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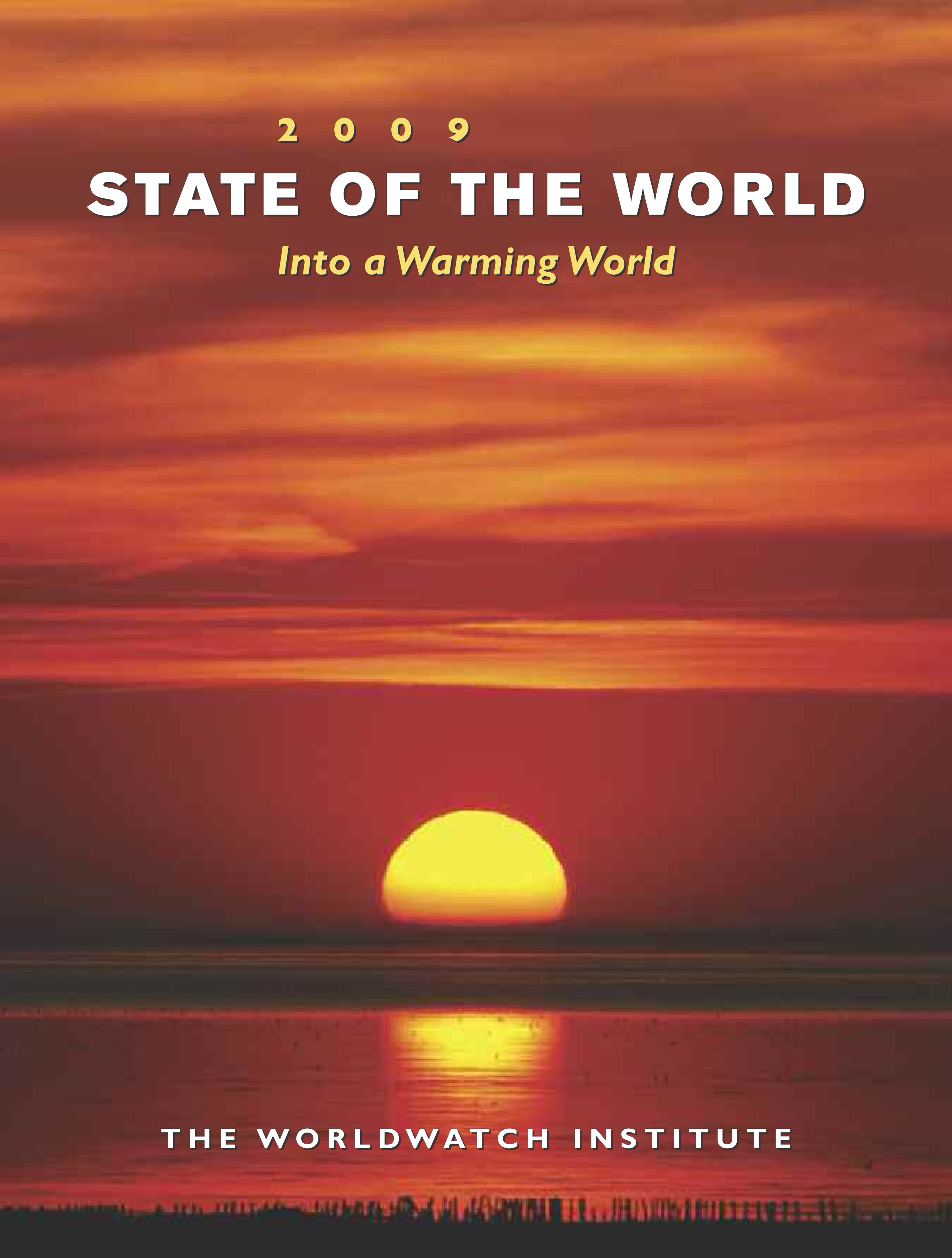
STATE OF THE WORLD

Into a Warming World



THE WORLDWATCH INSTITUTE

CHAPTER 4

An Enduring Energy Future

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In 1992, Güssing was a dying town not far from the rusting remains of the Iron Curtain and the capital of one of Austria's poorest districts. Just nine years later, Güssing was energy self-sufficient, producing biodiesel from local rapeseed and used cooking oil, as well as heat and power from the sun, and had a new biomass-steam gasification plant that sold surplus electricity to the national grid. New industries and more than 1,000 jobs flocked to the town. Today, not only do Güssing residents enjoy much higher living standards, they have cut their carbon emissions by more than 90 percent. And Güssing is not an isolated case. The Danish island of Samsø and several other communities have achieved similar transformations using various combinations of innovations.[1]

A growing number of towns are rapidly transitioning to low-carbon renewable energy, and larger cities are attempting to follow their lead. But most of the world remains wedded to polluting, carbon-intensive fossil fuels, despite rising economic costs and threats to human health, national security, and the environment. Until recently, fossil fuels were cheap and abundant; as a result, they have been used very inefficiently. The tenfold rise in the price of oil in the past decade and recent increases in natural gas and coal prices mean fossil fuels are no longer cheap, and their volatile prices have devastated many economies. Readily accessible conventional fuels are in increasingly shorter supply as discoveries fail to keep up with demand, and extraction requires developing ever more remote resources and using increasingly drastic measures—from removing mountain tops to heating tar sands. Competition for fossil fuels is heightening international tensions, a trend likely to intensify over time. The urgent need to reduce the release of carbon dioxide (CO_2) and methane in order to avoid catastrophic climate change has finally focused the

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world's attention on the need for a rapid shift in how energy services are provided.[2]

Energy scenarios offer a wide range of estimates of how much renewable sources can contribute and how fast. The International Energy Agency (IEA) recently projected that the share of primary world energy from renewables will remain at 13 percent between 2005 and 2030. But if national policies now under consideration are implemented, that share could rise to 17 percent, and renewables could be generating 29 percent of global electricity by then. The Intergovernmental Panel on Climate Change (IPCC) projects that, with a CO_2-equivalent price of up to $50 per ton, renewables could generate 30–35 percent of electricity by 2030. As a 2007 review of global energy scenarios noted, the "energy future we ultimately experience is the result of choice; it is not fate."[3]

The transition away from fossil fuels involves a dual strategy: reducing the amount of energy required through energy efficiency and then meeting most of the remaining needs with renewable sources. The IEA estimates that $45 trillion in investment, or an average 1 percent of annual global economic output, will be needed between now and 2050 in order to wean the world off oil and cut CO_2 emissions in half. It is imperative that the vast majority of these investments be in efficiency improvements and renewable energy.[4]

Renewables already provide a significant share of the world's energy. In 2007 renewable energy, including large hydro, generated more than 18 percent of global electricity. At least 50 million households use the sun to heat water. Renewable resources are universally distributed, as are the technologies. While much of the current capacity is in the industrial world, developing countries account for about 40 percent of renewable power capacity and 70 percent of existing solar water heating.[5]

As this chapter describes, a range of renewable technologies are used to produce electricity and meet heating and cooling needs. They are available now and ready for rapid scale-up. Most of them are experiencing annual growth rates in the double digits, with several in the 20–50 percent range. Once these technologies are in place, the fuel for most of them is forever available and forever free. The current technical potential of renewable resources is enormous—many times current global energy use. (See Figure 4–1.)[6]

Some observers propose that coal with carbon capture and storage or nuclear power may be needed to address climate change while meeting rising energy demand. But renewable energy combined with energy efficiency can do the job, and renewables are the only technologies available right now that can achieve the emissions reductions needed in the near term. Efficiently delivered energy services that use natural energy flows will protect the global climate, strengthen the economy, create millions of new jobs, help developing countries reduce poverty, increase personal and societal security in all countries, reduce international tensions over resources, and improve the health of people and ecosystems alike. Although this chapter focuses on industrial countries and rapidly developing emerging markets, it is important not to forget the needs of people in the poorest economies.

