from *Plan B 4.0: Mobilizing to Save Civilization*, by Lester R. Brown

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Stabilizing Climate: Shifting to Renewable Energy

As fossil fuel prices rise, as oil insecurity deepens, and as concerns about climate change cast a shadow over the future of coal, a new energy economy is emerging. The old energy economy, fueled by oil, coal, and natural gas, is being replaced by one powered by wind, solar, and geothermal energy. Despite the global economic crisis, this energy transition is moving at a pace and on a scale that we could not have imagined even two years ago. And it is a worldwide phenomenon.

Consider Texas. Long the leading U.S. oil-producing state, it is now also the leading generator of electricity from wind, having overtaken California three years ago. Texas now has 7,900 megawatts of wind generating capacity online, 1,100 more in the construction stage, and a huge amount in the development stage. When all of these wind farms are completed, Texas will have 53,000 megawatts of wind generating capacity—the equivalent of 53 coal-fired power plants. This will more than satisfy the residential needs of the state's 24 million people, enabling Texas to export electricity, just as it has long exported oil.[1]

Texas is not alone. In South Dakota, a wind-rich, sparsely populated state, development has begun on a vast 5,050-

megawatt wind farm (1 megawatt of wind capacity supplies 300 U.S. homes) that when completed will produce nearly five times as much electricity as the 796,000 people living in the state need. Altogether, some 10 states in the United States, most of them in the Great Plains, and several Canadian provinces are planning to export wind energy.[2]

Across the Atlantic, the government of Scotland is negotiating with two sovereign wealth funds in the Middle East to invest $7 billion in a grid in the North Sea off its eastern coast. This grid will enable Scotland to develop nearly 60,000 megawatts of off-shore wind generating capacity, close to the 79,000 megawatts of current electrical generating capacity for the United Kingdom.[3]

We are witnessing an embrace of renewable energy on a scale we've never seen for fossil fuels or nuclear power. And not only in industrial countries. Algeria, which knows it will not be exporting oil forever, is planning to build 6,000 megawatts of solar thermal generating capacity for export to Europe via undersea cable. The Algerians note that they have enough harnessable solar energy in their vast desert to power the entire world economy. This is not a mathematical error. A similarly striking fact is that the sunlight striking the earth in just one hour is enough to power the world economy for one year.[4]

Turkey, which now has 39,000 megawatts of total electrical generating capacity, issued a request for proposals in 2007 to build wind farms. It received bids from both domestic and international wind development firms to build a staggering 78,000 megawatts of wind generating capacity. Having selected 15,000 megawatts of the most promising proposals, the government is now issuing construction permits.[5]

In mid-2008, Indonesia—a country with 128 active volcanoes and therefore rich in geothermal energy—announced that it would develop 6,900 megawatts of geothermal generating capacity, with Pertamina, the state oil company, responsible for developing the lion's share. Indonesia's oil production has been declining for the last decade, and in each of the last four years the country has been an oil importer. As Pertamina shifts resources from oil into the development of geothermal energy, it could become the first oil company—state-owned or independent—to make the transition from oil to renewable energy.[6]

These are only a few of the visionary initiatives to tap the earth's renewable energy. The resources are vast. In the United States, three states—North Dakota, Kansas, and Texas—have enough harnessable wind energy to run the entire economy. In China, wind will likely become the dominant power source. Indonesia could one day get all its power from geothermal energy alone. Europe will be powered largely by wind farms in the North Sea and solar thermal power plants in the North African desert.[7]

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. This is not Plan A, business as usual. This is Plan B—a wartime mobilization, an all-out response that is designed to avoid destabilizing economic and political stresses that will come with unmanageable climate change.

To reduce worldwide net carbon dioxide (CO_2) emissions by 80 percent by 2020, the first priority is to replace all coal- and oil-fired electricity generation with renewable sources. Whereas the twentieth century was marked by the globalization of the world energy economy as countries everywhere turned to oil, much of it coming from the Middle East, this century will see the localization of energy production as the world turns to wind, solar, and geothermal energy.

This century will also see the electrification of the economy. The transport sector will shift from gasoline-powered automobiles to plug-in gas-electric hybrids, all-electric cars, light rail transit, and high-speed intercity rail. And for long-distance freight, the shift will be from diesel-powered trucks to electrically powered rail freight systems. The movement of people and goods will be powered largely by electricity. In this new energy economy, buildings will rely on renewable electricity almost exclusively for heating, cooling, and lighting.

In the electrification of the economy, we do not count on a buildup in nuclear power. Our assumption is that the limited number of nuclear power plants now under construction worldwide will simply offset the closing of aging plants, with no overall growth in capacity by 2020. If we use full-cost pricing—requiring utilities to absorb the costs of disposing of nuclear waste, of decommissioning a plant when it wears out, and of insuring reactors against possible accidents and terrorist attacks—building nuclear plants in a competitive electricity market is simply not economical.[8]

Beyond the costs of nuclear power are the political questions. If we say that expanding nuclear power is an important part of our energy future, do we mean for all countries or only for some countries? If the latter, who makes the A-list and the B-list of countries? And who enforces the listings?

In laying out the climate component of Plan B, we also exclude the oft-discussed option of carbon sequestration at coal-fired power plants. Given the costs and the lack of investor interest within the coal community itself, this technology is not likely to be economically viable on a meaningful scale by 2020.

Can we expand renewable energy use fast enough? We think so. Recent trends in the adoption 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 doubled every two years. By 2001 there were 961 million cell phones—nearly a 1,000-fold increase in just 15 years. And now there are more than 4 billion cell phone subscribers worldwide.[9]

Sales of personal computers followed a similar trajectory. In 1980 roughly a million were sold, but by 2008 the figure was an estimated 270 million—a 270-fold jump in 28 years. We are now seeing similar growth figures for renewable energy technologies. Installations of solar cells are doubling every two years, and the annual growth in wind generating capacity is not far behind. Just as the communications and information economies have changed beyond recognition over the past two decades, so too will the energy economy over the next decade.[10]

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

Turning to the Wind

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.

