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Turning to Renewable Energy

Just as the nineteenth century belonged to coal and the twentieth century to oil, the twenty-first century will belong to the sun, the wind, and energy from within the earth. In Europe, the addition of electrical generating capacity from renewable energy sources in 2006 exceeded that from conventional sources, making it the first continent to enter the new energy era. Meanwhile, in the United States electrical generating capacity from wind increased 27 percent in 2006, while that from coal decreased slightly.[1]

We can see the Plan B energy economy emerging in many areas. In Texas, the state government is coordinating a vast expansion of wind power that could yield 23,000 megawatts of new generating capacity, an amount equal to 23 coal-fired power plants. In China, some 160 million people now get their hot water from rooftop solar water heaters. In Iceland, almost 90 percent of homes are heated with geothermal energy. In Europe, 60 million people rely on wind farms for their electricity. And in the Philippines, 19 million people get their electricity from geothermal power plants.[2]

In the last chapter, we described how to offset the projected increases in energy use to 2020 with gains in efficiency. This chapter addresses the challenge of harnessing renewable energy on a scale that will help reduce worldwide carbon dioxide (CO_2) emissions by 80 percent. The first priority is to replace all coal- and oil-fired electricity generation with renewable sources.

The Plan B goals for developing renewable sources of energy by 2020 that are laid out in this chapter are based not on what is conventionally believed to be politically feasible, but on what we think is needed to prevent irreversible climate change. This is not Plan A, business as usual. This is Plan B—a wartime mobilization, an all-out response proportionate to the threat that global warming presents to our future.

Can we expand renewable energy use fast enough? We think so. Recent trends in the use of mobile phones and personal computers give a sense of how quickly new technologies can spread. Once cumulative mobile phone sales reached 1 million units in 1986, the stage was set for explosive growth, and the number of cell phone subscribers doubled in each of the next three years. Over the next 12 years the number of people owning a mobile phone more than doubled every two years. By 2001 there were 995 million cell phones—a 1,000-fold increase in just 15 years. As of 2007, there were more than 2 billion cell phone subscribers worldwide.[3]

Sales of personal computers followed a similar trajectory. In 1983 roughly a million were sold, but by 2003 the figure was an estimated 160 million—a 160-fold jump in 20 years. We are now seeing similar growth figures for renewable energy technologies. Sales of solar cells are doubling every two years, and the annual growth in wind generating capacity is not far behind. Just as the information and communications economies have changed beyond recognition over the past two decades, so too will the energy economy over the next decade.[4]

There is one outstanding difference. Whereas the restructuring of the information and communications sectors was shaped by advancing technology and market forces, the restructuring of the energy economy will be driven also by the realization that the fate of our global civilization may depend not only on doing so, but doing so at wartime speed.

Harnessing the Wind

A worldwide survey of wind energy by the Stanford team of Cristina Archer and Mark Jacobson concluded that harnessing one fifth of the earth's available wind energy would provide seven times as much electricity as the world currently uses. For example, China—with vast wind-swept plains in the north and west, countless mountain ridges, and a long coastline, all rich with wind—has enough readily harnessable wind energy to easily double its current electrical generating capacity.[5]

In 1991 the U.S. Department of Energy (DOE) released a national wind resource inventory, noting that three wind-rich states—North Dakota, Kansas, and Texas—had enough harnessable wind energy to satisfy national electricity needs. Advances in wind turbine design since then allow turbines to operate at lower wind speeds and to convert wind into electricity more efficiently. And because they are now 100 meters tall, instead of less than 40 meters, they harvest a far larger, stronger, and more reliable wind regime, generating 20 times as much electricity as the turbines installed in the early 1980s when modern wind power development began. With these new turbine technologies, the three states singled out by DOE could satisfy not only national electricity needs but national energy needs.[6]

In addition, a 2005 DOE assessment of offshore wind energy concluded that U.S. offshore wind out to a distance of 50 miles alone is sufficient to meet 70 percent of national electricity needs. Europe is already tapping its offshore wind. A 2004 assessment by the Garrad Hassan wind energy consulting group concluded that if governments aggressively develop their vast offshore resources, wind could supply all of Europe's residential electricity by 2020.[7]

From 2000 to 2007, world wind generating capacity increased from 18,000 megawatts to an estimated 92,000 megawatts. In early 2008 it will pass the 100,000-megawatt milestone. Since 2000, capacity has been growing at 25 percent annually, doubling every three years.[8]

The world leader in total capacity is Germany, followed by the United States, Spain, India, and Denmark. Measured by share of national electricity supplied by wind, Denmark is the leader, at 20 percent. Three north German states now get more than 30 percent of their electricity from wind. For Germany as a whole, it is 7 percent—and climbing.[9]

Denmark is now looking to push the wind share of its electricity to 50 percent, with most of the additional power coming from offshore. In contemplating the prospect of wind becoming the leading source of electricity, Danish planners have turned energy policy upside down. They are looking at using wind as the mainstay of their electrical generating system and fossil-fuel-generated power to fill in when the wind ebbs.[10]

For many years now, the top five countries—with roughly 70 percent of world wind generating capacity—have dominated growth in the industry, but this is now changing as the industry goes global, with 70 countries now harnessing their wind resources. Among the emerging wind powers are China, France, and Canada, each of which doubled its wind electric generation in 2006.[11]

One of the early concerns with wind energy was the risk it posed to birds, but this can be overcome by conducting studies and careful siting to avoid risky areas for birds. The most recent research indicates that bird fatalities from wind farms are minuscule compared with deaths from flying into skyscrapers, colliding with cars, or being captured by cats.[12]

