" speed would quickly lower urban air pollution, carbon emissions, and the prospect of oil wars.[24]

The economic incentives to spur such growth could come in part from simply restructuring global energy subsidies—shifting the $210 billion in annual fossil fuel subsidies to the development of wind and other renewable sources of energy. The investment capital could come from private capital markets but also from companies already in the energy business. Shell, for example, has become a major player in the world wind energy economy. In 2002, General Electric, one of the world's largest corporations, entered the wind business, becoming overnight a major wind turbine manufacturer.[25]

These goals may seem farfetched, but here and there around the world ambitious efforts are beginning to take shape. In the United States, a 3,000-megawatt wind farm is in the early planning stages. Located in South Dakota near the Iowa border, it is being initiated by Clipper Wind, led by James Dehlsen, a wind energy pioneer in California. Designed to feed power into the industrial Midwest around Chicago, this project is not only large by wind power standards, it is one of the largest energy projects of any kind in the world today. In the eastern United States, Cape Wind is planning a 420-megawatt wind farm off the coast of Cape Cod, Massachusetts.[26]

Some 24 states now have commercial-scale wind farms feeding electricity into the U.S. grid. Although there is occasionally a NIMBY problem ("not in my backyard"), the PIMBY response ("put it in my backyard") is much more pervasive. This is not surprising, since a single large turbine can easily generate $100,000 worth of electricity in a year.[27]

The competition among farmers in places like Iowa or ranchers in Colorado for wind farms is intense. Farmers, with no investment on their part, typically receive $3,000–5,000 a year in royalties from the local utility for siting a single, large, advanced-design wind turbine, which occupies a quarter-acre of land. This land would produce 40 bushels of corn worth $120 or, in ranch country, beef worth perhaps $15.[28]

In addition to the additional income, tax revenue, and jobs that wind farms bring, money spent on electricity generated from wind farms stays in the community, creating a ripple effect throughout the local economy. Within a matter of years, thousands of ranchers could be earning far more from electricity sales than from cattle sales.

The question is not whether wind is a potentially vast source of climate-benign energy that can be used to stabilize climate. It is. But will we develop it fast enough to head off economically disruptive climate change?

Hybrid Cars and Wind Power

With the price of oil over $60 a barrel at this writing in September 2005, with political instability in the Middle East on the rise, with little slack in the world oil economy, and with temperatures rising, the world needs a new energy economy. Fortunately, the foundation for a new transportation energy economy has been laid with two new technologies—the gas-electric hybrid engines pioneered by Toyota and advanced-design wind turbines.[29]

These technologies deployed together can dramatically reduce world oil use. As noted earlier, the United States could easily cut its gasoline use in half by converting the U.S. automobile fleet to hybrid cars as efficient as the Toyota Prius. No change in the number of vehicles, no change in miles driven—just doing it with the most efficient propulsion technology on the market.[30]

In fact, there are now several gas-electric hybrid car models on the market in addition to the Prius, including the Honda Insight and a hybrid version of the Honda Civic. According to the Environmental Protection Agency, the Prius—a midsize car on the cutting-edge of automotive technology—gets an astounding 55 miles per gallon in combined city/highway driving compared with 22 miles per gallon for the average new passenger vehicle. No wonder there are lists of eager buyers willing to wait several months for delivery.[31]

Recently, Ford released a hybrid model of its Escape SUV, and Honda released a hybrid version of its popular Accord sedan. General Motors will offer hybrid versions of several of its cars beginning with the Saturn VUE in 2006, followed by the Chevy Tahoe and Chevy Malibu.[32]

Earlier in this chapter we outlined how to cut U.S. gasoline use in half by shifting to gas-electric hybrid vehicles over the next decade. As we shift to these cars, the stage is set for the second step to reduce gasoline use, namely the use of wind-generated electricity to power automobiles. If we add to the gas-electric hybrid a second battery to increase its electricity storage and a plug-in capacity so the batteries can also be recharged from the grid, motorists could then do their commuting, grocery shopping, and other short-distance travel largely with electricity, saving gasoline for the occasional long trip. Even more exciting, recharging batteries with off-peak wind-generated electricity would cost the equivalent of gasoline at 50¢ per gallon. This modification of hybrids could reduce remaining gasoline use by perhaps another 40 percent (or 20 percent of the original level of use), for a total reduction of gasoline use of 70 percent.[33]