A worldwide survey of wind energy by the Stanford University 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.[11]

The United States is also richly endowed. In addition to having enough land-based wind energy to satisfy national electricity needs several times over, the National Renewable Energy Lab has identified 1,000 gigawatts (1 gigawatt equals 1,000 megawatts) of wind energy waiting to be tapped off the East Coast and 900 gigawatts off the West Coast. This offshore capacity alone is sufficient to power the U.S. economy.[12]

Europe is already tapping its off-shore wind. An assessment by the Garrad Hassan wind energy consulting group concluded that if governments aggressively develop their vast off-shore resources, wind could supply all of Europe's residential electricity by 2020.[13]

For many years, a small handful of countries dominated growth in the industry, but this is changing as the industry goes global, with some 70 countries now harnessing wind resources. World wind electric generation is growing at a frenetic pace. From 2000 to 2008, generating capacity increased from 17,000 megawatts to an estimated 121,000 megawatts. The world leader in total capacity is now the United States, followed by Germany (until recently the leader), Spain, China, and India. But with China's wind generation doubling each year, the U.S. lead may be short-lived.[14]

Measured by share of national electricity supplied by wind, Denmark is the leader, at 21 percent. Four north German states now get one third or more of their electricity from wind. For Germany as a whole, the figure is 8 percent—and climbing.[15]

Denmark is now looking to push the wind share of its electricity to 50 percent, with most of the additional power coming from off-shore. In contemplating this prospect, 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.[16]

In Spain, which already has nearly 17,000 megawatts of capacity, the government is shooting for 20,000 megawatts by 2010. France, a relative newcomer to wind energy, is looking to develop 25,000 megawatts of wind by 2020; out of this, 6,000 megawatts would be off-shore.[17]

As of early 2009 the United States had just over 28,000 megawatts of wind generating capacity, with an additional 38 wind farms under construction. Beyond this, proposed wind farms that can generate some 300,000 megawatts are on hold, awaiting grid construction.[18]

In addition to Texas and California, which is planning a 4,500-megawatt wind farm complex in the southern end of the state, several other states are emerging as wind superpowers. As noted earlier, Clipper Windpower and BP are teaming up to build the 5,050-megawatt Titan wind farm in eastern South Dakota. Colorado billionaire Philip Anschutz is developing a 2,000-megawatt wind farm in south central Wyoming to generate electricity for transmission to California, Arizona, and Nevada.[19]

In the east, Maine—a wind energy newcomer—is planning to develop 3,000 megawatts of wind generating capacity, far more than the state's 1.3 million residents need. New York State, which has 1,300 megawatts of wind generating capacity, plans to add another 8,000 megawatts, with most of the power being generated by winds coming off Lake Erie and Lake Ontario. And soon Oregon will nearly double its wind generating capacity with the 900-megawatt wind farm planned for the windy Columbia River Gorge.[20]

While U.S. attention has focused on the wind-rich Great Plains, and rightly so, another area is now gathering attention. For years, the only off-shore wind project in the east that was moving through the permitting stage was a 400-megawatt project off the coast of Cape Cod, Massachusetts. Now Massachusetts has been joined by Rhode Island, New York, New Jersey, and Delaware. Delaware is planning an off-shore wind farm of

up to 600 megawatts, an installation that could satisfy half the state's residential electricity needs.[21]

East Coast off-shore wind is attractive for three reasons. One, it is strong and reliable. The off-shore region stretching from Massachusetts southward to North Carolina has a potential wind generating capacity that exceeds the requirement of the states in the region. Two, the East Coast has an extensive, rather shallow off-shore area, which makes off-shore wind construction less costly. And three, this electricity source is close to consumers.[22]

To the north, Canada, with its vast area and only 33 million people, has one of the highest wind-to-population ratios of any country. Ontario, Quebec, and Alberta are far and away the leaders in installed capacity at this point. But in recent months three of Canada's four Atlantic provinces—New Brunswick, Prince Edward Island, and Nova Scotia—have begun discussions to jointly develop and export some of their wealth of wind energy to the densely populated U.S. Northeast.[23]

Impressive though the U.S. growth is, the expansion now under way in China is even more so. China has some 12,000 megawatts of wind generating capacity, mostly in the 50- to 100-megawatt wind farm category, with many more medium-size wind farms coming. Beyond this, its Wind Base program is creating six mega-complexes of wind farms of at least 10 gigawatts each. These are located in Gansu Province (15 gigawatts), Western Inner Mongolia (20 gigawatts), Eastern Inner Mongolia (30 gigawatts), Hebei Province (10 gigawatts), Xinjiang Hami (20 gigawatts), and along the coast north of Shanghai in Jiangsu Province (10 gigawatts). When completed, these complexes will have a generating capacity of 105 gigawatts—as much wind power as the entire world had in early 2008.[24]

In considering the land requirements to produce energy, wind turbines are extraordinarily efficient. For example, an acre of corn land in northern Iowa used to site a wind turbine can produce $300,000 worth of electricity per year. This same acre of land planted in corn would yield 480 gallons of ethanol worth $960. This extraordinary energy yield of land used for wind turbines helps explain why investors find wind farms so attractive.[25]

And since wind turbines occupy only 1 percent of the land covered by a wind farm, farmers and ranchers continue to grow grain and graze cattle. In effect, they can double crop their land, simultaneously harvesting a food crop—wheat, corn, or cattle—and energy. With no investment on their part, farmers and ranchers typically receive $3,000–10,000 a year in royalties for each wind turbine erected on their land. For thousands of ranchers in the U.S. Great Plains, the value of electricity produced on their land in the years ahead will dwarf their cattle sales.[26]

One of the early concerns with wind energy was the risk it posed to birds, but this can be managed by careful siting to avoid risky migration and breeding areas. The most recent research indicates that bird fatalities from wind farms are minuscule compared with the number of birds that die flying into skyscrapers, colliding with cars, or being captured by cats.[27]

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 rural communities, competition for wind farms—whether in ranch country in Colorado or dairy country in upstate New York—is intense. This is not surprising, since the jobs, the royalties from wind turbines, and the additional tax revenue are welcomed by local communities.

