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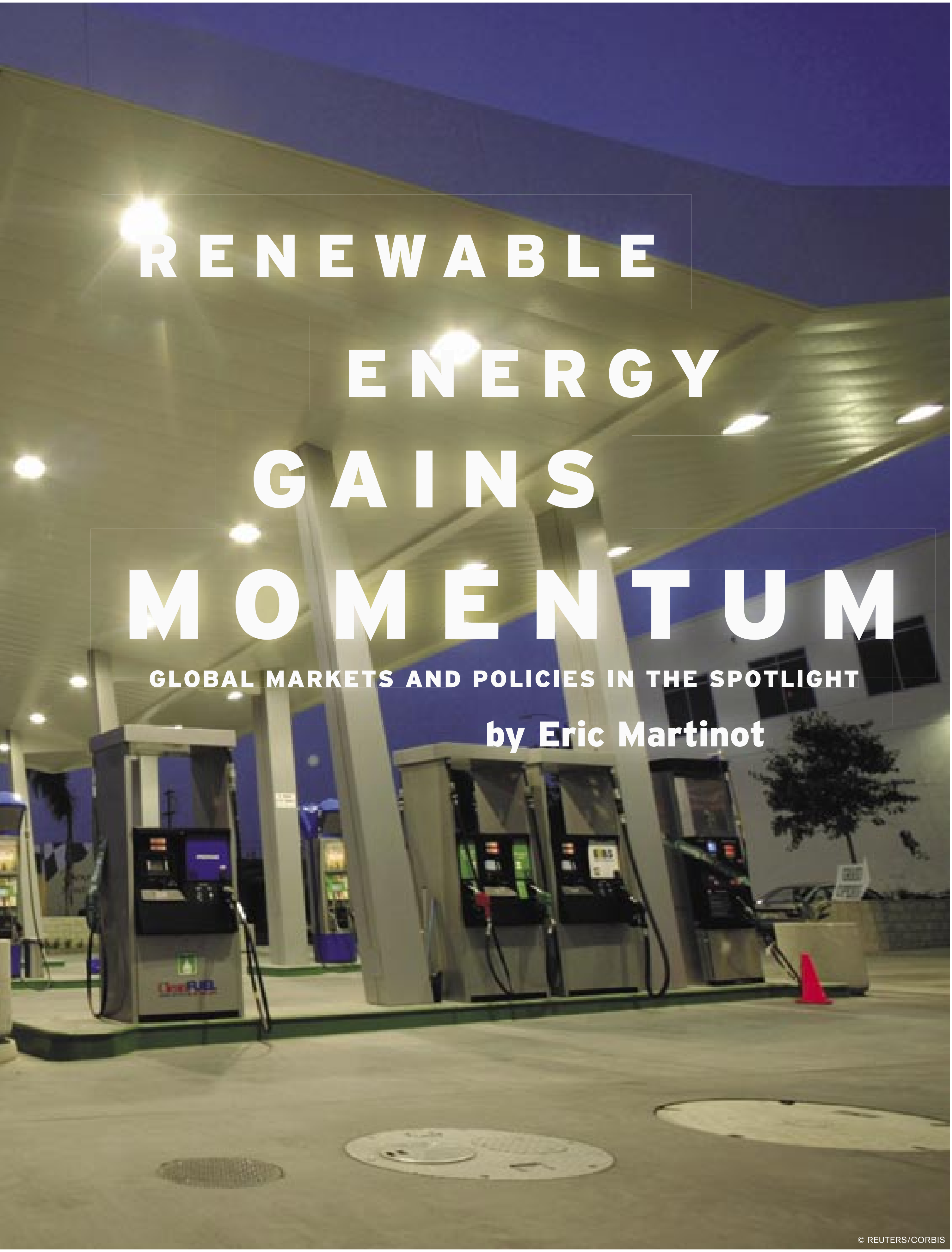
RENEWABLE ENERGY GAINS MOMENTUM

