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Harnessing Wind, Solar, and Geothermal 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 world energy economy is emerging. The old energy economy, fueled by oil, coal, and natural gas, is being replaced with an economy 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.[1]

The transition is well under way in the United States, where both oil and coal consumption have recently peaked. Oil consumption fell 8 percent between 2007 and 2010 and will likely continue falling over the longer term. During the same period, coal use also dropped 8 percent as a powerful grassroots anti-coal movement brought the licensing of new coal plants to a near standstill and began to work on closing existing ones.[2]

While U.S. coal use was falling, some 300 wind farms with a generating capacity of 21,000 megawatts came online. Geothermal generating capacity, which had been stagnant for 20 years, came alive. In mid-2010, the U.S.-based Geothermal Energy Association announced that 152 new geothermal power plants were being developed, enough to triple U.S. geothermal generating capacity. On

the solar front, solar cell installations are doubling every two years. The dozens of U.S. solar thermal power plants in the works could collectively add some 9,900 megawatts of generating capacity.[3]

This chapter lays out the worldwide Plan B goals for developing renewable sources of energy by 2020. The goal of cutting carbon emissions 80 percent by 2020 is based on what we think is needed to avoid civilization-threatening climate change. This is not Plan A, business as usual. This is Plan B—a wartime mobilization, an all-out effort to restructure the world energy economy.

To reach the Plan B goal, we replace all coal- and oil-fired electricity generation with that from 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.

The Plan B energy economy, which will be powered largely by electricity, does not rely on a buildup in nuclear power. If we used full-cost pricing—insisting that utilities pay for disposing of nuclear waste, decommissioning worn-out plants, and insuring reactors against possible accidents and terrorist attacks—no one would build a nuclear plant. They are simply not economical. Plan B also excludes the oft-discussed option of capturing and sequestering carbon dioxide (CO_2) from 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 by 2020, if ever.[4]

Instead, 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. A 2009 survey of world wind resources published by the U.S. National Academy of Sciences reports a wind-generating potential on land that is 40 times the current world consumption of electricity from all sources.[5]

For many years, a small handful of countries dominated growth in wind power, but this is changing as the industry goes global, with more than 70 countries now developing wind resources. Between 2000 and 2010, world wind electric generating capacity increased at a frenetic pace from 17,000 megawatts to nearly 200,000 megawatts.[6]

The United States, with 35,000 megawatts of wind generating capacity, leads the world in harnessing wind, followed by China and Germany with 26,000 megawatts each. Texas, long the leading U.S. oil-producing state, is now also the nation's leading generator of electricity from wind. It has 9,700 megawatts of wind generating capacity online, 370 megawatts more under construction, and a huge amount under development. If all of the wind farms projected for 2025 are completed, Texas will have 38,000 megawatts of wind generating capacity—the equivalent of 38 coal-fired power plants. This would satisfy roughly 90 percent of the current residential electricity needs of the state's 25 million people.[7]

In July 2010, ground was broken for the Alta Wind Energy Center (AWEC) in the Tehachapi Pass, some 75 miles north of Los Angeles, California. At 1,550 megawatts, it will be the largest U.S. wind farm. The AWEC is part of what will eventually be 4,500 megawatts of renewable power generation, enough to supply electricity to some 3 million homes.[8]

Since wind turbines occupy only 1 percent of the land covered by a wind farm, farmers and ranchers can continue to grow grain and graze cattle on land devoted to wind farms. In effect, they double-crop their land, simultaneously harvesting electricity and wheat, corn, or cattle. With no investment on their part, farmers and ranchers typically receive $3,000–10,000 a year in royal-

ties for each wind turbine on their land. For thousands of ranchers in the U.S. Great Plains, wind royalties will dwarf their net earnings from cattle sales.[9]

In considering the energy productivity of land, wind turbines are in a class by themselves. For example, an acre of land in northern Iowa planted in corn can yield $1,000 worth of ethanol per year. That same acre used to site a wind turbine can produce $300,000 worth of electricity per year. This helps explain why investors find wind farms so attractive.[10]