At the heart of Plan B is a crash program to develop 3,000 gigawatts (3 million megawatts) of wind generating capacity by 2020, enough to satisfy 40 percent of world electricity needs. This will require a near doubling of capacity every two years, up from a doubling every three years over the last decade.[28]

This climate-stabilizing initiative would require the installation of 1.5 million wind turbines of 2 megawatts each. Manufacturing such a huge number of wind turbines over the next 11 years sounds intimidating until it is compared with the 70 million automobiles the world produces each year. At $3 million per installed turbine, this would mean investing $4.5 trillion by 2020, or $409 billion per year. This compares with world oil and gas capital expenditures that are projected to reach $1 trillion per year by 2016.[29]

Wind turbines can be mass-produced on assembly lines, much as B-24 bombers were in World War II at Ford's massive Willow Run assembly plant in Michigan. Indeed, the idled capacity in the U.S. automobile industry is sufficient to produce all the wind turbines the world needs to reach the Plan B global goal. 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.[30]

Wind has many attractions. For utilities, being able to sign long-term fixed-price contracts is a godsend for them and their customers. When they look at natural gas, they look at a fuel source with a volatile price. When they look at coal-fired power, they face the uncertainty of future carbon costs.

The appeal of wind energy can be seen in its growth relative to other energy sources. In 2008, for example, wind accounted for 36 percent of new generating capacity in the European Union compared with 29 percent for natural gas, 18 percent for photovoltaics, 10 percent for oil, and only 3 percent for coal. In the United States, new wind generating capacity has exceeded coal by a wide margin each year since 2005. Worldwide, no new nuclear-generating capacity came online in 2008, while new wind generating capacity totaled 27,000 megawatts. The structure of the world energy economy is not just changing, it is changing fast.[31]

Solar Cells and Thermal Collectors

Energy from the sun can be harnessed with solar photovoltaics (PV) and solar thermal collectors. Solar PV cells—both often silicon-based semiconductors and thin films—convert sunlight directly into electricity. Solar thermal collectors convert sunlight into heat that can be used, for example, to warm water, as in rooftop solar water heaters. Alternatively, collectors can be used to concentrate sunlight on a vessel containing water to produce steam and generate electricity.

Worldwide, photovoltaic installations jumped by some 5,600 megawatts in 2008, pushing total installations to nearly 15,000 megawatts. One of the world's fastest-growing energy sources, solar PV production is growing by 45 percent annually, doubling every two years. In 2006, when Germany installed 1,100 megawatts of solar cell generating capacity, it became the first country to add over 1 gigawatt (1,000 megawatts) in a year.[32]

Until recently PV production was concentrated in Japan, Germany, and the United States. But several energetic new players have entered the field, with companies in China, Taiwan, the Philippines, South Korea, and the United Arab Emirates. China overtook the United States in PV production in 2006. Taiwan did so in 2007. Today there are scores of firms competing in the world market, driving investments in both research and manufacturing.[33]

For the nearly 1.6 billion people living in communities not yet connected to an electrical grid, it is now often cheaper to install PV panels 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.[34]

When a villager buys a solar PV system, that person is in effect buying a 25-year supply of electricity. With no fuel cost and very little maintenance, it is the upfront outlay that 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 homeowners in Bangladesh obtain solar cell systems. A second, much larger round of funding will enable 200,000 more families to do the same.[35]

Villagers in India who lack electricity 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 PV lighting system that replaces two lamps would pay for itself within four years and then become essentially a free source of electricity.[36]

Switching from kerosene to solar cells is particularly helpful in fighting climate change. Although the estimated 1.5 billion kerosene lamps used worldwide provide less than 1 percent of all residential lighting, they account for 29 percent of that sector's CO_2 emissions. They use the equivalent of 1.3 million barrels of oil per day, equal to roughly half the oil production of Kuwait.[37]

The cost of solar energy is falling fast in industrial countries. Michael Rogol and his PHOTON consulting firm estimate that by 2010 fully integrated companies that encompass all phases of solar PV 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 these costs will be dropping below those of conventional electricity in many locations, this will not automatically translate into a wholesale conversion to solar PV. But as one energy industry analyst observes, the "big bang" is under way.[38]

After starting with relatively small residential rooftop installations, investors are now turning to utility-scale solar cell complexes. A 20-megawatt facility completed in Spain in 2007 was the largest ever built—but not for long. A 60-megawatt facility, also in Spain, came online in 2008 and tripled the ante. Even larger solar cell installations are being planned, including 80-megawatt facilities in California and Israel.[39]

In mid-2008, Pacific Gas and Electric (PG&E), one of two large utilities in California, announced a contract with two firms to build solar PV installations with a combined generating capacity of 800 megawatts. Covering 12 square miles, this complex will generate as much electricity at peak power as a nuclear power plant. The bar has been raised yet again.[40]

And in early 2009, China Technology Development Group Corporation and Qinghai New Energy Group announced they were joining forces to build a 30-megawatt solar PV power facility in remote Qinghai Province. This is the first stage in what is eventually expected to become a 1,000-megawatt generating facility. For a country that ended 2008 with only 145 megawatts of installed solar cell capacity, this is a huge leap into the future.[41]

More and more countries, states, and provinces are setting solar installation goals. Italy's solar industry group is projecting 16,000 megawatts of installed capacity by 2020. Japan is planning 14,000 megawatts by 2020. The state of California has set a goal of 3,000 megawatts by 2017. New Jersey has a goal of 2,300 megawatts of solar installations by 2021, and Maryland is aiming for 1,500 megawatts by 2022.[42]

With installations of solar PV now doubling every two years and likely to continue doing so at least until 2020, annual installations, at nearly 5,600 megawatts in 2008, will climb to 500,000 megawatts in 2020. By this time the cumulative installed capacity would exceed 1.5 million megawatts (1,500 gigawatts). Although this may seem overly ambitious, it could in fact turn out to be a conservative goal. 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 home solar systems.[43]

A second, very promising way to harness solar energy on a massive scale is simply to use reflectors to concentrate sunlight on a closed vessel containing water or some other liquid, heating the liquid to produce steam that drives a turbine. This solar thermal technology, often referred to as concentrating solar power (CSP), first came on the scene with the construction of a 350-megawatt solar thermal power plant complex in California. Completed in 1991, it remained the world's only utility-scale solar thermal generating facility until the completion of a 64-megawatt power plant in Nevada in 2007. As of early 2009, the United States has 6,100 megawatts of solar thermal power plants under development, all with signed long-term power purchase agreements.[44]

In mid-2009 Lockheed Martin, an aerospace defense and information technology contractor, announced that it was building a 290-megawatt CSP plant in Arizona. This plant, like many other CSP plants, will have six hours of storage, enabling it to generate electricity until midnight or beyond. The entry into the solar field of a company with annual sales of $43 billion and vast engineering skills signals a major new commitment to harnessing the earth's abundance of solar energy.[45]