Other critics are concerned about the visual effect. When some people see a wind farm they see a blight on the landscape. Others see a civilization-saving source of energy. Although there are NIMBY problems ("not in my backyard"), the PIMBY response ("put it in my backyard") is much more pervasive. Within U.S. communities, for instance, among ranchers in Colorado or dairy farmers in upstate New York, the competition for wind farms is intense. This is not surprising, since a large, advanced design wind turbine can generate $300,000 worth of electricity in a year. Farmers, with no investment on their part, typically receive $3,000–10,000 a year in royalties for each wind turbine erected on their land.[13]

One of wind's attractions is that it requires so little land compared with other sources of renewable energy. For example, a corn farmer in northern Iowa can put a wind turbine on a quarter-acre of land that can produce $300,000 worth of electricity per year. This same quarter-acre would produce 40 bushels of corn that in turn could produce 120 gallons of ethanol worth $300. Since the turbines occupy less than 1 percent of the land in a wind farm, this technology lets farmers harvest both energy and crops from the same land. Thousands of ranchers in the wind-rich Great Plains will soon be earning more from wind royalties than from cattle sales.[14]

At the moment, growth in wind electricity generation is primarily constrained by wind turbine manufacturing capacity. But the important question is how much of the world's energy needs can wind power meet. To gain perspective, we look at what governments are planning, the size of wind farms under construction and proposed, and the transmission lines that are being planned.[15]

The official U.S. goal of one day getting 20 percent of its electricity from wind means developing at least 300,000 megawatts of wind generating capacity. Since 1 megawatt of wind generating capacity can supply electricity to 300 U.S. homes, wind development on this scale would satisfy the needs of 90 million households. In France, a newcomer to wind energy, the government target is 14,000 megawatts of wind by 2010. Spain, which already has nearly 12,000 megawatts of capacity, is shooting for 20,000 megawatts by 2010.[16]

At the local level, Texas, the state that long led the country in oil production, has taken the lead in wind generation as well. Governor Rick Perry assembled a number of wind farm developers and transmission line builders to link wind-rich west Texas and the Texas panhandle to the state's population centers. This package could lead to the development of 23,000 megawatts of wind generating capacity, enough to satisfy the residential electricity needs of 7 million homes.[17]

In California, the electric utility Southern California Edison is planning a 4,500-megawatt wind project in the southern end of the state. In east central South Dakota, Clipper Windpower has purchased wind rights on enough land to develop 3,000 megawatts of generating capacity. At the national level, wind farm proposals in late 2007 exceeded an estimated 100,000 megawatts, nearly 10 times existing capacity.[18]

In Canada, Katabatic Power and Deutsche Bank are planning a 3,000-megawatt wind farm in British Columbia, which would produce enough electricity to supply some 900,000 homes. The United Kingdom has a 1,000-megawatt offshore wind farm, the London Array, under construction in the Thames Estuary and a 1,500-megawatt wind farm, the Atlantic Array, off the coast of Devon, in the planning stage. Germany is planning several offshore wind farms of a similar size. And China has several 1,000-megawatt wind farms on the drawing board.[19]

Another clue to the scale of future wind farm development can be seen in transmission lines under construction and being planned. Legislatures in Texas, Colorado, New Mexico, California, and Minnesota in the United States combined their support for huge wind farm complexes with the construction of transmission lines to ensure that the two move forward together, avoiding the chicken-and-egg problem.[20]

A number of interstate transmission lines are also being built and discussed. In the north central United States, wind farms in eastern North Dakota and South Dakota are being linked to load centers in Minnesota and Wisconsin. A group of operators is proposing a transmission line that would link the vast wind resources of Kansas and Oklahoma with the southeastern United States, carrying electricity from proposed wind farms with 13,000 megawatts of generating capacity. Another group in the upper Midwest is looking at transmission lines that will link the wind resource riches of the Dakotas with the densely populated East Coast. In the West, the governors of California, Nevada, Utah, and Wyoming have agreed to build a "Frontier Line" that would link the low-cost wind resources of Wyoming with Salt Lake City, Las Vegas, and power-hungry California.[21]

In Europe, Airtricity, an Irish development firm with wind farms in several countries, and ABB, a leader in building energy infrastructure, have proposed an offshore super-grid for Europe stretching from the Baltic Sea to the North Sea and southward to the coast of Spain. This grid would not only aid in realizing Europe's huge offshore wind potential, it would link national grids with each other, thus facilitating more-efficient electricity use throughout the continent. To begin, the companies propose a 10,000-megawatt wind farm project in the North Sea between Germany, the United Kingdom, and the Netherlands that would supply 6 million homes with electricity.[22]

Wind is the centerpiece of the Plan B energy economy. It is abundant, low cost, and widely distributed; it scales up easily and can be developed quickly. Oil wells go dry and coal seams run out, but the earth's wind resources cannot be depleted.

Plan B involves a crash program to develop 3 million

megawatts of wind generating capacity by 2020. This will require a near doubling of capacity every two years, up from the doubling every three years for the last decade. It will mean 1 megawatt for every 2,500 of the world's projected 2020 population of 7.5 billion people. Denmark—with 1 megawatt for every 1,700 people—is already well beyond this goal. Spain will likely exceed this per capita goal before 2010 and Germany shortly thereafter.[23]

This climate-stabilizing initiative would require the installation of 1.5 million 2-megawatt wind turbines. Manufacturing such a huge number of wind turbines over the next 12 years sounds intimidating until the initiative is compared with the 65 million cars the world produces each year. At $3 million per installed turbine, this would involve investing $4.5 trillion over the next dozen years, or $375 billion per year. This compares with world oil and gas capital expenditures that are projected to reach $1 trillion per year by 2016.[24]

Wind turbines can be mass-produced on assembly lines. Indeed, the idled capacity in the U.S. automobile industry is sufficient to produce the wind turbines to reach the Plan B global goal.[25]

Not only do the idle plants exist, but there are skilled workers in these communities eager to return to work. The state of Michigan, for example, in the heart of the wind-rich Great Lakes region, has more than its share of idled auto assembly plants. The Spanish firm Gamesa, a leading wind turbine manufacturer, recently set up operations in an abandoned U.S. Steel plant in Pennsylvania.[26]

Wind-Powered Plug-in Hybrid Cars

In Chapter 10 we discussed measures that cities are using to reduce the need for cars. But even with fewer cars, the world desperately needs a new automotive energy economy, a new source of fuel. Fortunately, the foundation for this has been laid with two new technologies: the gas-electric hybrid cars pioneered by Toyota and advanced-design wind turbines.