Impressive though U.S. wind energy growth is, the expansion now under way in China is even more so. China has enough onshore harnessable wind energy to raise its current electricity consumption 16-fold. Today, most of China's 26,000 megawatts of wind generating capacity come from 50- to 100-megawatt wind farms. Beyond the many other wind farms of that size that are on the way, China's new Wind Base program is creating seven wind mega-complexes of 10 to 38 gigawatts each in six provinces (1 gigawatt equals 1,000 megawatts). When completed, these complexes will have a generating capacity of more than 130 gigawatts. This is equivalent to building one new coal plant per week for two and a half years.[11]

Of these 130 gigawatts, 7 gigawatts will be in the coastal waters of Jiangsu Province, one of China's most highly industrialized provinces. China is planning a total of 23 gigawatts of offshore wind generating capacity. The country's first major offshore project, the 102-megawatt Donghai Bridge Wind Farm near Shanghai, is already in operation.[12]

In Europe, which now has 2,400 megawatts of offshore wind online, wind developers are planning 140 gigawatts of offshore wind generating capacity, mostly in the North Sea. There is enough harnessable wind energy in offshore Europe to satisfy the continent's needs seven times over.[13]

In September 2010, the Scottish government announced that it was replacing its goal of 50 percent renewable electricity by 2020 with a new goal of 80 percent. By 2025, Scotland expects renewables to meet all of its electricity needs. Much of the new capacity will be provided by offshore wind.[14]

Measured by share of electricity supplied by wind, Denmark is the national leader at 21 percent. Three north German states now get 40 percent or more of their electricity from wind. For Germany as a whole, the figure is 8 percent—and climbing. And in the state of Iowa, enough wind turbines came online in the last few years to produce up to 20 percent of that state's electricity.[15]

Denmark is looking to push the wind share of its electricity to 50 percent by 2025, with most of the additional power coming from offshore. In contemplating this prospect, Danish planners have turned conventional energy policy upside down. They plan to use wind as the mainstay of their electrical generating system and to use fossil-fuel-generated power to fill in when the wind dies down.[16]

Spain, which has 19,000 megawatts of wind-generating capacity for its 45 million people, got 14 percent of its electricity from wind in 2009. On November 8th of that year, strong winds across Spain enabled wind turbines to supply 53 percent of the country's electricity over a five-hour stretch. London *Times* reporter Graham Keeley wrote from Barcelona that "the towering white wind turbines which loom over Castilla-La Mancha—home of Cervantes's hero, Don Quixote—and which dominate other parts of Spain, set a new record in wind energy production."[17]

In 2007, when Turkey issued a request for proposals to build wind farms, it received bids to build a staggering 78,000 megawatts of wind generating capacity, far beyond its 41,000 megawatts of total electrical generating

capacity. Having selected 7,000 megawatts of the most promising proposals, the government is issuing construction permits.[18]

In wind-rich Canada, Ontario, Quebec, and Alberta are the leaders in installed capacity. Ontario, Canada's most populous province, has received applications for offshore wind development rights on its side of the Great Lakes that could result in some 21,000 megawatts of generating capacity. The provincial goal is to back out all coal-fired power by 2014.[19]

On the U.S. side of Lake Ontario, New York State is also requesting proposals. Several of the seven other states that border the Great Lakes are planning to harness lake winds.[20]

At the heart of Plan B is a crash program to develop 4,000 gigawatts (4 million megawatts) of wind generating capacity by 2020, enough to cover over half of world electricity consumption in the Plan B economy. This will require a near doubling of capacity every two years, up from a doubling every three years over the last decade.[21]

This climate-stabilizing initiative would mean the installation of 2 million wind turbines of 2 megawatts each. Manufacturing 2 million wind turbines over the next 10 years sounds intimidating—until it is compared with the 70 million automobiles the world produces each year.[22]

At $3 million per installed turbine, the 2 million turbines would mean spending $600 billion per year worldwide between now and 2020. This compares with world oil and gas capital expenditures that are projected to double from $800 billion in 2010 to $1.6 trillion in 2015.[23]

The second key component of the Plan B energy economy is solar energy, which is even more ubiquitous than wind energy. It can be harnessed with both solar photovoltaics (PV) and solar thermal collectors. Solar PV—both silicon-based and thin film—converts sunlight directly into electricity. A large-scale solar thermal technology, often referred to as concentrating solar power (CSP), uses reflectors to concentrate sunlight on a liquid, producing steam to drive a turbine and generate electricity. On a smaller scale, solar thermal collectors can capture the sun's radiant energy to warm water, as in rooftop solar water heaters.