Making Every Building a Power Plant

Buildings use about 40 percent of global energy and account for a comparable share of heat-trapping emissions. About half of this demand is for direct space heating and hot water needs, and the rest is associated with the production of electricity for lighting, space cooling, appliances, and office equipment.[7]

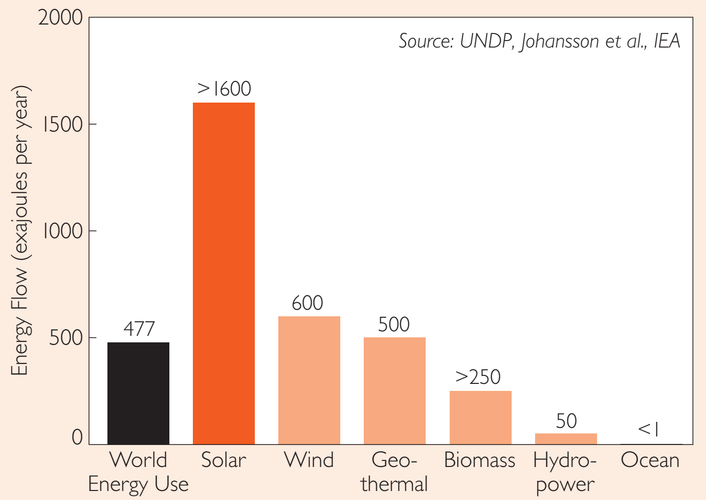
The advent of cheap and readily available energy enabled modern buildings to work in spite of nature rather than with it. But it is possible to reduce demand in existing buildings by insulating them properly, controlling unwanted air infiltration, and improving performance for space and water heating, lighting, ventilation, and air conditioning. For new construction, an integrated design with multiple energy efficiency measures can reduce energy use to at least half of a conventional building, and gains of greater than 80 percent have been achieved. The use of information technology to manage multiple functions can also help make the best use of energy.[8]

The potential savings could be great. The fragmented nature of building and lighting codes in the United States, for example, has meant the continuing construction of inefficient buildings and the unavailability of technologies that are common in Europe and Canada. India has no mandatory efficiency codes for commercial buildings, and most contractors do not know how to install insulation. But greener buildings are on the way in India as well. One of the largest green commercial developments in the world is under construction near Delhi; it is expected to exceed international energy performance standards.[9]

As energy efficiency improves, each energy unit is cheaper, so consumers might choose to use more energy or to spend their savings on other goods that require energy. This is known as the rebound effect or leakage, and it is measured by the difference between projected and actual energy savings that result from an increase in efficiency. Evidence suggests that in developing countries the rebound effect can be 100 percent or greater, meaning that efficiency improvements have at best no impact on energy use. In mature or wealthier markets, however, efficiency improvements in electrical equipment result in energy savings that are 60–100 percent of projected levels. Case studies in the United States have concluded that energy savings in commercial buildings—from schools to office towers—have frequently been greater than projected. Perhaps most promising are more-efficient, or even zero-net-energy, buildings.[10]

A zero-energy, zero-carbon building is one that produces all its own energy on site with renewable energy and emits no CO_2. Most buildings will need an energy supply

Figure 4–1. World Energy Use in 2005 and Annual Renewable Energy Potential with Current Technologies



from outside to meet peak demands at particular times of day. Still, such buildings can be zero-net-energy if they produce as much energy as they consume in a year. And if they import renewable, or zero-carbon, energy from elsewhere, they can also be zero-carbon buildings. The United Kingdom has mandated that all new homes built after 2016 and all commercial buildings constructed after 2019 must be zero-carbon.[11]

Once buildings are as efficient as possible, remaining energy demands can be met with renewable technologies. Passive solar heating and thermal storage in buildings can significantly lower the need for additional heating, and judicious placement of windows and roof shading can reduce cooling needs. In many locations, solar thermal panels can cost-effectively provide water and space heating. Solar photovoltaics (PVs) can be integrated into rooftops and even building facades, where they are often cheaper than traditional sidings. In some locations PVs are already cost-competitive with conventional power at peak demand times as they compete with the price customers pay for power rather than utility wholesale rates. They are also often cheaper than extending the electric grid or using diesel generators.[12]

The Passivhaus Institute in Germany has built more than 6,000 dwelling units that consume about one tenth the energy of standard German homes. These low demand levels are achieved through passive solar orientation for heating and daylighting, efficient lighting and appliances, super insulation and ultra-tight air barriers on doors and windows, and heat recovery ventilators. As peak loads decline for lighting, heating, ventilation, and cooling, so does the required size of fans, boilers, and other equipment, providing greater savings.[13]

There are multiple benefits to the on-site generation of energy from a variety of distributed production sites or nodes. New production units can be brought on line in small increments that conform to the new demand in a timely manner without requiring additional transmission lines and often without additional distribution lines. Since power is produced and consumed on site, transmission and distribution (T&D) of electricity from central plants are lowered, and losses are reduced—so less energy must be generated to meet the same demand. Local thermal power systems allow the capture and use of waste heat along with the production of electricity, providing heat to adjacent buildings and thereby reducing energy use and associated emissions; using renewable energy sources reduces emissions even more.

A multi-nodal system of distributed energy is more resilient and more reliable, especially where the power grid is subject to frequent interruptions from accidents or other failures. Having more but smaller power production units reduces a system's vulnerability to major disruptions. An analysis following a major 2003 blackout in the U.S. Northeast found that a few hundred megawatts (MW) of distributed PV, strategically placed around the region, would have reduced the risk of power outages dramatically. Wind turbines might play a similar role, placed along transmission corridors, highways, or train tracks, as they are in parts of Denmark.[14]

Other options for distributed power include fuel cells and thermal power systems fueled by solid biomass, biogas or liquid biofuels, or conventional natural gas turbines; all provide heat as well. The U.K. government projects that distributed generation could provide electricity for 40 percent of Britain's homes by 2050.[15]

The full benefits of interconnected systems could be achieved by transforming the outdated central-power-plant-dominated T&D system into a dynamic "hybrid" network that relies on diverse and multiple production nodes, much like the Internet. This network would consist of locally sited renewable power and combined heating, cooling, and power units, some large-scale centralized power plants, and electricity storage systems. The development of "smart grids," which use information technology to manage supply and demand, will also be critical to achieving the full potential of renewables and multiple distributed storage devices. (See Box 4–1.)[16]

Many technical issues of interconnection for distributed systems have been addressed in Europe, where homes, farms, and businesses produce significant shares of electricity for the grid. Most remaining problems are due to regulatory rules. In many places, electric utilities have monopolistic control over generation; in others, distributed generators must pay retail rates for electricity from the grid but are then paid only wholesale rates—or, in some cases, nothing—for power

Box 4–1. Building a Smarter Grid

In today's "dumb" electricity grid, communication is only one-way, from consumers to utilities, which attempt to adjust to changes in demand by ramping production up and down. When utilities cannot respond as needed, system problems such as blackouts can occur. Kurt Yeager, former president of the U.S.-based Electric Power Research Institute, compares the current electromechanically controlled grid to "a railroad on which it takes 10 days to open or close a switch."

Yet the digital age, which has increased demand for electricity and highly reliable power systems, is now allowing the transition to a faster, smarter grid that can provide better-quality power with two-way communication, balancing supply and demand in real time, smoothing out demand peaks, and making customers active participants in the production as well as consumption of electricity. The smart grid allows more-efficient use of existing power capacity and of T&D infrastructure by reducing line losses through the use of more local, distributed generation. As the share of generation from variable renewable resources increases, a smart grid can better handle fluctuations in power when the wind ebbs or clouds hide the sun. It will also allow electric vehicles to store power for transport use or to sell back to the grid when needed.