These are not the only technologies that can dramatically cut gasoline use. Amory Lovins, a highly regarded pioneer in devising ways of reducing energy use, observes that most efforts to reduce automotive fuel efficiency focus on designing more-efficient engines, largely overlooking the potential of fuel savings from reducing vehicle weight. He notes that substituting advanced polymer composites for steel in constructing the body of automobiles can "roughly double the efficiency of a normal-weight hybrid without materially raising its total manufacturing cost." If we build gas-electric hybrids using the new advanced polymer composites, then we can cut the remaining 30 percent of fuel use by another half, for a total reduction of 85 percent.[34]

Unlike the widely discussed fuel cell/hydrogen transportation model, the gas-electric hybrid/wind model does not require a costly new infrastructure, since the network of gasoline service stations and the electricity grid are already in place. To fully exploit this technology, the United States would need to integrate its weak regional grids into a strong national one, which it needs to do anyway to reduce the risk of blackouts. This, combined with the building of thousands of wind farms across the country, would allow the nation's fleet of automobiles to run largely on wind energy.[35]

One of the few weaknesses of wind energy—its irregularity—is largely offset with the use of plug-in gas-electric hybrids, since the vehicle batteries become a storage system for wind energy. Beyond this, there is always the tank of gasoline as a backup.

The combination of gas-electric hybrids with a second storage battery and a plug-in capacity, the development of wind resources, and the use of advanced polymer composites to reduce vehicle weight has been discussed in a U.S. context but it is a model that can be used throughout the world. It is particularly appropriate for countries that are richly endowed with wind energy, such as China, Russia, Australia, Argentina, and many of those in Europe.[36]

Moving to the highly efficient plug-in gas-electric hybrids, combined with the construction of thousands of wind farms across the country to feed electricity into a strong, integrated national grid, could cut U.S. gasoline use by 85 percent. It would also rejuvenate farm and ranch communities and shrink the U.S. balance-of-trade deficit. Even more important, it could cut automobile carbon emissions by some 85 percent, making the United States a model for other countries.

Converting Sunlight to Electricity

Wind is not the only vast untapped source of energy. When a team of three scientists at Bell Labs in Princeton, New Jersey, discovered in 1952 that sunlight striking a silicon surface could generate electricity, they opened the door to another near limitless source of energy—photovoltaic (or solar) cells. "No country uses as much energy as is contained in the sunlight that strikes its buildings each day," writes Denis Hayes, former Director of the U.S. government's Solar Energy Research Institute.[37]

Sales of solar cells worldwide jumped by a phenomenal 57 percent in 2004, pushing the generating capacity installed during the year to 1,200 megawatts. With this addition, world solar-cell generating capacity, which has doubled in the last two years, now exceeds 4,300 megawatts, roughly the equivalent of 13 coal-fired power plants. (See Figure 10–2.) A decade ago the United States had roughly half of the world market, but this has now dropped to 12 percent as Japan and Germany have surged ahead with ambitious solar programs.[38]

Solar cells are used either in stand-alone systems or in systems that can feed into the grid. In its early years, the solar cell industry was dominated by non-grid uses to supply electricity to communication satellites and in remote sites such as national forests or parks, offshore lighthouses, summer homes in isolated mountain regions, or islands.

Over the last decade, solar cell installations that feed into the grid have grown rapidly in response to incentives offered by governments, and they now account for more than three fourths of