The Toyota Prius—a fast-selling mid-size hybrid car—gets an impressive 46 miles per gallon in combined city/highway driving, compared with 20 miles per gallon for the average new U.S. passenger vehicle. The United States could easily cut its gasoline use in half simply by converting the U.S. automobile fleet to highly efficient hybrid cars. No change in the number of vehicles. No change in the miles driven. Just doing it with the most efficient propulsion technology on the market.[27]

Now that hybrid cars are well established, it is a relatively small step to manufacturing plug-in hybrids that run largely on electricity. By putting a larger battery in a gas-electric hybrid to increase its storage of electricity and adding a plug-in capacity so the battery can be recharged from the power grid, drivers can do their commuting, grocery shopping, and other short-distance travel almost entirely 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 less than $1 per gallon of gasoline. This modification of hybrids to run largely on electricity could reduce remaining gasoline use an additional 60 percent, for a total reduction of 80 percent.[28]

But this is not all. Amory Lovins—an energy efficiency pioneer—notes that substituting advanced polymer composites for steel in auto bodies can "roughly double the efficiency of a normal-weight hybrid without materially raising its total manufacturing cost." Thus, building gas-electric hybrids using the new advanced polymer composites, which are being introduced by Boeing in its new 787 Dreamliner jumbo jet, can cut the remaining 20 percent of fuel use by another half, for a total reduction of 90 percent.[29]

The plug-in electric hybrid/wind power transportation model does not require a costly new infrastructure, since the network of gasoline service stations and the electricity grid are already in place. A 2006 study by the U.S. government's Pacific Northwest National Laboratory estimated that 84 percent of the electricity used by a national fleet of plug-in cars, pickup trucks, and SUVs could be satisfied with the existing electrical infrastructure since the recharging would take place largely at night, when there is an excess of generating capacity.[30]

The variability of wind energy is of concern to many commentators, but it can be largely offset by integrating local and regional grids into a strong national grid, something that is needed anyhow to raise load-management efficiency. Since no two wind farms have identical wind flows, each wind farm added to a large grid reduces variability. With many wind farms on a large grid, variability largely disappears.[31]

Another major source of stability will come from the shift to plug-in hybrids, since the vehicle batteries become a storage system for wind energy. With a smart grid, motorists could profitably sell electricity back to the grid when needed during peak demand. In effect, the shift to plug-in hybrids, with their electricity storage capacity and backup tank of gasoline, buffers the variability of wind energy, enabling it to become the centerpiece of the Plan B energy economy.[32]

The shift to fuel-efficient plug-in hybrid cars combined with the construction of thousands of wind farms across the United States will rejuvenate farm and ranch communities and dramatically shrink the U.S. balance-of-trade deficit. Even more important, it could cut automobile CO_2 emissions by some 90 percent, making the United States a model for other countries.[33]

The fast-growing support for plug-in hybrids has coalesced into a national grassroots initiative called Plug-In Partners. As of late 2007, Plug-In Partners had 617 members, including 169 electrical utilities, 168 corporations, 71 city governments, and 67 environmental groups. A number of the Plug-In Partners have announced advanced orders for plug-in cars and delivery vans, including the government of New York State, Southern California Edison, and Pacific Gas and Electric. These so-called soft orders, now totaling more than 11,000 vehicles, will go to the first company that makes it to the market with a plug-in hybrid.[34]

Among the companies planning to manufacture these vehicles are Nissan, Toyota, General Motors (GM, with its Chevrolet Volt), and Ford Motor Company (with the Airstream). Chrysler's Dodge Sprinter plug-in hybrid vans are already being tested by various firms, including Pacific Gas and Electric. The first companies to market plug-in hybrids may find it difficult to keep up with the demand.[35]

The Chevrolet Volt, which will be on the market in 2010, will have a 40-mile range on electricity only. Beyond this distance, a small gasoline engine will generate electricity to recharge the battery. For the 78 percent of Americans who live 20 miles or less from their work site, it will be possible to commute without using any gasoline. For those with longer commutes, plugging in at the worksite is also an option. Based on an analysis of U.S. driving patterns, GM estimates that the Volt will get 150 miles per gallon, since the gas-powered recharger engine would come into play only occasionally. It is this prospect of triple-digit gasoline mileage that is selling consumers on plug-in hybrids.[36]

Solar Cells and Collectors

Several technologies are now used to harness the sun's energy, including both solar thermal collectors and solar photovoltaic cells. Solar thermal collectors, widely used to heat water, are now also used for space heating. Collectors, which concentrate sunlight to boil water and produce steam-generated electricity, and assemblages of solar electric cells are both used on a commercial power plant scale, with individual plants capable of supplying thousands of homes with electricity.