Smart technologies—including smart meters, automated controls systems, and digital sensors—will provide consumers with real-time pricing and enable them to save money and power by setting appliances, entire building heating and cooling systems, or industrial loads to shut off at specific times or when electricity prices exceed a certain level or there is a drop in generation from large wind plants. They can help shift loads to low-demand periods, when line losses are lowest and the dirtiest, least efficient plants are not operating. And they allow grid controllers to anticipate and instantly respond to troubles in the grid. Pilot programs have demonstrated significant consumer savings and demand reductions.

Full development of smart grids is 10–30 years away, depending on the policies enacted. But many countries and regions are well on their way. Pacific Gas and Electric in California, for example, is in the process of installing 9 million smart meters for its customers, while the Netherlands aims for a "base level" of smart metering and replacement of all 7 million household meters by autumn 2012. When starting from scratch, smart grids are cheaper than conventional systems, and they are helping to electrify regions of sub-Saharan Africa for the first time. The IEA has projected that more than $16 trillion will be spent in pursuit of smart grids worldwide between 2003 and 2030. If consumers are provided direct access to associated benefits, Kurt Yeager projects that a smart grid will open "the door to entrepreneurial innovation which will transform electricity efficiency, reliability and individual consumer service quality beyond even our imagination today."

Source: See endnote 16.

they feed back into it. Guaranteed access to both the electric grid and the market—through either feed-in tariffs (local generators are paid a set price for all the renewable electricity they produce) or net metering (they are paid, generally at the retail rate, for any excess power sent into the grid)—is critical to the expansion of distributed energy and renewables in general, enabling renewable energy not only to add energy supply but also to replace existing fossil fuel sources over time. While most locally generated power will not make use of transmission lines, it will use local distribution systems. An issue still to be resolved is the level of payment for use of the distribution system for the relatively small amount of electricity from local distributed sources.[17]

Smarter Central Power with Large-scale Renewables

Central electric generating stations will continue to be part of the electricity supply system in order to take advantage of an energy resource or to meet large industrial or urban loads. According to the IPCC, installed generating capacity worldwide is now about 2 million MW; it is estimated that demand growth and the need to replace existing plants will require an additional 6 million MW by 2030—at a cost of $5.2 trillion.[18]

Today electricity generation accounts for 41 percent of global primary energy use—meaning total energy use, from coal mine to appliances or other "end uses"—and 44 percent of CO_2 emissions. Thermal power plants typically convert only one third of the energy in fuels to electricity; at least 5–10 percent of that electricity is then lost in transmission, distribution, and voltage adjustments. End-use devices such as computers and appliances are also especially inefficient, and it can take 320 units of energy at a power station to produce one unit of energy in the form of light from an incandescent bulb. Technology available today and just over the horizon can revolutionize such systems, dramatically reducing inefficiencies and associated carbon emissions.[19]

Every country has large-scale domestic sources of renewable energy. Africa has the most in the world. An area covering less than 4 percent of the Sahara Desert, for example, could produce an amount of solar electricity equal to current global electricity demand. The Middle East, India, China, Australia, and the United States also have enormous solar resources. China's wind resources alone could generate far more electricity than that country currently uses, and in the United States wind energy in just a few states could meet total national electricity demand. Vast resources of geothermal, biomass, and ocean energy are also found throughout the world.[20]

Renewables currently provide nearly one fifth of the world's electricity. Although most of this comes from large hydropower, the share from other renewable sources is rising, thanks to growth rates that rival those of the computer and mobile phone industries. In 2007, wind power represented 40 percent of new capacity installations in Europe and 35 percent in the United States. Cumulative installations of solar photovoltaics have grown more than fivefold over the past five years, albeit from a very small base. As economies of scale improve and conventional fuel costs rise, renewables are rapidly becoming cost-competitive. Electricity from wind is cheaper than that from natural gas in many markets and might compete with coal in China by 2015, if not sooner. Solar thermal power now competes with gas peaking plants in California and is close to being economically feasible in China and India. And experts project that PVs will be cost-competitive without subsidies in much of the world within a decade.[21]

Despite such advances, skepticism abounds: some observers claim that renewables lack power density or are too far from demand centers, that they cannot provide baseload power—power available 24 hours a day all year long, that they require 100 percent backup, that they cannot meet more than a small share of global power needs, or that it will be many decades before they play a significant role. Certainly, renewables face significant challenges in achieving large penetrations of the world's electricity system over the time frame required, but all of these hurdles are surmountable.

Large-scale renewable resources far from population centers require new transmission lines. Although this poses a challenge, it is nothing new. The United States, Egypt, Brazil, Canada, China, and Russia transmit power from dams to cities hundreds of miles away, and new lines were required to bring electricity from large nuclear facilities and from coal plants near mines. New transmission infrastructure will be required for all forms of generation as capacity expands, and vulnerable, ailing grids will need to be replaced.[22]

There will be opposition to new power lines in many places, and minimizing the environmental and social impacts will certainly require careful analysis. But innovative technologies, such as high-voltage direct current lines, offer the potential to transmit electricity reliably over enormous distances with lower line losses. Extensive direct current grids have already been erected to balance wind power in Germany and Denmark with hydropower from Norway, for example. Now several European nations are considering a massive grid to North Africa's tremendous solar resource of the Sahara.[23]

In the United States, studies have found that adding new transmission to transport wind energy from the Great Plains to population centers would yield large net economic savings for customers as the benefit of competitive and stable long-term wind power prices outweighs the costs of new transmission. And some of the best renewable resources do not need to travel far. For example, solar in the U.S. Southwest and wind and ocean resources along coastlines offer many large cities the potential to get clean energy while reducing grid congestion and line losses and improving system reliability.[24]

Renewable resources—including biomass, geothermal, ocean thermal, and hydropower—can in fact provide large-scale baseload power, and many already do. New concentrating solar thermal plants in Spain and under construction in the United States can store heat for up to seven hours in molten salts, enabling them to dispatch power on demand and maximize production when it is of greatest value, during hot summer afternoons and early evenings. In coming decades, ocean energy technologies under development will offer power that is baseload or highly predictable. Economical options are being pursued to store wind and PV energy and allow generation of high-value electricity even when the wind is not blowing and the sun is not shining.[25]

For more than a century, pumped hydro and large hydroelectric reservoirs have provided storage for conventional power, enhancing grid stability and balancing demand and supply. They now do the same for renewables. Facilities that store compressed air in underground caverns have operated for years in Alabama in the United States and in Huntorf, Germany, and are under development elsewhere. Low-cost power is used to compress air that can later increase the output of natural gas turbines during peak demand periods. Studies have found that compressed air storage would allow wind power to provide baseload power and that any cost-effective storage option could boost wind's share of the electricity system to more than 80 percent. A diversity of rapidly advancing battery technologies offer great storage potential, particularly in electric vehicles, which could revolutionize how the world produces and uses power and enable all renewables to displace oil. And the value of storage goes beyond renewables, enabling better management of peak demand, providing a more stable grid and better power quality, and in some cases reducing the need for new transmission lines.[26]

Better storage has often been called renewable energy's "Holy Grail." But even without storage, electric utilities are recognizing that individual variable renewable sources like the sun or wind—despite variations in availability from moment to hour to season—can provide as much as 20 percent of a system's electricity, and in some cases more, without serious technical problems. So far no additional backup capacity has been required because existing systems are designed to handle variations in demand and outages of power plants or transmission lines on a routine basis.[27]

The addition of new renewables changes the degree—but not the kind—of variability that utilities face in matching supply with demand. The capacity to absorb large amounts of renewable power is determined primarily by regulatory and market barriers rather than technical constraints. Variability and uncertainty may increase operating costs, but generally by modest amounts, and the overall cost and risk reductions associated with free fuel of most renewables can be significant. It is also worth noting that there are costs to integrating conventional power plants into existing systems, but a lack of studies makes cost comparisons impossible.[28]

Denmark generated 21 percent of its electricity with the wind in 2007, and occasionally wind power meets more than 100 percent of peak demand in parts of western Denmark. Four German states produced more than 30 percent of their electricity with wind power in 2007. In California, renewables make up more than 30 percent of the portfolios of some large utilities. Utilities have balanced supply and demand through the interconnection of grid systems over large regions with a diversity of loads and resources, use of hydropower as temporary storage, dispersal of renewable power plants over large geographic areas, and solar and wind forecasting an hour or a day ahead. These "hybrid grid" tools help utilities to regulate supply, but there is also more they can do to control the demand side—to reduce demand or shift it away from time-insensitive uses.[29]

In the United States, adding new transmission to transport wind energy from the Great Plains to population centers would yield large net economic savings for customers.