GLOBAL MARKETS AND POLICIES IN THE SPOTLIGHT

by Eric Martinot



AS RENEWABLE energy markets accelerate and policies multiply around the world, so do the environmental benefits. Use of renewable energy avoided the release of an estimated 0.9 billion tons of carbon dioxide (CO_2) emissions in 2004 and displaced about 3 percent of global power generation that would otherwise come from fossil fuels.[1] However, environmental impact is only part of the picture. The $39 billion invested in renewable energy capacity worldwide in 2005, up from $14 billion in 2000, underscores that renewable energy has become big business. This investment is a significant percentage of the roughly $150 billion invested in all forms of power generation globally each year. More and more, renewable energy means investment and profit. A group of the 80 leading renewable energy companies was valued at more than $55 billion in market capitalization in 2006. The solar photovoltaic (PV) industry alone made an estimated $6 billion investment in new plant and equipment in 2005 as it expanded production by 50 percent. Although pronouncements like "renewable energy enters the mainstream" and "renewable energy comes of age" rarely capture headlines, when well-known firms make large investments in renewable energy—Goldman-Sachs, General Electric (GE), BP, and Siemens to name a few—the world takes notice.[2]

Common perceptions of renewable energy among policymakers, business leaders, and the public still lag far behind the reality implied by these investment and market trends. Few people realize that there are more than 650,000 solar PV rooftops worldwide, that 45 million households use solar hot water heaters, that 4.5 million households voluntarily purchase "green power," or that 30 percent of all gasoline sold in the United States has ethanol blended with it. More than 50 countries around the world now have policies supporting renewable energy at national and state/provincial levels. Most would be surprised to learn that the installed capacity of renewable energy (182 gigawatts (GW) in 2005, excluding large hydropower) is now almost half that of nuclear power (370 GW) and growing much faster (see the box on page 29 for descriptions of the various technologies).[3]

Most of these trends reflect strong growth during the past five years, and follow earlier developments in the United States starting in the 1980s and in Europe starting in the early 1990s. Those earlier eras marked the beginning of strong policy support for renewables, which has contributed greatly to the cost reduction, policy experience, and industry maturity that underlie today's markets. Renewable energy has become the fastest growing energy technology in the world. The overall market leaders today are Europe, China, and the United States. Other leading markets are in Brazil, India, Japan, and Thailand.[4]

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Wind farms like this one in Nagercoil, India, are regular features of the landscape. India expects to add 10 gigawatts of renewable electric power capacity by 2012.

From Fossil Fuels to Renewable Energy

The world's energy supply has historically been dominated by fossil fuels. Today, 77 percent of global primary energy comes from fossil fuels, with the remainder from traditional biomass (9 percent), large hydropower (6 percent), nuclear (6 percent), and renewable energy (2 percent).[5] Unfortunately, fossil fuel energy consumption has serious side-effects: Environmental insults arising from the use of coal and petroleum in particular result in a growing number of human illnesses and ecosystem disruptions and represent a growing threat to society from climate change. For example, sulfur emissions to the atmosphere from human activities are on the order of 80 million tons per year, 85 percent from burning fossil fuels. This compares to a natural baseline flow of about 30 million tons per year to the atmosphere. The results include acid rain, water and soil acidification, forest die-off, increases in human respiratory diseases and health costs, and loss of agricultural productivity. Lead emissions to the atmosphere from human activities are on the order of 0.2 million tons per year, 40 percent of that from fossil fuels and 18 times the natural baseline flow. About 2 million tons per year of oil are released into the oceans, 10 times the baseline of natural oil flow. The atmospheric concentration of CO_2, a primary greenhouse gas, has increased from 280 parts-per-million (ppm) in pre-industrial times to 380 ppm today. About 75 percent of human-caused emissions of CO_2 come from burning fossil-fuels.[6]

The environmental benefits of renewable energy are quite clear when renewable energy displaces conventional fossil-fuel power generation. These benefits can be quantified in reductions of direct emissions into the atmosphere of CO_2, sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulates, and heavy metals. Another way to quantify these benefits is by measuring the real economic costs of these environmental insults, called "external costs" by economists if not borne by energy producers or users. These external costs have been estimated by a recent European Commission study at between 2 and 12 cents per kilowatt-hour (kWh) for coal power plants. Thus, external costs can be double or triple the direct costs of base-load coal power (typically 3–4 cents per kWh). The external costs of renewable energy were put at 0.1–2.5 cents per kWh by the same study. From this perspective, the costs of environmental damage from fossil fuels can far outweigh the cost differences between renewables and fossil fuels.[7]