As noted earlier, the government of Algeria plans to produce 6,000 megawatts of solar thermal electrical capacity for transmission to Europe via undersea cable. The German government was quick to respond to the Algerian initiative. The plan is to build a 1,900-mile high-voltage transmission line from Adrar deep in the Algerian desert to Aachen, a town on Germany's border with the Netherlands.[46]

The first plant under construction in Algeria is a solar/natural-gas hybrid, with the natural gas taking over power generation entirely after the sun goes down. Although the first few plants in this massive new project will be hybrids, New Energy Algeria, the government firm specifically created to encourage renewable energy development, plans soon to switch exclusively to solar thermal power. These plants will likely use molten salt or some other medium for storing heat in order to extend generation several hours beyond sundown and through the high-demand evening hours.[47]

The U.S. plants under development and this announcement by the Algerians were the early indications that the world is entering the utility-scale solar thermal power era. By the end of 2008, there were some 60 commercial-scale solar thermal power plants in the pipeline, most of them in the United States and Spain. Among the 10 largest proposed plants, 8 are to be built in the United States. Ranging in size from 250 to 900 megawatts, most of them will be in California. The early months of 2009 brought many more announcements. BrightSource Energy announced a blockbuster package with Southern California Edison of seven projects with a collective total of 1,300 megawatts of generating capacity. Shortly thereafter, it announced an identical package with PG&E's. NRG, a New Jersey–based firm, and eSolar announced that together they would develop 500 megawatts of CSP at sites in the southwestern United States.[48]

Spain, another solar superpower, has 50 or so plants, each close to 50 megawatts in size, in various phases of development. There are a scattering of proposed CSP plants in other countries, including Israel, Australia, South Africa, the United Arab Emirates, and Egypt. At least a dozen other sun-drenched countries now recognize the potential of this inexhaustible, low-cost source of electricity and are mobilizing to tap it.[49]

One of the countries for which CSP plants are ideally suited is India. Although this nation is not nearly as richly endowed with wind energy as, say, China or the United States, the Great Indian Desert in the northwest offers a huge opportunity for building solar thermal power plants. Hundreds of plants in the desert could satisfy most of India's electricity needs. And because it is such a compact country, the distance for building transmission lines to connect with major population centers is relatively short.

Solar thermal electricity costs are falling fast. Today it costs roughly 12–18¢ per kilowatt-hour. The U.S. Department of Energy goal is to invest in research that will lower the cost to 5–7¢ per kilowatt-hour by 2020.[50]

We know solar energy is abundant. The American Solar Energy Society notes there are enough solar thermal resources in the U.S. Southwest to satisfy current U.S. electricity needs nearly four times over. The U.S. Bureau of Land Management, the agency that manages public lands, has received requests for the land rights to develop solar thermal power plants or photovoltaic complexes with a total of 23,000 megawatts of generating capacity in Nevada, 40,000 megawatts in Arizona, and over 54,000 megawatts in the desert region of southern California.[51]

At the global level, Greenpeace, the European Solar Thermal Electricity Association, and the International Energy Agency's SolarPACES program have outlined a plan to develop 1.5 million megawatts of solar thermal power plant capacity by 2050. For Plan B we suggest a more immediate world goal of 200,000 megawatts by 2020, a goal that may well be exceeded as the economic potential becomes clearer.[52]

The pace of solar energy development is accelerating as solar water heaters—the other use of solar collectors—take off. China, for example, is now home to 27 million rooftop solar water heaters. With nearly 4,000 Chinese companies manufacturing these devices, this relatively simple low-cost technology has 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. Beijing plans to boost the current 114 million square meters of rooftop solar collectors for heating water to 300 million by 2020.[53]

The energy harnessed by these installations in China is equal to the electricity generated by 49 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. Once the initial installment cost of rooftop solar water heaters is paid, the hot water is essentially free.[54]

In Europe, where energy costs are relatively high, rooftop solar water heaters are also spreading fast. In Austria, 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 the Worldwatch Institute notes that some 2 million Germans are now living in homes where water and space are both heated by rooftop solar systems.[55]

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 1 square meter of rooftop collector for every European by 2020—a goal slightly greater than the 0.93 square meters per person found today in Cyprus, the world leader. Most installations are projected to be Solar-Combi systems that are engineered to heat both water and space.[56]

Europe's solar collectors are 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. Portugal followed quickly with its own mandate. 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.[57]

The U.S. rooftop solar water heating industry has historically concentrated on a niche market—selling and marketing 10 million square meters of solar water heaters for swimming pools between 1995 and 2005. Given this base, however, the industry was poised to mass-market residential solar water and space heating systems when federal tax credits were introduced in 2006. Led by Hawaii, California, and Florida, U.S. installation of these systems tripled in 2006 and has continued at a rapid pace since then.[58]

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 for Europe by 2020, a U.S. installation of 300 million square meters by 2020 is certainly within reach given the recently adopted tax incentives. Japan, which now has 7 million square meters of rooftop solar collectors heating water but which imports virtually all its fossil fuels, could easily reach 80 million square meters by 2020.[59]

If China and the European Union achieve their goals and Japan and the United States reach the projected adoptions, they will have a combined total of 1,180 million square meters of water and space heating capacity by 2020. With appropriate assumptions for developing countries other than China, the global total in 2020 could exceed 1.5 billion square meters. This would give the world a solar thermal capacity by 2020 of 1,100 thermal gigawatts, the equivalent of 690 coal-fired power plants.[60]

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.