The growth in solar cell production can only be described as explosive. It climbed from an annual expansion of 38 percent in 2006 to an off-the-chart 89 percent in 2008, before settling back to 51 percent in 2009. At the end of 2009, there were 23,000 megawatts of PV installations worldwide, which when operating at peak power could match the output of 23 nuclear power plants.[24]

On the manufacturing front, the early leaders—the United States, Japan, and Germany—have been overtaken by China, which produces more than twice as many solar cells annually as Japan. Number three, Taiwan, is moving fast and may overtake Japan in 2010. World PV production has roughly doubled every two years since 2001 and will likely approach 20,000 megawatts in 2010.[25]

Germany, with an installed PV power generating capacity of almost 10,000 megawatts, is far and away the world leader in installations. Spain is second with 3,400 megawatts, followed by Japan, the United States, and Italy. Ironically, China, the world's largest manufacturer of solar cells, has an installed capacity of only 305 megawatts, but this is likely to change quickly as PV costs fall.[26]

Historically, photovoltaic installations were small-scale—mostly residential rooftop installations. Now that is changing as utility-scale PV projects are being launched in several countries. The United States, for example, has under construction and development some 77 utility-scale projects, adding up to 13,200 megawatts of generating capacity. Morocco is now planning five large solar-generating projects, either photovoltaic or solar thermal or both, each ranging from 100 to 500 megawatts in size.[27]

More and more countries, states, and provinces are setting solar installation goals. Italy's solar industry group is projecting 15,000 megawatts of installed capacity by 2020. Japan is planning 28,000 megawatts by 2020. The state of California has set a goal of 3,000 megawatts by 2017.[28]

Solar-rich Saudi Arabia recently announced that it plans to shift from oil to solar energy to power new desalination plants that supply the country's residential water. It currently uses 1.5 million barrels of oil per day to operate some 30 desalting plants.[29]

With installations of solar PV climbing, with costs continuing to fall, and with concerns about climate change escalating, cumulative PV installations could reach 1.5 million megawatts (1,500 gigawatts) in 2020. Although this estimate may seem overly ambitious, it could in fact be conservative, because if most of the 1.5 billion people who lack electricity today get it by 2020, it will likely be because they have installed home solar systems. In many cases, it is cheaper to install solar cells for individual homes than it is to build a grid and a central power plant.[30]

The second, very promising way to harness solar energy on a massive scale is CSP, which first came on the scene with the construction of a 350-megawatt solar thermal power plant complex in California. Completed in 1991, it was the world's only utility-scale solar thermal generating facility until the completion of a 64-megawatt power plant in Nevada in 2007.[31]

Two years later, in July 2009, a group of 11 leading European firms and one Algerian firm, led by Munich Re and including Deutsche Bank, Siemens, and ABB, announced that they were going to craft a strategy and funding proposal to develop solar thermal generating capacity in North Africa and the Middle East. Their proposal would meet the needs of the producer countries and supply part of Europe's electricity via undersea cable.[32]

This initiative, known as the Desertec Industrial Initiative, could develop 300,000 megawatts of solar thermal generating capacity—huge by any standard. It is driven by concerns about disruptive climate change and by depletion of oil and gas reserves. Caio Koch-Weser, vice chair of Deutsche Bank, noted that "the Initiative shows in what dimensions and on what scale we must think if we are to master the challenges from climate change."[33]

Even before this proposal, Algeria—for decades an oil exporter—was 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 similar point often appears in the solar literature when it is noted that the sunlight striking the earth in one hour could power the world economy for one year. 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.[34]

Although solar thermal power has been slow to get under way, utility-scale plants are being built rapidly now. The two leaders in this field are the United States and Spain. The United States has more than 40 solar thermal power plants operating, under construction, and under development that range from 10 to 1,200 megawatts each. Spain has 60 power plants in these same stages of development, most of which are 50 megawatts each.[35]