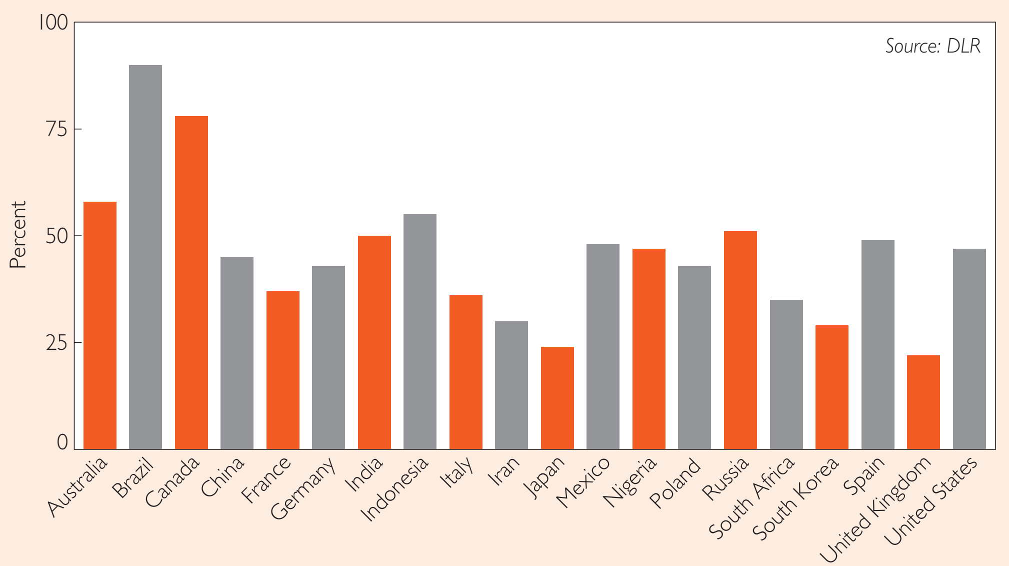
Through demand-side management programs, utilities help customers undertake conservation, efficiency, or load shifting to reduce demand or shift it to off-peak periods, when electricity can be generated and transmitted more efficiently, in order to avoid the need for new power plants. Thanks to a Californian program that decoupled transmission utility revenue from sales in 1982, per capita electricity use of the average Californian has remained nearly constant for 25 years and is significantly less than that of the average American. Efficiency improvements enable renewables to more rapidly play a greater role.[30]

But unleashing the full potential of efficiency and renewables will require a modern, more reliable, intelligent grid at the distribution level, where lower voltage power lines transport electricity to (and increasingly from) homes, offices, and other facilities. Smart grid technologies, now being installed in Africa, Asia, Europe, New Zealand, and the United States, will be able to smoothly integrate all types of central plants with renewables, distributed generation, electric vehicles, and electrical storage facilities while enhancing grid reliability. By controlling the flow of electricity electronically, in real time, smart technologies maximize the capacity of existing grid infrastructure and minimize the need for backup and storage, enabling grids to absorb unlimited renewable capacity.[31]

Implementation of smart, hybrid grid systems will require rethinking how the electric industry works in much of the world, but addressing climate change requires such a transformation in any case. Some utilities are already making this transition. The Danish power company DONG is making conventional power plants more flexible so they can be turned down, or even off, when the wind is blowing. "In the old times," explains Chief Executive Anders Eldrup, "wind power was just something we layered on top of our regular production. In the future, wind will provide a big chunk of our baseload production."[32]

A report by the German Aerospace Center (DLR) projects that by 2030 renewables could generate at least 40 percent of national electricity in 13 of the 20 largest economies. (See Figure 4–2.) Hydro, wind, and biomass power will likely achieve the greatest market shares in the near to medium term, with geothermal and particularly solar power playing greater roles in the longer term. By 2050, renewables could contribute at least 50 percent of national electric power in each of the world's large economies, and up to 90 percent in some countries. Some projections

Figure 4–2. Renewables' Potential Share of Electricity Supply in 2030 in 20 Largest National Economies



go even further—a U.S. study projects that by 2050 solar power alone could provide 69 percent of the nation's electricity, plus enough power to fuel 344 million plug-in hybrid vehicles.[33]

By tapping the potential of all renewables, the world can move away from fossil fuels in the next few decades, not only reducing the threat of climate change but also creating a more secure and far less polluting electricity system. The Combined Power Plant, a project linking 36 wind, solar, biomass, and hydropower installations throughout Germany, has already demonstrated that a combination of renewable sources and more-effective control can balance out short-term fluctuations and provide reliable electricity with 100 percent renewable sources. In a recent interview about the future of the electric industry, S. David Freeman, a 50-year veteran of the U.S. electric industry, said "it still will take 25, 30 years to phase out the existing coal-fired plants and have an all-renewable world." But, he concludes, "I'm a utility executive that ran major utilities, and I can tell you there is no reason why the electric-power industry can't be all renewable."[34]

Heating and Cooling with Renewables

Renewable heating and cooling are too often the neglected twins when it comes to climate change and energy policies. They account for 40–50 percent of global energy demand. A large share comes from fossil fuels and is provided inefficiently by electricity or direct combustion.[35]

As early as the Bronze Age, wood was used to turn sand into glass, extract metals from stone, and fuel furnaces to make bronze and pottery. There is evidence that high-temperature geothermal water was used to heat buildings in ancient Pompeii, while Greeks and Romans captured the sun's warmth to do the same job. Today renewable energy and improved efficiency options exist to meet a wide range of heating and cooling needs, from residential and district heating and cooling systems to industrial-scale refrigeration and high-temperature heat. (See Table 4–1.)[36]

Among new renewables, solar heating ranks second only to wind power for meeting world energy demands. China leads the world in the production and use of solar thermal systems, with an estimated 1 in 10 households tapping the sun to heat water; Cyprus, Israel, and Austria top the list for per person use. Solar water heating is mainstream in Israel thanks to a 1980s law requiring its use in new homes. Hybrid solar hot water/photovoltaic systems are now available to capture a large amount of the heat absorbed by PVs, thereby cooling them and increasing their efficiency while simultaneously heating domestic water. One of the first systems sits atop the roof of a central building in Beijing's Olympic Village.[37]

The majority of solar thermal systems in use are for domestic water and space heating, yet solar heating systems—including systems similar to solar heaters for residential buildings and concentrating solar collectors—offer enormous potential for meeting industrial heat demand, particularly at low and medium temperatures (up to 250 degrees Celsius). By late 2007 about 90 solar thermal plants provided process heat for a broad range of industries, from chemical production to desalination and the food and textile industries. Existing plants worldwide represent a tiny fraction of the industrial heat potential available in Europe alone.[38]