Solar water and space heaters in Europe and China have a strong economic appeal. On average, in industrial countries these systems pay for themselves from electricity savings in fewer than 10 years. They are also responsive to energy security and climate change concerns.[61]

With the cost of rooftop heating systems declining, particularly in China, many other countries will likely join Israel, Spain, and Portugal in mandating that all new buildings incorporate rooftop solar water heaters. No longer a passing fad, these rooftop appliances are fast entering the mainstream.[62]

Thus the harnessing of solar energy is expanding on every front as concerns about climate change and energy security escalate, as government incentives for harnessing solar energy expand, and as these costs decline while those of fossil fuels rise. In 2009, new U.S. generating capacity from solar sources could exceed that from coal for the first time.[63]

Energy from the Earth

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—a startling statistic that few people are aware of. Despite this abundance, only 10,500 megawatts of geothermal generating capacity have been harnessed worldwide.[64]

Partly because of the dominance of the oil, gas, and coal industries, which have been providing cheap fuel by omitting the costs of climate change and air pollution from fuel prices, 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.[65]

Half the world's existing generating capacity is in the United States and the Philippines. Mexico, Indonesia, Italy, and Japan account for most of the remainder. Altogether some 24 countries now convert geothermal energy into electricity. Iceland, the Philippines, and El Salvador respectively get 27, 26, and 23 percent of their electricity from geothermal power plants.[66]

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.[67]

Beyond geothermal electrical generation, an estimated 100,000 thermal megawatts of geothermal energy are 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.[68]

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 massively develop geothermal energy. This technology involves drilling down to the hot rock layer, fracturing the rock and pumping water into the cracked rock, then extracting the superheated water to drive a steam turbine. The MIT team notes that with this technology the United States has enough geothermal energy to meet its energy needs 2,000 times over.[69]

Though it is still costly, this technology can be used almost anywhere to convert geothermal heat into electricity. Australia is currently the leader in developing pilot plants using this technology, followed by Germany and France. To fully realize this potential for the United States, the MIT team estimated that the government would need to invest $1 billion in geothermal research and development in the years immediately ahead, roughly the cost of one coal-fired power plant.[70]

Even before this exciting new technology is widely deployed, investors are moving ahead with existing technologies. For many years, U.S. geothermal energy was confined largely to the Geysers project north of San Francisco, easily the world's largest geothermal generating complex, with 850 megawatts of generating capacity. Now the United States, which has more than 3,000 megawatts of geothermal generation, is experiencing a geothermal renaissance. Some 126 power plants under development in 12 states are expected to nearly triple U.S. geothermal generating capacity. With California, Nevada, Oregon, Idaho, and Utah leading the way, and with many new companies in the field, the stage is set for massive U.S. geothermal development.[71]

Indonesia, richly endowed with geothermal energy, stole the spotlight in 2008 when it announced a plan to develop 6,900 megawatts of geothermal generating capacity. The Philippines, currently the world's number two generator of electricity from geothermal sources, is planning a number of new projects.[72]

Among the Great Rift countries in Africa—including Tanzania, Kenya, Uganda, Eritrea, Ethiopia, and Djibouti—Kenya is the early leader. It now has over 100 megawatts of geothermal generating capacity and is planning 1,200 more megawatts by 2015. This would double its current electrical generating capacity of 1,200 megawatts from all sources.[73]

Japan, which has 18 geothermal power plants with a total of 535 megawatts of generating capacity, was an early leader in this field. Now, following nearly two decades of inactivity, this geothermally rich country—long known for its thousands of hot

baths—is again beginning to build geothermal power plants.[74]

In Europe, Germany has 4 small geothermal power plants in operation and some 180 plants in the pipeline. Werner Bussmann, head of the German Geothermal Association, says, "Geothermal sources could supply Germany's electricity needs 600 times over." Monique Barbut, head of the Global Environment Facility, expects the number of countries tapping geothermal energy for electricity to rise from roughly 20 when the century began to close to 50 by 2010.[75]

Beyond geothermal power plants, geothermal (ground source) heat pumps are now being widely used for both heating and cooling. These take advantage of the remarkable stability of the earth's temperature near the surface and then use that as a source of heat in the winter when the air temperature is low and a source of cooling in the summer when the temperature is high. The great attraction of this technology is that it can provide both heating and cooling and do so with 25–50 percent less electricity than would be needed with conventional systems. In Germany, for example, there are now 130,000 geothermal heat pumps operating in residential or commercial buildings. This base is growing steadily, as at least 25,000 new pumps are installed each year.[76]

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 homes has largely eliminated coal for this use. 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.[77]

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.[78]

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 of tilapia, striped bass, and catfish using warm water from underground.[79]

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.[80]

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.[81]

If the four most populous countries located on the Pacific Ring of Fire—the United States, Japan, China, and Indonesia—were to seriously invest in developing their geothermal resources, they could easily make this a leading world energy source. With a conservatively estimated potential in the United States and Japan alone of 240,000 megawatts of generation, it is easy to envisage a world with thousands of geothermal power plants generating some 200,000 megawatts of electricity, the Plan B goal, by 2020.[82]

Plant-Based Sources of Energy

As oil and natural gas reserves are being depleted, the world's attention is also turning to plant-based energy sources. In addition to the energy crops discussed in Chapter 2, these include forest industry byproducts, sugar industry byproducts, urban waste, livestock waste, plantations of fast-growing trees, crop residues, and urban tree and yard wastes—all of which can be used for electrical generation, heating, or the production of automotive fuels.

The potential use of plant-based sources of energy is limited because even corn—the most efficient of the grain crops—can convert just 0.5 percent of solar energy into a usable form. In contrast, solar PV or solar thermal power plants convert roughly 15 percent of sunlight into a usable form, namely electricity. In a land–scarce world, energy crops cannot compete with solar electricity, much less with the far more land-efficient wind power.[83]

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 nearly 11,000 megawatts in U.S. plant-based electrical generation comes primarily from burning forest waste.[84]

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 2007 oil had been largely replaced by wood chips and urban waste.[85]

In the United States, St. Paul, Minnesota—a city of 275,000 people—began to develop district heating more than 20 years ago. It built a combined heat and power plant to use tree waste from the city's parks, industrial wood waste, and wood from other sources. The 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.[86]

Oglethorpe Power, a large group of utilities in the state of Georgia, has announced plans to build up to three 100-megawatt biomass-fueled power plants. The principal feedstocks will be wood chips, sawmill wood waste, forest harvest residue, and, when available, pecan hulls and peanut shells.[87]

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 their fermentation process and generate electricity that they could sell to the local utility. This system, now well established, is spreading to sugar mills in other countries that produce the remaining four fifths of the world's sugar harvest.[88]

Within cities, garbage is also burned to produce heat and power after, it is hoped, any recyclable materials have been removed. In Europe, waste-to-energy plants supply 20 million consumers with heat. France, with 128 plants, and Germany, with 67 plants, 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. It would, however, be preferable to work toward a zero-garbage economy where the energy invested in the paper, cardboard, plastic, and other combustible materials could largely be recovered by recycling. Burning garbage is not a smart way to deal with the waste problem.[89]