One country ideally suited for CSP plants is India. The Great Indian Desert in its northwest offers a huge opportunity for building solar thermal power plants. Hundreds of large plants in the desert could meet most of India's electricity needs. And because it is such a compact country, the distance for building transmission lines to major population centers is relatively short.[36]

One of the attractions of utility-scale CSP plants is that heat during the day can be stored in molten salt at temperatures above 1,000 degrees Fahrenheit. The heat can then be used to keep the turbines running for eight or more hours after sunset.[37]

The American Solar Energy Society notes that solar thermal resources in the U.S. Southwest can satisfy current U.S. electricity needs nearly four times over.[38]

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.[39]

The pace of solar energy development is accelerating as the installation of rooftop solar water heaters—the other use of solar collectors—takes off. China, for example, now has an estimated 1.9 billion square feet of rooftop solar thermal collectors installed, enough to supply 120 million Chinese households with hot water. With some 5,000 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 install a rooftop solar collector and take their first hot shower. This technology is sweeping China like wildfire, already approaching market saturation in some communities. Beijing's goal is to add another billion square feet to its rooftop solar water heating capacity by 2020, a goal it is likely to exceed.[40]

Other developing countries such as India and Brazil may also soon see millions of households turning to this inexpensive water heating technology. Once the initial installment cost of rooftop solar water heaters is paid back, the hot water is essentially free.

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. As in China, in some Austrian villages nearly all homes have rooftop collectors. Germany is also forging ahead. Some 2 million Germans are now living in homes where water and space are both heated by rooftop solar systems.[41]

The U.S. rooftop solar water heating industry has historically concentrated on a niche market—selling and marketing 100 million square feet of solar water heaters for swimming pools between 1995 and 2005. Given this base, 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, annual U.S. installation of these systems has more than tripled since 2005. The boldest initiative in the United States is California's goal of installing 200,000 solar water heaters by 2017. Not far behind is one launched in 2010 in New York State, which aims to have 170,000 residential solar water systems in operation by 2020.[42]

Solar water and space heaters in Europe and China have a strong economic appeal, often paying for themselves from electricity savings in less than 10 years. With the cost of rooftop heating systems declining, many other countries will likely join Israel, Spain, and Portugal in mandating that all new buildings incorporate rooftop solar water heaters. The state of Hawaii requires that all

new single-family homes have rooftop solar water heaters. Worldwide, Plan B calls for a total of 1,100 thermal gigawatts of rooftop solar water and space heating capacity by 2020.[43]

The third principal component in the Plan B energy economy is geothermal energy. The heat in the upper six miles of the earth's crust contains 50,000 times as much energy as found in all of the world's oil and gas reserves combined—a startling statistic. Despite this abundance, as of mid-2010 only 10,700 megawatts of geothermal generating capacity have been harnessed worldwide, enough for some 10 million homes.[44]

Roughly half the world's installed geothermal generating capacity is concentrated in the United States and the Philippines. Most of the remainder is generated in Mexico, Indonesia, Italy, and Japan. Altogether some 24 countries now convert geothermal energy into electricity. El Salvador, Iceland, and the Philippines respectively get 26, 25, and 18 percent of their electricity from geothermal power plants.[45]

The geothermal potential to provide electricity, to heat homes, and to supply process heat for industry is vast. Among the geothermally rich countries 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 well-endowed countries include those along the Great Rift Valley of Africa, including Ethiopia, Kenya, Tanzania, and Uganda, and those around the Eastern Mediterranean. As of 2010, there are some 70 countries with projects under development or active consideration, up from 46 in 2007.[46]

Beyond geothermal electrical generation, up to 100,000 thermal megawatts of geothermal energy are used directly—without conversion into electricity—to heat homes and greenhouses and to provide process heat to industry. For example, 90 percent of the homes in Iceland are heated with geothermal energy.[47]

An interdisciplinary team of 13 scientists and engineers assembled by the Massachusetts Institute of Technology 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 help the United States meet its energy needs 2,000 times over.[48]