Across Europe, the United States, and elsewhere, people are turning to efficient pellet stoves and in some cases using liquid biofuels in boilers to meet heating needs. Between 1980 and 2005, taxes on energy and CO_2 in Sweden drove a major shift from

Table 4–1. Alternatives to Fossil Fuels for Heating and Cooling

Technology	Description	Where Available or Possible
Absorption cooling	Uses a heat source (such as the sun or waste heat from combined heat and power (CHP)) to cool air through an evaporative process; small to large-scale	Anywhere
Bioheat	Heat derived from the combustion of biomass, such as wood or pellets; residential to large-scale	Anywhere close to sustainable wood or other biomass resources
Combined heat and power (cogeneration)	Use of a power plant to produce both heat and electricity; residential to large-scale	Anywhere
Concentrating solar thermal	Uses optical concentrators to focus the sun to provide higher-temperature heat and steam for industrial processes (and thermal electricity production)	Needs clear skies as in Spain, North Africa, parts of China and India, or U.S. Southwest
District heating (or cooling)	Distribution of heating (cooling) from a central generating site, through a piped network, to meet local residential and commercial needs	Possible anywhere for use in urban and campus settings with multiple buildings
Geothermal high-temperature heat	Geothermal steam or hot water used for district water and space heating, warming greenhouses, aquaculture, spas and swimming pools, industrial purposes (and thermal electricity production)	Regions of active or geologically young volcanoes, including Iceland, western North and South America, Philippines, Japan, East Africa
Ground-source heat pump	Pump that makes use of ground-stored solar heat or well water to provide space and water heating/cooling; residential to large-scale	Anywhere
Passive solar heating	Collects solar heat through appropriate building orientation and window placement	Anywhere heating is needed
Passive cooling	Avoids excess heat absorption by designing buildings to reduce passive solar gain, such as avoiding glass and using passive ventilation	Hot, particularly dry, regions
Seawater or lake cooling	Harnesses constant coolness of deep water to provide space cooling (and cold water) to buildings through a piped network	Requires proximity to cold water resource (along deep rivers, lakes, or coastlines)
Solar thermal heat system	Uses the sun's heat to provide space and water heating for buildings and low-temperature heat and hot water for industrial processes	Anywhere

fossil fuels to biomass for district heating, reducing associated emissions to less than one third their 1980 level. Austria and Denmark also rely heavily on biomass to heat homes, farms, and district systems. Poland is replacing coal with biomass for power and heating needs. Biomass can directly replace fossil fuels, and modern wood burners can convert biomass to heat at efficiency rates of up to 90 percent.[39]

Geothermal energy is used for everything from space heating and cooling to warming greenhouses and melting snow on roads and bridges. In France, Iceland, New Zealand, the Philippines, Turkey, the United States, and other countries with high-temperature resources, geothermal heat is used for electricity generation, district heat, and industrial processes like pulp and paper production. Ground-source heat pumps, which can be used virtually anywhere, use the stored solar energy of Earth or well water as a heat sink in summer and heat source in winter. The United States has the world's largest heat pump market, with up to 60,000 systems installed annually.[40]

Because buildings generally require heat as well as electricity, combined heat and power units can be designed to supply both. CHP plants generate electricity and capture remaining heat energy for use in industries, cities, or individual buildings. They convert about 75–80 percent of fuel into useful energy, with efficiencies exceeding 90 percent for the most advanced plants. As a result, even traditional fossil fuel CHP systems can reduce carbon emissions by at least 45 percent. These systems can also make use of absorption chillers for space cooling to lower electricity demand even further. Residential-scale CHP units have been widely available in Japan and Europe for years and were recently introduced in the United States.[41]

Seawater and lake source district cooling systems have been developed for a range of climates, from Kona in Hawaii to Stockholm in Sweden, and can save more than 85 percent of the energy required for conventional air conditioning. The cold waters of Lake Ontario provide district cooling to Toronto in Canada; the system has the capacity to cool more than 3.2 million square meters of building space, avoiding 79,000 tons of CO_2 annually. Many of the world's big cities are near large water bodies, which they could tap for cooling. And as paradoxical as it might seem, solar energy can also provide cooling via the oldest form of air conditioning technology—absorption cooling—with the same devices that provide heat in the winter. While such systems are still relatively costly, several are already in operation, including a solar-driven cooling system in Phitsanulok, Thailand.[42]

Economical heat storage over a wide range of temperatures and time periods can significantly increase the potential of renewable systems. Some storage options are already available and cost-effective, particularly in combination with large-scale district systems. For example, surplus solar heat in summer can be transferred to underground storage for space and water heating in winter.[43]

According to the IEA, "solar water heating, biomass for industrial and domestic heating, deep geothermal heat and shallow geothermal heat pumps are amongst the lowest cost options for reducing both CO_2 emissions and fossil fuel dependency. In many circumstances these technologies offer net savings as compared to conventional heating systems in terms of life-cycle costs." And yet these renewable sources and technologies currently meet only 2–3 percent of total demand.[44]

Attitudes have begun to change as fuel prices rise and countries recognize the enormous potential of renewables. To date, the most successful countries have enacted combinations of policies to address the different barriers facing renewable heating and cooling technologies. These include lack of public awareness, the need to train a work force and educate city planners and architects about integrating renewables, high upfront costs, the "tenant-owner" dilemma (where building owners and inhabitants are different people, and the person who pays does not benefit), and the need for scale.[45]

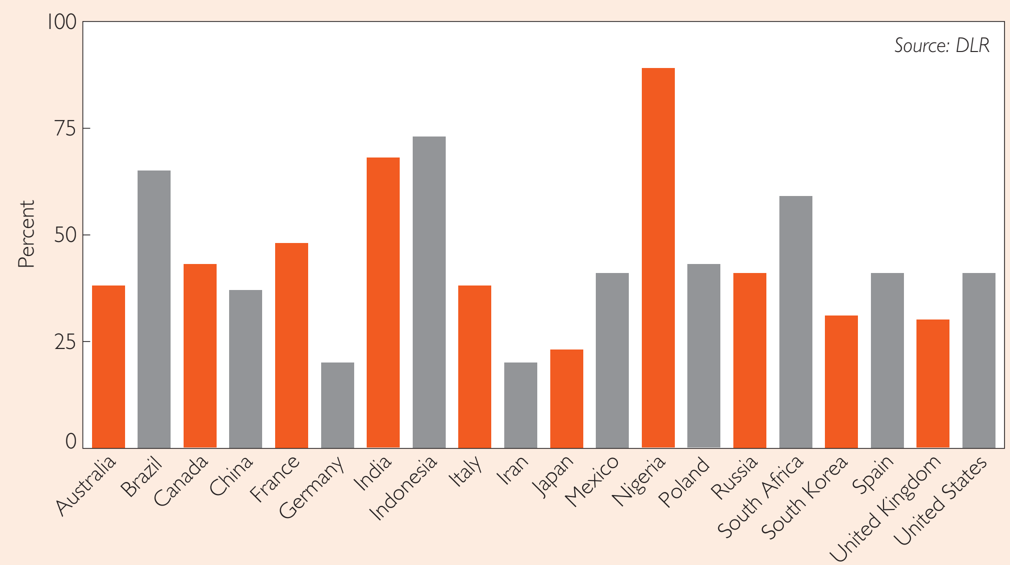
Cloudy Germany has one of the largest solar thermal heat markets in the world thanks to public awareness of the technology and long-term government investment subsidies. The German state of Baden Württemberg now requires that all building plans for new homes include renewable systems to meet at least 20 percent of space and water heating needs, and as of 1 January 2009 the German federal government requires new buildings to meet at least 15 percent of their heating requirements with renewable sources. Since 2006 Spain has mandated solar systems for all new or renovated buildings, and Hawaii will require solar water heaters on all new homes starting in 2010.[46]