Perhaps the most exciting recent development in the world solar economy is the installation of some 40 million rooftop solar water heaters in China. With 2,000 Chinese companies manufacturing rooftop solar water heaters, this relatively simple low-cost technology is not only widely used in cities, it has also leapfrogged into villages that do not yet have electricity. For as little as $200, villagers can have a rooftop solar collector installed and take their first hot shower. This technology is sweeping China like wildfire, already approaching market saturation in some communities. Even more exciting, Beijing plans to more than double the current 124 million square meters of rooftop solar collectors for heating water to 300 million by 2020.[37]

The energy harnessed by these installations in China is equal to the electricity generated by 54 coal-fired power plants. Other developing countries such as India and Brazil may also soon see millions of households turning to this inexpensive water heating technology. This leapfrogging into rural areas without an electricity grid is similar to the way cell phones bypassed the traditional fixed-line grid, providing services to millions of people who would still be on waiting lists if they had relied on traditional phone lines. The great attraction of rooftop solar water heaters is that once the initial installment cost is paid, the hot water is essentially free.[38]

In Europe, where energy costs are relatively high, rooftop solar water heaters are also spreading fast. In Austria, Europe's

leader, 15 percent of all households now rely on them for hot water. And, as in China, in some Austrian villages nearly all homes have rooftop collectors. Germany is also forging ahead. Janet Sawin of Worldwatch Institute notes that some 2 million Germans are now living in homes where water and space are both heated by rooftop solar systems.[39]

Inspired by the rapid adoption of rooftop water and space heaters in Europe in recent years, the European Solar Thermal Industry Federation (ESTIF) has established an ambitious goal of 500 million square meters, or one square meter of rooftop collector for every European by 2020, a goal that exceeds the 0.74 square meters per person today in Israel, the world leader. Most installations are projected to be Solar-Combi systems that are engineered to heat both water and space.[40]

In 2007, Europe's solar collectors were concentrated in Germany, Austria, and Greece, with France and Spain also beginning to mobilize. Spain's initiative was boosted by a March 2006 mandate requiring installation of collectors on all new or renovated buildings. ESTIF estimates that the European Union has a long-term potential of developing 1,200 thermal gigawatts of solar water and space heating, which means that the sun could meet most of Europe's low-temperature heating needs.[41]

The U.S. rooftop solar water heating industry has thus far concentrated on a niche market—selling and marketing 10 million square meters of water heaters for swimming pools between 1995 and 2005. Given this base, however, the industry is poised to mass-market residential solar water and space heating systems.[42]

We now have the data to make some global projections. With China setting a goal of 300 million square meters of solar water heating capacity by 2020, and ESTIF's goal of 500 million square meters by 2020, a U.S. installation of 200 million square meters by 2020 is certainly within reach given the recently adopted tax incentives. Japan, which now has 11 million square meters of rooftop solar collectors heating water but which imports almost all its fossil fuels, could easily reach 80 million square meters by 2020. If China, the United States, Japan, and the European Union achieve their goals, they will have a combined total of 1,080 million square meters of water and space heating capacity by 2020. This would come to 0.45 square meters per person for the 2.4 billion people in these countries, still well below Israel's figure today.[43]

If the developing world's 5 billion people in 2020 have 0.1 square meter of rooftop water heating capacity per person by 2020, roughly the same as in China or Turkey today, this would add 500 million square meters to the world total, pushing it over 1.5 billion square meters. If we assume that each meter provides 0.7 thermal kilowatts of power, then we are looking at a world solar thermal capacity by 2020 of 1,100 thermal gigawatts, the equivalent of 690 coal-fired power plants.[44]

The huge projected expansion in solar water and space heating in industrial countries could close some existing coal-fired power plants and reduce natural gas use, as solar water heaters replace electric and gas water heaters. In countries such as China and India, however, solar water heaters will simply reduce the need for new coal-fired power plants.

One reason for the explosive growth of solar water and space heaters in Europe and China is the economic appeal. On average, in industrial countries these systems pay for themselves from electricity savings in fewer than 10 years.[45]

With the cost of rooftop heating systems declining, other countries will likely join Israel and Spain in mandating that all new buildings incorporate rooftop water and space heaters. No longer a passing fad, these rooftop appliances are fast becoming a mainstream source of energy as fossil fuel prices rise.[46]

While the direct use of sunlight to heat water has dominated the harnessing of solar energy to date, the world's fastest-growing energy source is the solar cells that convert sunlight into electricity. Installations worldwide now total 8,600 megawatts. Although solar cells are still only a minor source of electricity, their use is growing by over 40 percent annually, doubling every two years. In 2006, Germany installed 1,150 megawatts of solar cell–generating capacity, making it the first country to install over 1 gigawatt (1,000 megawatts) in a year.[47]

Until recently, the production of solar cells was concentrated in Japan, Germany, and the United States, but several energetic new players have recently entered the industry, featuring companies in China, Taiwan, the Philippines, South Korea, and the United Arab Emirates. China overtook the United States in solar cell production in 2006. Taiwan may do so in 2007. Today there are scores of firms competing in the world market, driving investments in both research and manufacturing.[48]

For the nearly 1.6 billion people living in communities not yet connected to an electrical grid, it is now often cheaper to install solar cells rooftop-by-rooftop than to build a central power plant and a grid to reach potential consumers. For Andean villagers, for example, who have depended on tallow-based candles for their lighting, the monthly payment for a solar cell installation over 30 months is less than the monthly outlay for candles.[49]

Villagers in India who are not yet connected to a grid and who depend on kerosene lamps face a similar cost calculation. Installing a home solar electric system in India, including batteries, costs roughly $400. Such systems will power two, three, or four small appliances or lights and are widely used in homes and shops in lieu of polluting and increasingly costly kerosene lamps. In one year a kerosene lamp burns nearly 20 gallons of kerosene, which at $3 a gallon means $60 per lamp. A solar cell lighting system that replaced only two lamps would pay for itself within four years.[50]

The estimated 1.5 billion kerosene lamps in use today provide only 0.5 percent of all residential lighting but account for 29 percent of residential lighting's CO_2 emissions. They use the equivalent of 1.3 million barrels of oil per day, which is equal to roughly half the oil production of Kuwait. Replacing these lamps with solar cell installations would cut world oil use by 1.5 percent and reduce annual carbon emissions by 52 million tons.[51]