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 has more than 3,000 megawatts of existing geothermal electrical capacity and projects under development in 13 states. With California, Nevada, Oregon, Idaho, and Utah leading the way, and with many new companies in the field, the stage is set for a geothermal renaissance.[49]

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; Pertamina, the state oil company, is responsible for developing the lion's share. Indonesia's oil production has been declining for the last decade, and in each of the last five years it has been an oil importer. As Pertamina shifts resources from oil to 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.[50]

Japan, which has 16 geothermal power plants with a total of 535 megawatts of generating capacity, was an early leader in this field. After nearly two decades of inactivity, this geothermally rich country—long known for its thousands of hot baths—is again building geothermal power plants.[51]

Among the Great Rift countries in Africa, Kenya is the early geothermal leader. It now has 167 megawatts of generating capacity and is planning 1,200 more megawatts by 2015, enough to nearly double its current electrical generating capacity from all sources. It is aiming for 4,000 geothermal megawatts by 2030.[52]

Beyond 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 air 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, 178,000 ground-source heat pumps are now operating in residential or commercial buildings. At least 25,000 new pumps are installed each year.[53]

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 winter. With rising oil prices boosting fresh produce transport costs, this practice will likely become far more common.[54]

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, 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.[55]

As oil and natural gas reserves are being depleted, the world's attention is also turning to plant-based energy sources, including energy crops, 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 energy crops is limited because even corn—the most efficient of the grain crops—can convert only 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 electricity. And the value of electricity produced on an acre of land occupied by a wind turbine is over 300 times that of the corn-based ethanol produced on an acre. In this land–scarce world, energy crops cannot compete with solar-generated electricity, much less with wind power.[56]

Yet another source of renewable energy is hydropower. The term 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.[57]

Roughly 16 percent of the world's electricity comes from hydropower, most of it from large dams. Some countries, such as Brazil, Norway, and the Democratic Republic of the Congo, get the bulk of their electricity from river power.[58]

Tidal power holds a certain fascination because of its sheer potential scale. The first large tidal generating facility—La Rance Tidal 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 that would provide all the electricity for

the half-million people living in the nearby city of Ansan. At another site to the north, engineers are planning a 1,320-megawatt tidal facility in Incheon Bay, near Seoul. And New Zealand is planning a 200-megawatt project in the Kaipara Harbour on that country's northwest coast.[59]

Wave power, though a few years behind tidal power, is also now attracting the attention of both engineers and investors. Scottish firms Aquamarine Power and SSE Renewables are teaming up to build 1,000 megawatts of wave and tidal power off the coast of Ireland and the United Kingdom. Ireland is planning 500 megawatts of wave generating capacity by 2020, enough to supply 8 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 capacity from all sources.[60]

We project that the 980 gigawatts (980,000 megawatts) of hydroelectric power in operation worldwide in 2009 will expand to 1,350 gigawatts by 2020. According to China's official projections, 180 gigawatts should be added there, mostly from large dams in the southwest. The remaining 190 gigawatts in our projected growth of hydropower would come from a scattering of large dams still being built in countries like Brazil and Turkey, dams now in the planning stages in sub-Saharan Africa, a large number of small hydro facilities, a fast-growing number of tidal projects, and numerous smaller wave power projects.[61]

The efficiency gains outlined in the preceding chapter more than offset projected growth in energy use to 2020. The next step in the Plan B 80-percent reduction of carbon emissions comes from replacing fossil fuels with renewable sources of energy. In looking at the broad shifts from the reference year of 2008 to the Plan B energy economy of 2020, fossil-fuel-generated electricity drops by 90 percent worldwide as the fivefold growth in renewably generated electricity replaces all the coal and oil and 70 percent of the natural gas now used to generate electricity. Wind, solar photovoltaic, solar thermal, and geothermal will dominate the Plan B energy economy, but as noted earlier wind will be the centerpiece—the principal source of the electricity to heat, cool, and light buildings and to run cars and trains.[62]

The Plan B projected tripling of renewable thermal heating generation by 2020, roughly half of it to come from direct uses of geothermal energy, will sharply reduce the use of both oil and gas to heat buildings and water. And in the transportation sector, energy use from fossil fuels drops by some 70 percent. This comes from shifting to all-electric and highly efficient plug-in hybrid 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.[63]

Each country's energy profile will be shaped by its unique endowment of renewable sources of energy. Some countries, such as the United States, Turkey, and China, will likely rely on a broad base of renewables—wind, solar, and geothermal power. But wind, including both onshore and offshore, is likely to emerge as the leading energy source in all three cases.