DLR in Germany projects that 12 of the 20 largest economies could meet at least 40 percent of their heating needs with renewables by 2030, representing a significant increase from current shares for most countries. (See Figure 4–3.) By 2050, renewables' share in the majority of these countries could exceed 60 percent, according to DLR and REN21 estimates, with renewables supplying at least 70 percent of heating in some countries.[47]

Waste Not, Want Not

In the natural world, waste from one process provides nutrients for another. Nothing is wasted. The human world, however, functions quite differently. For example, most of the world's power plants convert heat to mechanical energy to electricity; in the process, about two thirds of the primary energy fed into

Figure 4–3. Renewables' Potential Share of Heat Supply in 2030 in 20 Largest National Economies



these plants is released into the environment as heat. In Europe, losses from power generation are so great that if they were captured and rerouted they could meet the region's heat demand through district heating. Heat is just one form of waste that could be captured to dramatically increase useful energy without burning more fossil fuels.[48]

A 2005 study by the U.S. Lawrence Berkeley National Laboratory examined 19 different technologies at various scales that can recover energy from waste heat, manure, food industry waste, landfill gas, wastewater, steam and gas pipeline pressure differentials, fuel pipeline leakages and flaring, and numerous other sources. In the United States alone they offer the technical potential to profitably generate almost 100,000 MW of electrical capacity—enough to provide about 19 percent of the nation's electricity in 2002—in addition to useful heat or steam.[49]

Around the world, some of these "wastes" are already being tapped. For example, combined heat and power is used widely in much of northern Europe, with Denmark, Finland, and Russia leading in the shares of national power production. Finland meets about half of its heating needs with district systems, mainly CHP plants. District Energy in the U.S. city of Saint Paul, Minnesota, provides electricity, heating, and cooling to its customers; 70 percent of its fuel is local wood waste.[50]

The world's petrochemical, glass, metal, and other heavy industries offer enormous potential for using waste heat through CHP and through capturing and reusing "cascading" heat for lower temperature uses. Mittal Steel, on the southern shore of Lake Michigan in the United States, captures high-temperature heat released from 250 ovens used to produce coke for its blast furnace; this heat energy, which was formerly vented, today produces 93 MW of electricity plus useful steam. As a result, Mittal saves $23 million and avoids 5 million tons of CO_2 emissions annually.[51]

In China, energy-intensive industries account for almost half of energy use. Nearly 30 percent of large steel furnaces and most cement manufacturers in this country do not capture and reuse waste heat, so the savings potential is enormous. Thus China has been called the "Saudi Arabia of waste heat." A large Baosteel furnace uses waste heat to generate 192,000 kilowatt-hours of electricity a day, enough to meet the needs of more than 43,000 average Chinese. In eastern China, CHP plants are gradually replacing individual kilns and boilers to heat industrial parks and residential facilities clustered with factories.[52]

Anaerobic digesters decompose organic matter in the absence of oxygen to produce biogas for cooking or transport fuel or to generate electricity, as well as create high-quality compost for fertilizer. Biodigesters, fed primarily with animal manure, are widespread throughout India, Nepal, China, and Viet Nam and provide cheap fuel while reducing pollution and diseases caused by untreated waste. On a larger scale, dozens of municipalities in Sweden convert human sewage to biogas for transport fuel; biogas is also available as vehicle fuel in Austria, France, Germany, and Switzerland.[53]

Fats and waste oils can be converted into renewable diesel and jet fuel, which can be transported through existing pipelines. Anything that contains carbon, oxygen, and hydrogen—including construction debris, waste paper, plastic, wood, and lawn trimmings—can be turned into some form of motor fuel today, which has the added benefit of extending the life of landfills. The challenge for many of these technologies is obtaining the capital to scale up and commercialize.[54]

While still in the early stages of development, algae can convert as much as 80 percent of the CO_2 released from coal and natural-gas-fired power plants into biomass. Algae can be used in power plants as fuel or converted into bioethanol, biodiesel, or biogas and provide high-protein feed for livestock and aquaculture. It can grow in polluted or salt water, on nonarable land, or at wastewater treatment facilities. It requires far less water than most biofuel crops, produces several times the biofuels per hectare, and can be productive even in desert regions. Harvesting and processing algae is an energy-intensive process, but it offers the potential to "burn carbon twice"—providing additional energy for each unit of CO_2 emitted and an alternative to long-term physical storage of carbon dioxide.[55]

Using energy more efficiently can reduce emissions even further. For example, lighting accounts for 19 percent of world electricity consumption, yet technologies available today, including compact fluorescent lamps and light-emitting diodes, could halve electricity use for lighting. Realistically, it is feasible to eliminate at least one third of global electricity consumption for lighting simply by changing lightbulbs—saving money and avoiding about 450 million tons of CO_2 in the process. By reducing waste in the production and use of energy, more energy services can be provided with lower carbon dioxide emissions.[56]

Scaling Up Renewables

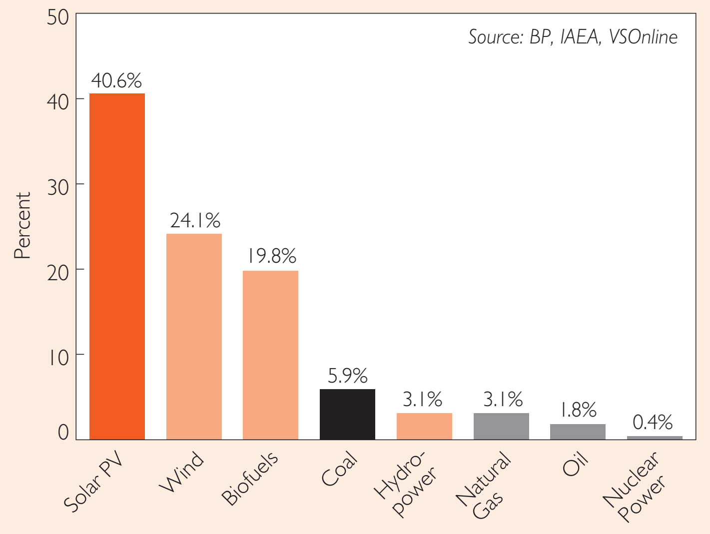
Some analysts conclude that only very large facilities such as nuclear power, large-scale hydro, or large coal plants with carbon capture and storage can meet the world's rapidly growing energy needs. Renewable energy, it is argued, is too small-scale and too dispersed to make more than a modest contribution. But experiences with renewables in Germany and elsewhere prove otherwise, as described in the next section.

Furthermore, large projects cannot produce any power until construction is completed, which can take a very long time. Consider, for example, that a 1,000-megawatt power facility takes approximately 10 years to complete. If all goes well and it operates at full power in year 11, it will produce almost 8.8 million megawatt-hours of electricity that year. Now consider starting at the same time construction of a modular unit that can produce one tenth as much electricity per year as the single large unit but that begins producing power at the end of year one. This process is repeated each year until 10 modular units have been built and come online in each of 10 years. If each one operates at full capacity, by the end of the eleventh year the modular units will have produced nearly five times as much power as the large unit produces in its first year of operation, and after that the two facilities will produce the same amount annually.