For industrial countries, Michael Rogol and his PHOTON consulting company estimate that by 2010 fully integrated companies that encompass all phases of solar cell manufacturing will be installing systems that produce electricity for 12¢ a kilowatt-hour in sun-drenched Spain and 18¢ a kilowatt-hour in southern Germany. Although solar cell costs will be dropping below those of conventional electricity in many locations, this will not automatically translate into a wholesale conversion to solar cells. But as one energy CEO observes, the "big bang" is under way.[52]

With sales of solar cells now doubling every two years and likely to continue doing so at least until 2020, the estimated sales for 2008 of over 5,000 megawatts will climb to 320,000 megawatts in 2020. By this time the cumulative installed capacity would exceed 1 million megawatts (1,000 gigawatts). Although this projection may seem ambitious, it may in fact turn out to be conservative. For one thing, if most of the nearly 1.6 billion people who lack electricity today get it by 2020, it will likely be because they have installed solar home systems.[53]

When a villager buys a solar cell system, that person is in effect buying a 25-year supply of electricity. Since there is no fuel cost and very little maintenance, it is the upfront outlay that counts, and that typically requires financing. Recognizing this, the World Bank and the U.N. Environment Programme have stepped in with programs to help local lenders set up credit systems to finance this cheap source of electricity. An initial World Bank loan has helped 50,000 home owners in Bangladesh obtain solar cell systems. A second, much larger round of funding will enable 200,000 more families to do the same.[54]

Investors are also turning to large-scale solar cell power plants. A 20-megawatt facility under construction in South Korea, scheduled for completion in late 2008, is the largest in the world. It will soon be eclipsed, however, by a 40-megawatt facility being built near Leipzig, Germany, that is scheduled to start supplying electricity by 2009. In Spain, BP Solar contracted to build some 278 small generating facilities with a combined capacity of 25 megawatts. At its headquarters in Mountain View, California, Google—one of the many companies investing in solar electric cells—has installed a 1.6-megawatt array of solar cells to convert sunlight into electricity.[55]

More and more countries, states, and provinces are setting solar cell installation goals. Japan, for example, is planning 4,800 megawatts of solar cell–generating capacity by 2010, a goal it will likely exceed. The state of California has set a goal of 3,000 megawatts by 2017. On the U.S. East Coast, Maryland is aiming for 1,500 megawatts of solar installations by 2022. And in China, Shanghai is shooting for 100,000 rooftop solar cell installations, though for a city with 6 million rooftops this is only a beginning. Altogether, the global Plan B economy is projected to have 1,190 gigawatts of solar cell capacity by 2020.[56]

Another promising way to harness solar energy uses sunlight to heat water and produce steam to generate electricity. This solar thermal technology—often referred to as concentrated solar power—simply uses reflectors with automated tracking systems to concentrate sunlight on a closed vessel containing water or some other liquid, raising the temperature as high as 750 degrees Fahrenheit to produce steam. California installed 354 megawatts of solar thermal–generating capacity nearly 20 years ago, but with cheap fossil-fuel-fired electricity, investments in solar thermal power dried up. With fossil fuel prices and concern about climate change both climbing, there is now a resurgence of interest. A 64-megawatt solar thermal power plant completed in 2007 in Nevada, a similar one under construction in Spain, and a 300-megawatt facility proposed in Florida represent the new wave of these facilities.[57]

Prominent among the regions with the solar intensity needed to profitably operate solar thermal power plants are the U.S. Southwest, North Africa, Mediterranean Europe, the Middle East, Central Asia, and the desert regions of Pakistan, northwestern India, and northern and western China.[58]

The dream of using the Sahara Desert's vast solar resources to supply electricity to Europe may soon become a reality. In June 2007 Algeria announced plans to build 6,000 megawatts of solar thermal generating capacity for export by cable to Europe. In July 2007 construction began on a 150-megawatt natural gas/solar hybrid plant, where the gas takes over entirely at night when there is no sunlight. This plant is located at Hassi R'mel, 260 miles south of Algiers, the capital.[59]

Painfully aware that its oil and gas exports will not last forever, the Algerian government has created a company, New Energy Algeria, to manage the development and export of its solar energy. Its managing director, Tewfik Hasni, says "our potential in thermal solar power is four times the world's energy consumption." Construction of undersea cables linking the solar thermal–generating plants in the Sahara to Europe is planned for 2010–12.[60]

The great attraction of solar thermal generation in sunny climates is that it peaks during the day when air conditioning needs and personal power demands are also peaking. An American Solar Energy Society (ASES) study concluded that the sun-rich southwestern United States—after excluding its less promising areas—has a potential solar power generating capacity of 7,000 gigawatts of electricity, roughly seven times current U.S. generating capacity from all sources. Assuming that the 30 percent tax credit for investment in solar generating facilities continues and that the price of carbon climbs to $35 per ton, the ASES study concluded that 80 gigawatts of this generating potential could be developed by 2030.[61]

Greenpeace and ESTIF have outlined a worldwide plan to develop 600,000 megawatts of solar thermal power plant capacity by 2040. We suggest a more immediate goal of 200,000 megawatts by 2020, a goal that may well be exceeded as climate change concerns escalate.[62]

Energy from the Earth

It is widely known within the energy community that there is enough solar energy reaching the earth each hour to power the world economy for one year, but few people know that the heat in the upper six miles of the earth's crust contains 50,000 times as much energy as found in all the world's oil and gas reserves combined. Despite this abundance, only 9,300 megawatts of geothermal generating capacity have been harnessed worldwide.[63]