Until we get zero waste, however, the methane (natural gas) produced in existing landfills as organic materials in buried garbage decompose can also be tapped to produce industrial process heat or to generate electricity in combined heat and power plants. The 35-megawatt landfill-gas power plant planned by Puget Sound Energy and slated to draw methane from Seattle's landfill will join more than 100 other such power plants in operation in the United States.[90]

Near Atlanta, Interface—the world's largest manufacturer of industrial carpet—convinced the city to invest $3 million in capturing methane from the municipal landfill and to 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 while reducing operating costs for Interface.[91]

As discussed in Chapter 2, crops are also used to produce automotive fuels, including both ethanol and biodiesel. In 2009 the world was on track to produce 19 billion gallons of fuel ethanol and nearly 4 billion gallons of biodiesel. Half of the ethanol will come from the United States, a third from Brazil, and the remainder from a dozen or so other countries, led by China and Canada. Germany and France are each responsible for 15 percent of the world's biodiesel output; the other major producers are the United States, Brazil, and Italy.[92]

Once widely heralded as the alternative to oil, crop-based fuels have come under closer scrutiny in recent years, raising serious doubts about their feasibility. In the United States, which

surged ahead of Brazil in ethanol production in 2005, the near doubling of output during 2007 and 2008 helped to drive world food prices to all-time highs. In Europe, with its high goals for biodiesel use and low potential for expanding oilseed production, biodiesel refiners are turning to palm oil from Malaysia and Indonesia, driving the clearing of rainforests for palm plantations.[93]

In a world that no longer has excess cropland capacity, every acre planted in corn for ethanol means another acre must be cleared somewhere for crop production. An early 2008 study led by Tim Searchinger of Princeton University that was published in *Science* used a global agricultural model to show that when including the land clearing in the tropics, expanding U.S. biofuel production increased annual greenhouse gas emissions dramatically instead of reducing them, as more narrowly based studies claimed.[94]

Another study published in *Science*, this one by a team from the University of Minnesota, reached a similar conclusion. Focusing on the carbon emissions associated with tropical deforestation, it showed that converting rainforests or grasslands to corn, soybean, or palm oil biofuel production led to a carbon emissions increase—a "biofuel carbon debt"—that was at least 37 times greater than the annual reduction in greenhouse gases resulting from the shift from fossil fuels to biofuels.[95]

The case for crop-based biofuels was further undermined when a team led by Paul Crutzen, a Nobel Prize–winning chemist at the Max Planck Institute for Chemistry in Germany, concluded that emissions of nitrous oxide, a potent greenhouse gas, from the synthetic nitrogen fertilizer used to grow crops such as corn and rapeseed for biofuel production can negate any net reductions of CO_2 emissions from replacing fossil fuels with biofuels, thus making biofuels a threat to climate stability. Although the U.S. ethanol industry rejected these findings, the results were confirmed in a 2009 report from the International Council for Science, a worldwide federation of scientific associations.[96]

The more research is done on liquid biofuels, the less attractive they become. Fuel ethanol production today relies almost entirely on sugar and starch feedstocks, but work is now under way to develop efficient technologies to convert cellulosic materials into ethanol. Several studies indicate that switchgrass and hybrid poplars could produce relatively high ethanol yields on marginal lands, but there is no low-cost technology for converting cellulose into ethanol available today or in immediate prospect.[97]

A third report published in *Science* indicates that burning cellulosic crops directly to generate electricity to power electric cars yields 81 percent more transport miles than converting the crops into liquid fuel. The question is how much could plant materials contribute to the world's energy supply. Based on a study from the U.S. Departments of Energy and Agriculture, we estimate that using forest and urban wood waste, as well as some perennial crops such as switchgrass and fast-growing trees on nonagricultural land, the United States could develop more than 40 gigawatts of electrical generating capacity by 2020, roughly four times the current level. For Plan B, we estimate that the worldwide use of plant materials to generate electricity could contribute 200 gigawatts of capacity by 2020.[98]

Hydropower: Rivers, Tides, and Waves

The term hydropower has traditionally referred to dams that harnessed the energy in river flows, but today it also includes harnessing the energy in tides and waves as well as using smaller "in-stream" turbines to capture the energy in rivers and tides without building dams.[99]

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 the bulk 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 the costs of displacing people, ecological damage, and land inundation became more visible.[100]

Small-scale projects, which are not nearly as disruptive, are still in favor. 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 currently the only source of electricity. Though China leads in new construction, many other countries are also building small-scale structures, as

the economics of generation increasingly favor renewable sources over fossil fuels. And there is growing interest in in-stream turbines that do not need a dam and are less environmentally intrusive.[101]

Tidal power (actually, lunar power) holds a certain fascination because of its sheer potential scale. Canada's Bay of Fundy, for example, has a potential generating capacity of more than 4,000 megawatts. Other countries are looking at possible projects in the 7,000- to 15,000-megawatt range.[102]

The first large tidal generating facility—La Rance barrage, with a maximum 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. Scheduled for completion 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 Incheon. In March 2008, Lunar Energy of the United Kingdom reached agreement with Korea Midland Power to develop a turbine field off the coast of South Korea that would generate 300 megawatts of power. 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 northwest coast.[103]

Giant projects are under consideration in several countries, including India, Russia, and the United Kingdom. India is planning to build a 39-mile barrage across the Gulf of Khambhat on the country's northwest coast with a 7,000-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 country's southwest coast. This is equal to 11 percent of U.K. electrical generating capacity. Russian planners are talking in terms of a 15,000-megawatt tidal barrage in the White Sea in northwestern Russia, near Finland. Part of this power would likely be exported to Europe. A facility under discussion for Tugurski Bay on the country's Far Eastern coast would provide 8,000 megawatts to power local industry.[104]

In the United States, the focus is on smaller tidal facilities. Since 2007 the Federal Energy Regulatory Commission has issued more than 30 preliminary permits, including those 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 at least 20 megawatts of generating capacity.[105]

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 a 40-megawatt wave farm off the state's north coast. GreenWave Energy Solutions has been issued preliminary permits for two projects of up to 100 megawatts each off California's coast, one in the north and one in the south. And San Francisco is seeking a permit to develop a 10–30 megawatt wave power project off its coast.[106]