There are demonstrated advantages to modularity when it comes to scaling up production, even with fossil fuels. Most of the thermal electric power capacity introduced over the past 10 years in North America has been natural-gas-fired turbines for several reasons: they have become exceedingly efficient, their unit cost is low because of economies of scale, and they can be produced quickly in modules of 50–100 MW and installed within a year. Rapid installation means a low cost of borrowing and a better match and immediate production of power upon installation. Incentives in the deregulation process have also encouraged installation of these units.[57]

The magnitude of the evolution required is vast, but it is achievable. In 2007 wind power was the largest single source of new capacity in Europe and second only to natural

Figure 4–4. World Average Annual Growth Rates for Energy Resources, 2002–07



gas in the United States. Globally, even new solar photovoltaic capacity exceeded that of newly installed nuclear power capacity that year. And renewable technologies continue to advance—for example, a new PV technology introduced in 2007 bypasses silicon as a base material, could lower costs by 75 percent, and allows for increased rates of production.[58]

More countries are also joining the transition, promising to push growth rates even higher for the manufacture of and demand for renewables. Indian wind turbine manufacturers are acquiring European and North American suppliers and markets and are now among the top global producers and installers of wind turbines. China was barely in the wind business in 2004 but ranked third after the United States and Spain for new installations in 2007. Similarly, in 2003, China manufactured 9 MW of PV cells—1 percent of the global total. But by 2007, by some estimates, Chinese companies passed Japan and Europe to lead the world in solar PV production. China could account for two thirds of global production by 2010.[59]

Current growth rates indicate that wind, solar, and biomass plants can be manufactured at rates that are comparable to large-scale conventional power projects. (See Figure 4–4.) In 2002–07, photovoltaics grew at an annual average rate exceeding 40 percent and wind's average growth rate topped 24 percent. Annual PV and wind growth rates have actually accelerated in recent years. If current growth rates continue, tapping the wind will generate more electricity than nuclear power in 2020.[60]

Such massive undertakings have succeeded in the past. The U.S. public works projects of the Great Depression, the vast numbers of airplanes and warships built for two world wars, and the enormous number of automobiles manufactured annually provide testimony to possible rates of scaling up. It is a matter of setting priorities and having the political will to establish effective and long-term policies that support a new energy economy. The resources and capabilities exist. By one estimate, if two thirds of U.S. truck production were redirected to the production of wind turbines, about 100,000 MW of wind capacity—the cumulative total installed globally by early 2008—could be manufactured annually in the United States alone.[61]

Of course, energy will be required to move

Box 4–2. Replacing Old Power Plants

Almost all energy-using and energy-producing technologies have natural cycles of capital stock turnover, ranging from 3–4 years for computers to 10–20 years for vehicles and 50–150 years for buildings. Power plants, in contrast, get life extensions. Components degrade at different rates, and if there is no required maximum lifetime they are replaced as needed. Some components could be 40 years old and others two months old, providing a disincentive for utilities to ever retire their plants.

In the United States, power plants constructed before a specific year are exempt from air quality standards unless they are "substantially upgraded." Utilities therefore hold on to old inefficient power plants, retrofitting the minimum required to keep plants operating for as long as possible. As a result, the average efficiency of U.S. coal-burning power plants is only 33 percent and the median age is over 40 years. A similar situation faces heavy coal-producing and coal-consuming countries like China, India, Indonesia, Australia, and Russia.

Economies that successfully reduce their electricity use will have a comparatively easy time retiring older, less efficient, high-emissions plants as demand falls. Those with stable demand must decide which plants to shut down as they wear out or become obsolete and which technologies will replace them. Rapidly expanding economies with a lot of new capacity might not replace plants for some time, but they must make decisions about future additions. To avoid getting locked further into carbon-intensive fuels, low-carbon plants—distributed or central renewable power capacity—should be installed as new capacity is needed. To accelerate the closing of older plants everywhere, governments must set phaseout dates and provide incentives.

Source: See endnote 62.

away from fossil fuels. This is one reason to use the natural capital stock turnover time to replace older plants when they reach the end of their useful lives. (See Box 4–2.) When existing infrastructure is replaced, as much of the energy embodied in the concrete and steel as possible should be recovered through material recycling.[62]

Building massive numbers of new wind, solar, geothermal, and biomass plants and other renewable systems will also require large amounts of energy. But the energy payback periods for renewables are declining as efficiencies increase. They are already relatively short—three to eight months (depending on wind speed) for a wind turbine and one to five years for today's solar PV panels (depending on cell type and location), which have a lifetime of close to 30 years. And once most renewable technologies are built, no further energy is required to extract and transport fuels for them to operate.[63]

Finally, the dramatic improvement in energy efficiency and the matching of supply to demand that is both required and possible today means that the replacement of existing power generators with smaller units capable of delivering comparable energy services with less energy should accelerate in coming years.

Kicking the Habit

Shifting to a sustainable energy system based on efficiency and renewable energy requires replacing an entire complex system. Can such a transformation be accomplished in time to avoid the worst consequences of climate change? Several communities and countries provide hope that it can. Some of the most rapid transitions have taken place at the local level, as seen in Güssing. Many cities are devising innovative means to finance renewables and expand markets. And several countries are demonstrating that transformation can happen quickly even on a national scale.

In the early 1990s Germany had virtually no renewable energy industry and seemed unlikely ever to be in the forefront of these technologies. Yet within a decade this nation had become a world leader, despite the fact that its renewable resources are a fraction of those available in many other countries. In 2000, just over 6.3 percent of Germany's electricity came from renewable sources. Only six years later, this industrial power—the world's leading exporter—generated more than 14 percent of its electricity with renewables, well ahead of official targets for 2010. The fast pace of growth and associated benefits—from new jobs and industries to an improved environment—led the government to set more ambitious targets in 2007. Germany now aims for renewables to generate 30 percent of the country's electricity by 2020 and 45 percent by 2030, meaning renewables will become the largest power source within the next decade.[64]

Germany's experience provides proof that, with a clear sense of direction and effective policies, rapid change is possible. And Germany is not alone. Denmark's economy has grown 75 percent since 1980, while the share of energy from renewables increased from 3 percent to 17 percent by mid-2008. The Danes aim to get 20 percent of their total energy from renewable sources by 2011 and 30 percent by 2030. Costa Rica, Iceland, New Zealand, Norway, and Sweden aim to be carbon-neutral in a matter of decades, relying heavily on efficiency and renewable energy.[65]

What might a low-carbon or even a carbon-free energy future look like? And how might countries with far larger populations than New Zealand or Iceland, or that use much more energy than Germany, make this transition? The United States, for example, has a thousand times as many inhabitants as Iceland does and uses more than one fifth of the world's energy.[66]

Imagine that it is 2030 and that all new buildings in the United States are zero-carbon, the current goal of the American Institute of Architects. A large share of existing buildings have been retrofitted with better insulation, windows, and doors. And all buildings use the most efficient lighting and appliances available. As the Passivhaus Institute projects and other highly efficient buildings already demonstrate, the remaining modest energy supplies for many buildings can be produced on site with renewables or highly efficient systems. Further, industries can dramatically reduce their energy use by eliminating waste and cascading heat from one step to the next, generating more useful energy with the same amount of fuel. By 2030, the resulting energy and economic savings are enormous, and thousands of new local jobs have been created.[67]

Most buildings and factories are still connected through the electric grid, but a modern, smarter, more reliable grid allows utilities to balance the two-way flow of electricity supply and demand in real time. The smart grid in combination with distributed power production and storage—including electric vehicles that charge when the sun shines on PV-covered homes or parking lots, or at night when the wind is blowing—allows even variable renewables to generate a large share of U.S. electricity.

According to a 2008 report by the U.S. Department of Energy, by 2030 the wind could provide 20 percent of U.S. electricity (assuming that U.S. electricity demand increases 39 percent by then). As a result, the nation's CO_2 and other emissions would be significantly lower than they would otherwise be. Tens of thousands of new jobs would be created and rural economies would flourish as wind farms provided new sources of income for landowners and tax revenue for local communities. If fossil fuel prices remain stable over this period (an unlikely assumption), a 20-percent wind portfolio would cost less than an additional 0.06¢ per kilowatt-hour by 2030, or about 50¢ a month for the average household.[68]

One of the most important steps governments can take to address climate change is to eliminate subsidies for conventional fuels and technologies.