Partly because of the dominance of the oil, gas, and coal industries, which have been providing cheap fuel by omitting the indirect costs of fossil fuel burning, relatively little has been invested in developing the earth's geothermal heat resources. Over the last decade, geothermal energy has been growing at scarcely 3 percent a year. Half the world's generating capacity is concentrated in the United States and the Philippines. Four other countries—Mexico, Indonesia, Italy, and Japan—account for most of the remainder. Altogether some 24 countries now convert geothermal energy into electricity. The Philippines, with geothermally generated power supplying 25 percent of its electricity, and El Salvador, at 22 percent, are the leaders.[64]

Beyond this, an estimated 100,000 thermal megawatts of geothermal energy, roughly 10 times the amount converted to electricity, is used directly—without conversion into electricity—to heat homes and greenhouses and as process heat in industry. This includes, for example, the energy used in hot baths in Japan and to heat homes in Iceland and greenhouses in Russia.[65]

An interdisciplinary team of 13 scientists and engineers assembled by the Massachusetts Institute of Technology (MIT) in 2006 assessed U.S. geothermal electrical-generating potential. Drawing on the latest technologies, including those used by oil and gas companies in drilling and in enhanced oil recovery, the team estimated that enhanced geothermal systems could be used to develop 100,000 megawatts of electrical generating capacity in the United States by 2050, a capacity equal to 250 coal-fired power plants. To fully realize this potential, the MIT team estimated that the government would have to invest up to $1 billion in geothermal research and development in the years immediately ahead, roughly the cost of one large coal-fired power plant.[66]

Even without this research commitment, some 61 U.S. geothermal projects were under construction or in development in early 2007. If the United States can develop 100,000 megawatts of geothermal generating capacity, how much could other countries, many of them far more richly endowed, develop with the same technologies? A decade-old estimate for Japan indicated that country could develop 69,000 megawatts of generating capacity. With enhanced geothermal systems, this might easily double to 140,000 megawatts.[67]

Indonesia, with 500 volcanoes, 128 of which are still active, undoubtedly has a far greater potential. It could get all its electricity from cheap, easily tapped geothermal energy. With its oil production falling, Indonesia is fortunate to be so richly endowed with an energy source that can last forever.[68]

The potential of geothermal energy to provide electricity, to heat homes, and to supply process heat for industry is vast. Among the countries rich in geothermal energy are those bordering the Pacific in the so-called ring of fire, including Chile, Peru, Colombia, Mexico, the United States, Canada, Russia, China, Japan, the Philippines, Indonesia, and Australia. Other geothermally rich countries include those along the Great Rift Valley of Africa, such as Kenya and Ethiopia, and those around the Eastern Mediterranean.[69]

In the direct use of geothermal heat, Iceland and France are among the leaders. Iceland's use of geothermal energy to heat almost 90 percent of its houses has largely eliminated the use of coal for home heating. Geothermal energy accounts for more than one third of Iceland's total energy use. Following the two oil price hikes in the 1970s, some 70 geothermal heating facilities were constructed in France, providing both heat and hot water for an estimated 200,000 residences. In the United States, individual homes are supplied directly with geothermal heat in Reno, Nevada, and in Klamath Falls, Oregon. Other countries that have extensive geothermally based district-heating systems include China, Japan, and Turkey.[70]

Geothermal heat is ideal for greenhouses in northern countries. Russia, Hungary, Iceland, and the United States are among the many countries that use it to produce fresh vegetables in the winter. With rising oil prices boosting fresh produce transport costs, this practice will likely become far more common in the years ahead.[71]

Among the 16 countries using geothermal energy for aquaculture are China, Israel, and the United States. In California, for example, 15 fish farms annually produce some 10 million pounds (4.5 million kilograms) of tilapia, striped bass, and catfish using warm water from underground.[72]

The number of countries turning to geothermal energy for both electricity and heat is rising fast. So, too, is the range of uses. Romania, for instance, uses geothermal energy for district heating, for greenhouses, and to supply hot water for homes and factories.[73]

Hot underground water is widely used for both bathing and swimming. Japan has 2,800 spas, 5,500 public bathhouses, and 15,600 hotels and inns that use geothermal hot water. Iceland uses geothermal energy to heat some 100 public swimming pools, most of them year-round open-air pools. Hungary heats 1,200 swimming pools with geothermal energy.[74]

If the four most populous countries located on the Pacific "ring of fire"—the United States, Japan, China, and Indonesia, with nearly 2 billion people—were to seriously invest in developing their geothermal resources, they could easily make geothermal energy one of the world's leading sources of electricity. With a potential in the United States and Japan alone of 240,000 megawatts of geothermal power generation, it is easy to envisage a world with 200,000 megawatts of geothermally generated electricity by 2020.[75]

Plant-Based Sources of Energy

As oil and natural gas reserves are being depleted, the world's attention is turning to plant-based energy sources. These include forest industry byproducts, sugar industry byproducts, urban waste, livestock waste, energy crops, crop residues, and urban tree and yard wastes—all of which can be used for electrical generation, heating, or the production of automotive fuels.