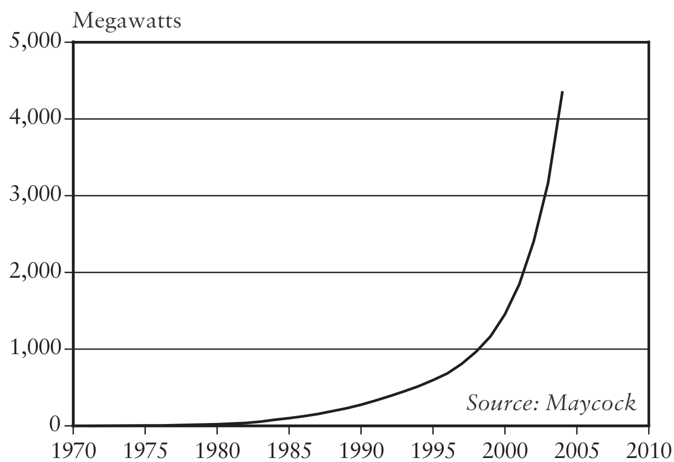

Figure 10–2. *World Photovoltaic Generating Capacity, 1971–2004*

all new installations. Two-way meters that enable utility customers to feed surpluses into the grid for a fixed rate have spurred rapid growth in solar cell use. The U.S. Energy Policy Act of 2005 established two-way metering for any customer requesting it. Some countries have established a fixed price for utilities to pay for electricity fed into the grid. In Germany, this has been set well above the market price to reflect the value of clean electricity and to get the fledgling solar cell industry off the ground.[39]

The residential use of solar cells is expanding at a breakneck pace in some countries. In Japan, where companies have commercialized a solar roofing material, the idea of making the roof the power plant for the home is increasingly popular. This, combined with Japan's 70,000 Roofs Program launched in 1994 to subsidize the installations, got the country off to a fast start, making it a world leader in solar-generated electricity.[40]

In 1998, Germany initiated a 100,000 Roofs Program, which gave consumers 10-year loans for buying photovoltaic systems at reduced interest rates. This ended in 2003 when the goal of 100,000 solar roofs was reached. With this fast-growing market, solar cell costs now have fallen to where German manufacturers are quite competitive internationally.[41]

Within the United States, California is also providing attractive incentives for the residential installation of solar cells. In a climate where peak capacity on hot summer days presses against the limits of the grid, solar cells are seen as an alternative to fossil fuel plants, mostly gas-fired, that operate only during the peak daytime demand. Happily, solar cells generate the most electricity during the hottest times of the day, making them ideal for satisfying peak power demands.[42]

Solar cell installations may be even more economical in large buildings. In Manchester, England, a 40-story office building in need of renovation will be covered with photovoltaic material. With three sides of this 400-foot building covered with this material, the building has a huge generating surface. An official of the building owner and occupant, the Co-operative Insurance Society, noted with a smile that it would produce enough electricity each year to make 9 million cups of tea.[43]

In recent years, a vast new off-grid solar cell market has opened up in developing-country villages, where the cost of building a centralized power plant and a grid to deliver relatively small amounts of electricity to individual consumers is prohibitive. With solar cells costs falling, however, it is now often cheaper to provide electricity from solar cell installations than from a centralized source.

In Andean villages, solar installations are replacing candles as a source of lighting. For villagers who are paying for the installation over 30 months, the monthly payment is roughly equal to the cost of a month's supply of candles. Once the solar cells are paid for, the villagers then have an essentially free source of power—one that can supply electricity for decades. Similarly, in villages in India, where light now comes from kerosene lamps, soaring oil prices mean that kerosene from imported oil may now cost far more than solar cells.[44]

Today more than 1 million homes in villages in the developing world are getting their electricity from solar cells, but this represents less than 1 percent of the 1.7 billion people who do not yet have electricity. The principal obstacle to the spread of solar cell installations in villages is not the cost per se, but the lack of small-scale credit programs to finance them. If this credit shortfall is quickly overcome, village purchases of solar cells will soar.[45]

The future of solar cells is promising. Japan, for example, where residential installations exceeded 1,000 megawatts at the end of 2004, plans to get 10 percent of its electricity from solar cells by 2030. Germany now has 700 megawatts of installed capacity and is growing fast. The United States, a distant third, introduced a solar tax credit in the Energy Policy Act of 2005. The first such credit in 20 years, it promises to rejuvenate the U.S. solar industry.[46]

The cost of solar cells has been dropping for several decades and is expected to continue falling for the indefinite future. With each doubling of cumulative production, the manufacturing economics of scale drop the price an additional 20 percent. In addition, technologies for producing solar cells that convert more sunlight into electricity and do so at a lower cost are being worked on at numerous research facilities in several countries.[47]

In addition to generating electricity from solar cells, solar energy can also be concentrated to boil water and produce steam, driving a turbine to generate electricity. There are various designs used in solar-thermal power plants, including power