Rigorous studies have not yet been carried out for other renewable technologies, but the potential for increasing energy generation with a hybrid electric power generation system that includes wind, solar, biomass, geothermal, small- and large-scale hydropower, and eventually ocean energy is enormous. A 2007 study concluded that efficiency in concert with renewable energy could reduce U.S. carbon emissions 33–44 percent below current levels by 2030. Efficiency improvements could achieve 57 percent of the needed reductions; renewables could provide the rest while generating about half of U.S. electricity. And the study did not consider electricity storage or highly efficient transmission lines for transporting electricity long distances, nor did it include ocean energy or renewable heating.[69]

The United States is rich in renewable resources. But many other nations are as well, and each country on Earth has a diversity of renewable energy sources to draw on. Some of the fastest-growing economies have some of the best resources—for example, China, India, and Brazil have vast solar, wind, biomass, and other renewable resources.[70]

For the world to avoid catastrophic climate change and an insecure economic future, the transition already under way must be accelerated. Success stories must be scaled up, and strategies must be shared across national boundaries. It is important to realize that countries are at different points in their development trajectory and must tailor their approaches to their particular resources and customize technologies to meet specific needs. At the same time, there are several key regulatory and policy changes that, if implemented broadly worldwide, could put humanity on course to steer clear of the worst impacts of climate change.

Putting a price on carbon that increases over time is a critical first step. To encourage an effective transition, most of the revenue generated in the near term can be redirected to help individuals and businesses adjust to higher prices while adopting and advancing the needed technologies. In the 1990s, Denmark began taxing industry for the carbon it emitted and subsidizing environmental innovation with the tax revenues. At the same time, the government made significant investments in renewable energy. The tax gave industry a reason to stop using carbon-intensive fuel, and advances in renewables provided a viable alternative. By 2005, per capita CO_2 emissions in Denmark were almost 15 percent below 1990 levels. But the global price per ton of carbon will have to rise considerably before needed changes and investments come about worldwide, and institutional and regulatory barriers must be overcome with policies that drive the required revolution.[71]

Policies that begin to wring out energy waste and increase efficiency will be critical for reducing demand growth. A combination of financial incentives, such as low-cost loans and tax benefits to purchase renewable and energy-saving technologies, plus continuously tightening efficiency standards for lighting and appliances, is needed. Regulatory barriers to the introduction of distributed energy and CHP generation must be removed, and codes to improve building performance and to use more renewable space conditioning and daylighting must be introduced. Establishing an energy rating system for all buildings at the time of sale, as some European countries have done, would encourage continuous upgrading of existing structures. Training architects, construction tradespeople, and inspectors is essential for designing and constructing more-efficient buildings. Efficiency improvements will reduce energy use and provide life-cycle economic savings as well.[72]

Regulatory systems must foster innovation and motivate vested interests to speed the transition rather than fighting to maintain the status quo. Governments must make it more profitable for electric utilities to invest in renewable energy and efficiency than it is to build new fossil fuel plants or even continue operating old ones. Within the next decade, many power plants in industrial countries will reach the end of their technical lifetimes, and it will be critical to ensure than they are replaced with renewable options. Some countries are starting to phase out subsidies for coal or even its use—for example, the province of Ontario in Canada plans to stop burning coal by 2014—but others have big plans to build new coal plants. It will be critical to minimize their numbers and to enact policies that encourage industrial and rapidly developing countries to blaze new development paths. And governments must work with utilities to upgrade the electric grid so it can use a multiplicity of technologies, both distributed and centralized, and take advantage of active demand management through information technology. Otherwise it will not be possible to take full advantage of renewable energy sources or many energy efficiency measures.[73]

As Germany's experience demonstrates, policies that create markets for renewable technologies can drive dramatic and rapid change. Under the German feed-in tariff, priority grid access combined with a guaranteed market and long-term minimum payments for renewable power have reduced investment risks, making it profitable to invest in renewable technologies and easier to obtain financing. The policy has created nearly 300,000 jobs, strong and broad public support for renewable energy, robust new industries, and significant reductions in CO_2 emissions—all for the cost of a loaf of bread a month for the average German household. In 2007, emissions trading reduced the country's emissions by an estimated 9 million tons; the feed law avoided approximately 79 million tons of CO_2 emissions and is considered Germany's primary climate protection policy. Several studies have determined that feed-in laws are the most effective and economically efficient policy option for advancing renewable electricity generation. Following Germany's lead, more than 40 other countries, states, and provinces have adopted variations of this law.[74]

Although feed laws and other policies that encourage private investment in research and development (R&D) can play a critical role in technology advancement, public R&D funding is also important. According to the International Energy Agency, R&D funding for low-emission technologies including energy efficiency and renewables declined 50 percent between 1980 and 2004. And these technologies continue to receive a relatively small share of R&D funds. Between 2002 and 2007 in the United States, for example, R&D expenditures on energy technologies totaled $11.5 billion, but only 12 percent was directed to all renewable technologies. The vast majority went to nuclear power and fossil fuels.[75]

One of the most important steps governments can take to improve energy markets and address climate change is to eliminate subsidies for conventional fuels and technologies. According to the U.N. Environment Programme, global energy subsidies now approach $400 billion annually, with the vast majority going to fossil fuels. Eliminating fossil fuel subsidies could reduce global CO_2 emissions at least 6 percent between 2000 and 2010 while giving a small boost to the global economy. Recent analysis shows that 96 percent of the annual rise in energy use is occurring in developing countries that subsidize the price of energy at well below world market prices.[76]

Just as the transition to renewables and more efficient energy use has transformed Güssing and other towns, reforming the global energy economy will lead to major changes in national economies and societies. Renewable energy and efficiency improvements provide energy with little to no pollutants, ensuring that air and water will be cleaner, ecosystems stronger, and future generations healthier. They create jobs—today, by conservative estimates, about 2.3 million people worldwide work directly in renewable technology fields or indirectly in supplier industries. And some of the best renewable resources are in some of the poorest regions of the world. In June 2004, at a major conference on renewable energy in Bonn, Germany, government delegates from several African nations claimed that their countries could not develop without renewable energy. Renewable resources are readily available, reliable, and secure, and no battles will ever be waged over access to the wind or sun. As fossil fuel prices continue to rise, renewable energy prices will fall while technologies continue to advance and economies of scale increase.[77]

The dramatic and rapid changes needed to create this new energy economy appear daunting, but remember that the world underwent an energy revolution of comparable scale a century ago. Soon after Thomas Edison improved the electric lamp, skeptics criticized it with comments like this from the President of Stevens Institute: "Everyone acquainted with the subject will recognize it as a conspicuous failure." In 1907, only 8 percent of U.S. homes had electricity. Henry Ford had produced about 3,000 vehicles in his four-year-old factory, and the mass-produced Model T wasn't introduced until 1908. Few of those who supplied town gas for lighting or who met the needs of the extensive market for horse-drawn carriages felt threatened by impending change. Who could have imagined that by the mid-twentieth century virtually every American home—and millions of others around the world—would have electricity and lighting, that the automobile would redefine American lifestyles, and that the economy would be fundamentally transformed as a result?[78]

Fast forward to 2009. Non-hydro renewables generate less than 4 percent of the world's electricity and only a small percentage of its heating and cooling. We are only beginning to construct zero-carbon buildings, and plug-in hybrid vehicles and high-performance electric cars are just making their debut. Yet who can imagine how the mid-twenty-first century global economy will be transformed by more-efficient use of energy and cost-effective renewable energy sources, and how much they will limit the release of greenhouse gases into the atmosphere? We have a once-in-a-century opportunity to make a transformation from an unsustainable economy fueled by poorly distributed fossil fuels to an enduring and secure economy that runs on renewable energy that lasts forever.[79]

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