In the forest products industry, including both sawmills and paper mills, waste has long been used to generate electricity. U.S. companies burn forest wastes both to produce process heat for their own use and to generate electricity for sale to local utilities. The bulk of the nearly 10,000 megawatts in U.S. plant-based electrical generation comes from burning forest waste.[76]

Wood waste is also widely used in urban areas for combined heat and power production, with the heat typically used in district heating systems. In Sweden, nearly half of all residential and commercial buildings are served with district heating systems. As recently as 1980, imported oil supplied over 90 percent of the heat for these systems, but by 2005 it had been largely replaced by wood chips, urban waste, and lignite.[77]

In the United States, St. Paul, Minnesota—a city of nearly 300,000 people—began to develop district heating more than 20 years ago. It built a combined heat and power plant using tree waste from the city's parks, industrial wood waste, and wood from other sources. The combined heat and power plant, using 250,000 tons or more of waste wood per year, now supplies district heating to some 80 percent of the downtown area, or more than 1 square mile of residential and commercial floor space. This shift to wood waste largely replaced coal, thus simultaneously cutting carbon emissions by 76,000 tons per year, disposing of waste wood, and providing a sustainable source of heat and electricity.[78]

The sugar industry recently has begun to burn cane waste to cogenerate heat and power. This received a big boost in Brazil, when companies with cane-based ethanol distilleries realized that burning bagasse, the fibrous material left after the sugar syrup is extracted, could simultaneously produce heat for fermentation and generate electricity that they could sell to the local utility. This system, now well established in the Brazilian ethanol industry, is spreading to sugar mills in other countries that produce the remaining 80 percent of the world sugar harvest.[79]

Within cities, once recyclable materials are removed, garbage can also be burned to produce heat and power. In Europe, waste-to-energy plants supply 20 million consumers with heat. Germany, with 65 plants, and France are the European leaders. In the United States, some 89 waste-to-energy plants convert 20 million tons of waste into power for 6 million consumers.[80]

With U.S. livestock and poultry production now concentrated in large facilities, the use of animal waste in anaerobic digesters to produce methane (natural gas) is catching on fast. AES Corporation, one of the world's largest electrical power companies, is creating a business of capturing methane from animal waste. Using biodigesters, AES contracts with farmers to process their animal waste, producing methane and a nutrient-rich solid waste that farmers return to the fields as fertilizer. The methane collected in these generators can be burned to supply heat and generate power.[81]

Corporations and utilities are also tapping the methane produced in landfills as organic materials in buried garbage decompose, to produce industrial process heat or to generate electricity in combined heat and power plants. Interface—the world's largest manufacturer of industrial carpet—near Atlanta, Georgia, convinced the city to invest $3 million in capturing methane from the municipal landfill and build a nine-mile pipeline to an Interface factory. The natural gas in this pipeline, priced 30 percent below the world market price, meets 20 percent of the factory's needs. The landfill is projected to supply methane for 40 years, earning the city $35 million on its original $3 million investment. For Interface, operating costs are reduced and it gains an offset of its greenhouse gas emissions, thus enabling the factory to become climate-neutral.[82]

Crops can also be used to produce automotive fuels, including both ethanol and biodiesel. In 2007 the world produced 13.1 billion gallons of fuel ethanol and 2.3 billion gallons of biodiesel. Half of the ethanol came from the United States, a third came from Brazil, and the remainder came from a dozen other countries, led by China and Canada. Almost one fourth of the biodiesel was produced in Germany; the other major producers were the United States, France, and Italy.[83]

The United States, which surged ahead of Brazil in ethanol production in 2005, relies heavily on corn as a feedstock. With U.S. ethanol production projected to nearly double between 2007 and the end of 2008, U.S. output will jump to 13 billion gallons. This may already be exceeding the amount of U.S. grain that can be diverted to fuel without driving world food prices to an unacceptably high level. And expanding cane-based ethanol in Brazil means putting more pressure on the remaining Amazonian rainforest. Shifting to plug-in hybrids powered with wind or solar generated electricity would avoid that.[84]

As of mid-2007, growth in investment in ethanol and biodiesel was losing momentum as feedstock prices rose for both ethanol distilleries and biodiesel refineries and as soaring grain prices sounded alarm bells for food consumers everywhere. In Europe, with high goals for biodiesel use and low potential for expanding oilseed production, biodiesel refiners are turning to palm oil from Malaysia and Indonesia, where the clearing of rainforests for palm plantations is raising worldwide concern.[85]

Work is now under way to develop efficient technologies to convert cellulosic materials such as switchgrass, woodchips, wheat straw, and corn stalks into ethanol. Switchgrass and hybrid poplars would produce relatively high ethanol yields on marginal lands, but it likely will be another decade before cellulosic ethanol can compete with corn-based ethanol.[86]

An analysis by the American Solar Energy Society indicates that burning cellulosic crops to directly generate electricity is much more efficient than converting them to ethanol. The question is how much could plant materials contribute to the world's energy supply. ASES estimates that the United States could generate 110 gigawatts of electricity from burning crops such as switchgrass and fast growing trees, roughly 10 times the current level. This projected growth assumes that the anticipated expansion in cellulosic crop production would be used primarily for electricity generation rather than ethanol production. We anticipate that the worldwide use of plant materials to generate electricity could contribute 200 gigawatts to generating capacity by 2020.[87]

River, Tidal, and Wave Power

Roughly 16 percent of the world's electricity comes from hydropower, most of it from large dams. Some countries such as Brazil and the Democratic Republic of the Congo get most of their electricity from river power. Large dam building flourished during the third quarter of the last century, but then slowed as the remaining good sites for dam building dwindled and as opposition built because of the displacement of people and inundation of productive land.[88]

Small-scale projects continue to be built. In 2006 small dams with a combined 6,000 megawatts of generating capacity were built in rural areas of China. For many rural communities these are the only source of electricity. Though China leads, many other countries also are building small-scale structures, as the economics of generation increasingly favor renewable sources over fossil fuels. There is also a growing interest in in-stream turbines that do not need a dam and are thus less environmentally intrusive.[89]

The first large tidal generating facility—La Rance barrage, with a generating capacity of 240 megawatts—was built 40 years ago in France and is still operating today. Within the last few years interest in tidal power has spread rapidly. South Korea, for example, is building a 254-megawatt project on its west coast. When completed in 2009, this facility will provide enough electricity for the half-million people living in the nearby city of Ansan. At another site 30 miles to the north, engineers are planning an 812-megawatt tidal facility near Inchon.[90]