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 the mother lode. Still others will likely rely heavily on hydro, including Norway, Brazil, and Nepal. And some technologies, such as rooftop solar water heaters, will be used virtually everywhere.

As the transition progresses, the system for transporting energy from source to consumers will change beyond

recognition. In the old energy economy, pipelines and tankers carried oil long distances from oil fields to consumers, including a huge fleet of tankers that moved oil from the Persian Gulf to markets on every continent. In the new energy economy, pipelines will be replaced by transmission lines.

The proposed segments of what could eventually become a national U.S. grid are beginning to fall into place. Texas is planning up to 2,900 miles of new transmission lines to link the wind-rich regions of west Texas and the Texas panhandle to consumption centers such as Dallas-Fort Worth and San Antonio. Two high-voltage direct current (HVDC) lines will link the rich wind resources of Wyoming and Montana to California's huge market. Other proposed lines will link wind in the northern Great Plains with the industrial Midwest.[64]

In late 2009 Tres Amigas, a transmission company, announced its plans to build a "SuperStation" in Clovis, New Mexico, that would link the country's three major grids—the Western grid, the Eastern grid, and the Texas grid—for the first time. This would effectively create the country's first national grid. Scheduled to start construction in 2012 and to be completed in 2014, the SuperStation will allow electricity, much of it from renewable sources, to flow through the country's power transmission infrastructure.[65]

Google made headlines when it announced in mid-October 2010 that it was investing heavily in a $5-billion offshore transmission project stretching from New York to Virginia, called the Atlantic Wind Connection. This will facilitate the development of enough offshore wind farms to meet the electricity needs of 5 million East Coast residents.[66]

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 the prospect of thousands of wind farms spread from coast to coast and a national grid, wind becomes a stable source of energy, part of baseload power.[67]

Europe, too, is beginning to think seriously of investing in a supergrid. In early 2010, a total of 10 European companies formed Friends of the Supergrid, which is proposing to use HVDC undersea cables to build the European supergrid offshore, an approach that would avoid the time-consuming acquisition of land to build a continental land-based system. This grid could then mesh with the proposed Desertec initiative to integrate the offshore wind resources of northern Europe and the solar resources of North Africa into a single system that would supply both regions. The Swedish ABB Group, which in 2008 completed a 400-mile HVDC undersea cable linking Norway and the Netherlands, is well positioned to help build the necessary transmission lines.[68]

Governments are considering a variety of policy instruments to help drive the transition from fossil fuels to renewables. These include tax restructuring, lowering the tax on income and raising the tax on carbon emissions to include the indirect costs of burning fossil fuels. If we can create an honest energy market, the transition to renewables will accelerate dramatically.

Another measure that will speed the energy transition is eliminating fossil fuel subsidies. At present, governments are spending some $500 billion per year subsidizing the use of fossil fuels. This compares with renewable energy subsidies of only $46 billion per year.[69]

For restructuring the electricity sector, feed-in tariffs, in which utilities are required to pay set prices for electricity generated from renewable sources, have been remarkably successful. Germany's impressive early success with this measure has led to its adoption by some 50

other countries, including most of those in the European Union. In the United States, 29 states have adopted renewable portfolio standards requiring utilities to get up to 40 percent 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 ground-source heat pumps.[70]

To achieve some goals, governments are simply using mandates, such as those requiring rooftop solar water heaters on all new buildings. Governments at all levels are adopting energy efficiency building codes. Each government has to select the policy instruments that work best in its particular economic and cultural setting.[71]

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, we are investing in energy sources that can last forever.

Data, endnotes, and additional resources can be found on Earth Policy's Web site, at www.earth-policy.org.