The world's first wave farm, a 2-megawatt facility built by Pelamis Wave Power of the United Kingdom, is operating off the coast of Portugal. The project's second phase would expand this to 22 megawatts. Scottish firms Aquamarine Power and Airtricity are teaming up to build 1,000 megawatts of wave and tidal power off the coast of Ireland and the United Kingdom. Ireland as a whole has the most ambitious wave power development goal, planning 500 megawatts of wave generating capacity by 2020, enough to supply 7 percent of its electricity. Worldwide, the harnessing of wave power could generate a staggering 10,000 gigawatts of electricity, more than double current world electricity generation of 4,000 gigawatts from all sources.[107]

We project that the 945 gigawatts (945,000 megawatts) of hydroelectric power in operation worldwide in 2008 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 135 gigawatts in our projected growth of hydropower 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, and numerous smaller wave power projects.[108]

Within the United States, where there is little interest in new dams, there is a resurgence of interest in installing generating facilities in non-powered dams and in expanding existing hydro facilities. If the worldwide interest in tidal and wave energy continues to escalate, the additional capacity from hydro, tidal, and wave power by 2020 could easily exceed the 400 gigawatts needed to reach the Plan B goal.[109]

The World Energy Economy of 2020

As this chapter has described, the transition from coal, oil, and gas to wind, solar, and geothermal energy is well under way. In the old economy, energy was produced by burning something—oil, coal, or natural gas—leading to the carbon emissions that have come to define our economy. The new energy economy harnesses the energy in wind, the energy coming from the sun, and heat from within the earth itself. It will be largely electrically driven. In addition to its use for lighting and for household appliances, electricity will be widely used in the new economy both in transport and to heat and cool buildings. Climate-disrupting fossil fuels will fade into the past as countries turn to clean, climate-stabilizing, nondepletable sources of energy.

Backing away from fossil fuels begins with the electricity sector, where the development of 5,300 gigawatts of new renewable generating capacity worldwide 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. The addition of close to 1,500 gigawatts of thermal heating capacity by 2020, roughly two thirds of it from rooftop solar water and space heaters, will sharply reduce the use of both oil and gas for heating buildings and water. (See Table 5–1.)[110]

In looking at the broad shifts from 2008 to the Plan B energy economy of 2020, fossil-fuel-generated electricity drops by 90 percent worldwide. 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 first from shifting to all-electric and highly efficient plug-in hybrids cars that will run almost entirely on electricity, nearly all of it from renewable sources. And it also comes from shifting to electric trains, which are much more efficient than diesel-powered ones. Many buildings will be all-electric—heated, cooled, and illuminated entirely with carbon-free renewable electricity.

At the country and regional level, each energy profile will be shaped by the locally unique endowment of renewable sources of energy. Some countries, such as the United States, Turkey,

Table 5–1. *World Renewable Energy Capacity in 2008 and Plan B Goals for 2020*

Source	2008	Goal for 2020
Electricity Generating Capacity	(electrical gigawatts)	
Wind	121	3,000
Rooftop solar electric systems	13	1,400
Solar electric power plants	2	100
Solar thermal power plants	0	200
Geothermal	10	200
Biomass	52	200
Hydropower	945	1,350
Total	1,143	6,450
Thermal Energy Capacity	(thermal gigawatts)	
Solar rooftop water and space heaters	120	1,100
Geothermal	100	500
Biomass	250	350
Total	470	1,950

Source: See endnote 110.

and China, will likely rely on the broad base of renewables—wind, solar, and geothermal power—for their energy. But wind, including both onshore and offshore, is likely to emerge as the leading energy source in each of these countries.

In June 2009, Xiao Ziniu, director of China's National Climate Center, said that China had up to 1,200 gigawatts of wind generating potential. This compares with the country's current total electricity generating capacity of 790 gigawatts. Xiao said the new assessment he was citing "assures us that the country's entire electricity demand can be met by wind power alone." In addition, the study identified 250 gigawatts of offshore wind power potential. A senior Chinese official had earlier announced that wind generating capacity would reach 100 megawatts by 2020, which means it would overtake nuclear power well before then.[111]

Other countries, including Spain, Algeria, Egypt, India, and Mexico, will turn primarily to solar thermal power plants and solar PV arrays to power their economies. For Iceland, Indonesia, Japan, and the Philippines, geothermal energy will likely be their mother lode. Still others will likely rely heavily on hydro, including Norway, the Democratic Republic of the Congo, and Nepal. Some technologies, such as rooftop solar water heaters, will be used virtually everywhere.

With the Plan B energy economy of 2020, the United States will get 44 percent of its electricity from wind farms. Geothermal power plants will supply another 11 percent. Photovoltaic cells, most of them on rooftops, will supply 8 percent of electricity, with solar thermal power plants providing 5 percent. Roughly 7 percent will come from hydropower. The remaining 25 percent comes from nuclear power, biomass, and natural gas, in that order. (See capacity figures in Table 5–2.)[112]

As the energy transition progresses, the system for transporting energy from source to consumers will change beyond recognition. In the old energy economy, pipelines carried oil from fields to consumers or to ports, where it was loaded on tankers. A huge fleet of tankers moved oil from the Persian Gulf to markets on every continent.

Texas offers a model of how to build a grid to harness renewable energy. After a survey showed that the state had two strong concentrations of wind energy, one in West Texas and the other in the Panhandle, the Public Utility Commission coordinated the design of a network of high-voltage transmission lines to link these regions with consumption centers such as Dallas/Ft. Worth and San Antonio. With a $5-billion investment and up to 2,900 miles of transmission lines, the stage has been set to harness 18,500 megawatts of wind generating capacity from these two regions alone, enough to supply half of the state's 24 million residents.[113]

Already, major utilities and private investors are proposing to build highly efficient high-voltage direct-current (HVDC) lines to link wind-rich regions with consumption centers. For example, TransCanada is proposing to develop two high-voltage lines: the Zephyr Line, which will link wind-rich Wyoming with the California market, and the Chinook Line, which will do the same for wind-rich Montana. These lines of roughly

Table 5–2. *U.S. Electricity Generating Capacity in 2008 and Plan B Goals for 2020*

Source	2008	Goal for 2020
	(electrical gigawatts)	
Fossil Fuels and Nuclear		
Coal	337	0
Oil	62	0
Natural Gas	459	140
Nuclear	106	106
Total	965	246
Renewables		
Wind	25	710
Rooftop solar electric systems	1	190
Solar electric power plants	0	30
Solar thermal power plants	0	120
Geothermal	3	70
Biomass	11	40
Hydropower	78	100
Total	119	1,260

Note: Columns may not add to totals due to rounding.
Source: See endnote 112.