Not far away, China is planning a 300-megawatt tidal facility at the mouth of the Yalu River near North Korea. Far to the south, New Zealand is planning a 200-megawatt project in the Kaipara Harbour on the country's north coast.[91]

Gigantic projects are under consideration in several countries, including India, Britain, and Russia. India is planning to build a 39-mile barrage across the Gulf of Khambhat on the country's northwest coast with a 7,400-megawatt generating capacity. In the United Kingdom, several political leaders are pushing for an 8,600-megawatt tidal facility in the Severn Estuary on the county's southwest coast. Russian planners are also talking in terms of 10,000-megawatt tidal power plants. One such facility is to be built in the Sea of Okhotsk on the east coast, and another is proposed for the White Sea in northwestern Russia, near Finland.[92]

In the United States, the focus is on smaller tidal facilities. The Federal Energy Regulatory Commission has issued preliminary permits for projects in Puget Sound, San Francisco Bay, and New York's East River. The San Francisco Bay project by Oceana Energy Company will have 40 or more megawatts of generating capacity. In addition to these proposals, 38 applications are pending from states on both coasts.[93]

Wave power, though it is a few years behind tidal power, is now attracting the attention of both engineers and investors. In the United States, the northern Californian utility PG&E has filed a plan to develop two 40-megawatt wave farms off the state's north coast. Oil giant Chevron filed for a permit to develop up to 60 megawatts of wave generating capacity nearby.[94]

The South West of England Regional Development Agency invited bids by firms to test their technologies in the Wave Hub Project off the coast of Cornwall. The authority will provide cable connections to the U.K. grid from the offshore facilities for up to 20 megawatts of power. Ireland has the most ambitious wave power development goal: 500 megawatts of wave generating capacity by 2020, enough to supply 7 percent of its electricity.[95]

We project that the 850 gigawatts (850,000 megawatts) of hydroelectric power in operation worldwide in 2006 will expand to 1,350 gigawatts by 2020. According to China's official projections, 270 gigawatts will be added there, mostly from large dams in the country's southwest. The remaining 230 gigawatts in our projected growth by 2020 would come from a scattering of large dams still being built in countries like Brazil and Turkey, a large number of small hydro facilities, a fast-growing number of tidal projects (some of them in the multi-gigawatt range), and numerous smaller wave power projects. If the interest in tidal and wave power continues to escalate, the additional capacity from hydro, tidal, and wave by 2020 could easily exceed the 500 gigawatts needed to reach the Plan B goal.[96]

The World Energy Economy of 2020

Backing out fossil fuels begins with the electricity sector, where the development of 5,153 gigawatts of new renewable generating capacity by 2020, over half of it from wind, would be more than enough to replace all the coal and oil and 70 percent of the natural gas now used to generate electricity. (See Table 12–1.) The addition of 1,530 gigawatts of thermal capacity by 2020 will reduce the use of both oil and gas for heating buildings and water. Roughly two thirds of this growth will come from rooftop solar water and space heaters.[97]

In looking at the broad shifts from 2006 to the Plan B energy economy of 2020, fossil fuel–generated electricity drops by 90 percent. This is more than offset by the fivefold growth in renewably generated electricity. In the transportation sector, energy use from fossil fuels drops by some 70 percent. This comes from shifting not just to hybrids that run partly on electricity but to highly efficient plug-in hybrids that run largely on electricity from renewable sources. And it also comes from shifting to electric trains, which are much more efficient than diesel-powered trains.[98]

Closely related to this overall energy restructuring are several indirect energy savings. For example, when coal is phased out as a power source the vast amount of energy used to extract the coal, bring it to the surface, and transport it—typically hundreds of miles by rail to power plants—is no longer needed. Some 42 percent of U.S. freight is coal transported by diesel-powered locomotives.[99]

The new energy economy will be based much less on energy from combustion and more on the direct harnessing of energy from wind, the sun, and the earth itself. In the new economy, for example, cars will be running largely on wind energy.

Electricity will be much more prominent in the new energy economy. In 2020 it will be the principal source of energy for cars, largely replacing gasoline. For trains it will replace diesel fuel. In the new economy, many buildings will be all-electric—heated, cooled, and illuminated entirely with carbon-free renewable electricity.

Just as renewable energy technologies are advancing, so too are those that will lead to a smart grid, one that uses smart meters, to constantly monitor not only electricity flows but specific uses at the household level. It gives consumers a choice, for example, between running a dishwasher during peak demand and paying 9¢ per kilowatt-hour for electricity and running it at 3 a.m. using 5¢ electricity. Giving consumers options like this can

Table 12–1. *World Energy from Renewables in 2006 and Plan B Goals for 2020*

Source	2006	Goal for 2020
Electricity Generating Capacity	(electrical gigawatts)	
Wind	74	3,000
Rooftop solar electric systems	9	1,090
Solar electric power plants	0	100
Solar thermal power plants	0	200
Geothermal	9	200
Biomass	45	200
Hydropower	850	1,350
Total	987	6,140
Thermal Energy Capacity	(thermal gigawatts)	
Solar rooftop water and space heaters	100	1,100
Geothermal	100	500
Biomass	220	350
Total	420	1,950

Source: See endnote 97.

shrink their electricity bills and benefit utilities by reducing the generating capacity that utilities will need.[100]

Whereas fossil fuels helped globalize the energy economy, shifting to renewable sources will localize it. We anticipate that the energy transition will be driven largely by mounting concerns about climate change, by climbing oil prices, and by the restructuring of taxes to incorporate the indirect costs of burning fossil fuels. It is encouraging to know that we now have the technologies to build a new energy economy, one that is not climate-disruptive, that does not pollute the air, and that can last as long as the sun itself. The question is no longer whether we can develop a climate-stabilizing energy economy, but whether we can develop it before climate change spins out of control.