1,000 miles each are both designed to accommodate 3,000 megawatts of wind-generated electricity.[114]

In the Northern Plains and the Midwest, ITC Holdings Corporation is proposing what it calls the Green Power Express. This investment in 3,000 miles of high-voltage transmission lines is intended to link 12,000 megawatts of wind capacity from North Dakota, South Dakota, Iowa, and Minnesota with the more densely populated industrial Midwest. These initial heavy-duty transmission lines can eventually become part of the national grid that U.S. Energy Secretary Steven Chu wants to build.[115]

A strong, efficient national grid will reduce generating capacity needs, lower consumer costs, and cut carbon emissions. Since no two wind farms have identical wind profiles, each one added to the grid makes wind a more stable source of electricity. With thousands of wind farms spread from coast to coast, wind becomes a stable source of energy, part of baseload power. This, coupled with the capacity to forecast wind speeds and solar intensity throughout the country at least a day in advance, makes it possible to manage the diversity of renewable energy resources efficiently.[116]

For India, a national grid would enable it to harness the vast solar resources of the Great Indian Desert. Europe, too, is beginning to think seriously of investing in a continental supergrid. Stretching from Norway to Egypt and from Morocco to western Siberia, it would enable the region to harness vast amounts of wind energy, particularly in offshore Western Europe, and the almost unlimited solar energy in the northern Sahara and on Europe's southern coast. Like the proposed U.S. national grid, the Europe-wide grid would use high-voltage direct-current lines that transmit electricity far more efficiently than existing lines do.[117]

An Irish firm, Mainstream Renewable Power, is proposing to use HVDC undersea cables to build the European supergrid offshore. The grid would stretch from the Baltic Sea to the North Sea then south through the English Channel to southern Europe. The company notes that this could avoid the time-consuming acquisition of land to build a continental land-based system. The Swedish firm ABB Group, which has just completed a 400-mile HVDC undersea cable linking Norway and the Netherlands, is partnering with Mainstream Renewable Power in proposing to build the first stages of the supergrid.[118]

A long-standing proposal by the Club of Rome, called DESERTEC, goes further, with plans to connect Europe to the abundant solar energy of North Africa and the Middle East. In July 2009, 11 leading European firms—including Munich Re, Deutsche Bank, ABB, and Siemens—and an Algerian company, Cevital, announced a plan to create the DESERTEC Industrial Initiative. This firm's goal will be to craft a concrete plan and funding proposal to develop enough solar thermal generating capacity in North Africa and the Middle East to export electricity to Europe and to meet the needs of producer countries. This energy proposal, which could exceed 300,000 megawatts of solar thermal generating capacity, is huge by any standard. It is being driven by concerns about disruptive climate change and by the depletion of oil and gas reserves. Caio Koch-Weser, Deutsche Bank vice chairman, said, "The Initiative shows in what dimensions and on what scale we must think if we are to master the challenges from climate change."[119]

The twentieth century witnessed the globalization of the world energy economy as the entire world came to depend heavily on a handful of countries for oil, many of them in one region of the world. This century will witness the localization of the world energy economy as countries begin to tap their indigenous resources of renewable energy.

The localization of the energy economy will lead to the localization of the food economy. For example, as the cost of shipping fresh produce from distant markets rises with the price of oil, there will be more local farmers' markets. Diets will be more locally based and seasonally sensitive than they are today. The combination of moving down the food chain and reducing the food miles in our diets will dramatically reduce energy use in the food economy.

As agriculture localizes, livestock production will likely start to shift from mega-sized cattle, hog, and poultry feeding operations. There will be fewer specialized farms and more mixed crop-livestock operations. Feeding operations will become smaller as the pressure to recycle nutrients mounts with the depletion of the world's finite phosphate reserves and as fertilizer prices rise. The recent growth in the number of small farms in the United States will likely continue. As world food insecurity mounts, more and more people will be looking to produce some of their own food in backyards, in front yards, on rooftops, in community gardens, and elsewhere, further contributing to the localization of agriculture.

The new energy economy will be highly visible from the air. A few years ago on a flight from Helsinki to London I counted 22 wind farms when crossing Denmark, long a wind power leader. Is this a glimpse of the future, I wondered? One day U.S. air travelers will see thousands of wind farms in the Great Plains, stretching from the Gulf Coast of Texas to the Canadian border, where ranchers and farmers will be double cropping wind with cattle, corn, and wheat.

The deserts of the U.S. Southwest will feature clusters of solar thermal power plants, with vast arrays of mirrors, covering several square miles each. Wind farms and solar thermal power plants will be among the more visible features of the new energy economy. The roofs of millions of homes and commercial buildings will sport solar cell arrays as rooftops become a source of electricity. How much more local can you get? There will also be millions of rooftops with solar water and space heaters.

Governments are using a variety of policy instruments to help drive this energy restructuring. These include tax restructuring—raising the tax on carbon emissions and lowering the tax on income—and carbon cap-and-trade systems. The former approach is more transparent and easily administered and not so readily manipulated as the latter.[120]

For restructuring the electricity sector, feed-in tariffs, in which utilities are required to pay more for electricity generated from renewable sources, have been remarkably successful. Germany's impressive early success with this measure has led to its adoption by more than 40 other countries, including most of those in the European Union. In the United States, at least 33 states have adopted renewable portfolio standards requiring utilities to get a certain share of their electricity from renewable sources. The United States has also used tax credits for wind, geothermal, solar photovoltaics, solar water and space heating, and geothermal heat pumps.[121]

To achieve some goals, governments are simply using mandates, such as those requiring rooftop solar water heaters on all new buildings, higher efficiency standards for cars and appliances, or a ban on the sale of incandescent light bulbs. Each government has to select the policy instruments that work best in its particular economic and cultural settings.

In the new energy economy, our cities will be unlike any we have known during our lifetime. The air will be clean and the streets will be quiet, with only the scarcely audible hum of electric motors. Air pollution alerts will be a thing of the past as coal-fired power plants are dismantled and recycled and as gasoline- and-diesel-burning engines largely disappear.

This transition is now building its own momentum, driven by an intense excitement from the realization that we are tapping energy sources that can last as long as the earth itself. Oil wells go dry and coal seams run out, but for the first time since the Industrial Revolution began we are investing in energy sources that can last forever.