Still, without external costs added, many say "renewables are too expensive." Costs of the most common renewable energy applications are shown in Table 1 on page 30.[8] In fact, some renewables are becoming competitive with coal and natural gas-fired power plants even without accounting for external costs. The high prices for oil and natural gas seen in recent years (both at levels two or three times higher than prices seen in the late 1990s) mean that the cost equation is changing. The cost of coal and natural gas power generation is largely a function of fuel prices, rather than power plant costs. Conversely, the cost of renewable energy is largely a function of initial investment cost. When comparing future costs, uncertainty must be included. The cost uncertainties of fossil-based power depend mostly on future fossil-fuel price volatility, while the cost uncertainties of renewable energy depend partly on technology cost reductions and partly on the future cost of capital (interest rates). The difference, however, is that once a renewable energy facility is built, at least with

RENEWABLE ENERGY TECHNOLOGIES

Renewable energy technologies in commercial or near-commercial applications can be divided into four basic categories, according to application:

• **Power Generation.** Large hydropower involves water flowing through a turbine-generator, typically from a reservoir behind a large dam. Small hydropower is similar, but the dam and reservoir are much smaller or, with a "run-of-river" dam, there is no reservoir. (The threshold between small and large hydropower is usually defined as 10 megawatts (MW) in most countries, but in China it is 50 MW.) Biomass power involves combustion of solid biomass, including forest product wastes, agricultural residues and waste, energy crops, and the organic component of municipal solid waste and industrial waste. Biomass co-firing involves mixing biomass fuel with coal in the same power plant. Biomass power may also be generated by combusting biogas in an engine; the biogas is produced separately via aerobic digestion of agricultural and animal wastes. Biomass gasification involves converting biomass directly into gas via industrial process and then fueling a gas turbine generator. Wind power is produced by wind turbine blades that use the force of wind to turn an electric generator; the two types are on-shore and off-shore. A solar photovoltaic (PV) cell converts sunlight directly into electricity; cells are the basic building block, which are then manufactured into modules and panels. A grid-connected rooftop solar PV installation can power a home and also feed power back into the electric grid. Geothermal power is produced from heat energy emitted from within the Earth, usually in the form of hot water or steam. Concentrating solar power, also called solar thermal power, transfers the sun's heat into some type of circulating fluid to create steam and generate power. Ocean thermal energy conversion, tidal power, and wave power all exploit different forms of ocean energy.

• **Hot Water, Heating, and Cooling.** Solar hot water is provided by a rooftop solar collector that heats water and stores it in a tank for use as domestic hot water. Solar space heating is often part of a "combisystem" that circulates solar heated water for interior space heating. Active solar cooling, also called solar-assisted air conditioning, uses the heat to drive an absorption cooling cycle. Biomass heat and geothermal heat similarly provide hot water and/or space heating from the heat provided from biomass combustion or geothermal sources, often in tandem with power generation as cogeneration. Passive solar heating and cooling is a commercially proven and widespread building design practice that optimizes orientation, materials, and shading for heat gain or loss.

• **Vehicle Fuels.** Biodiesel is a vehicle fuel for diesel-powered cars, trucks, buses, and other vehicles, produced from oilseed crops such as soy, rapeseed (canola), and mustard or from other vegetable oil sources such as waste cooking oil. Ethanol is a vehicle fuel made from biomass (typically corn, sugar cane, or wheat) that can replace ordinary gasoline in modest percentages or be used in pure form in specially modified vehicles. Gasohol is a popular name for a blend of gasoline and ethanol, typically 10-25 percent ethanol (called E10, E25, etc.). Cellulose-derived ethanol is produced from wood or agricultural waste products (still in research phase).

• **Rural (Off-Grid) Energy.** There are many different applications; Table 3 on page 39 offers some examples. Among the most common, a biogas digester converts animal and plant wastes into gas usable for lighting, cooking, and heating. Small/mini/micro/pico hydropower can provide small amount of off-grid electricity to homes and villages. A solar home system consists of a rooftop solar panel, battery, and charge controller that can provide modest amounts of power to rural homes, typically an evening's lighting (using efficient lights) and television viewing from one day's battery charging. Traditional biomass means unprocessed biomass, including agricultural waste, forest products waste, collected fuel wood, and animal dung, that is burned in stoves or furnaces to provide heat energy for cooking, heating, and agricultural and industrial processing.

fixed-rate financing, the cost of power from that facility is fixed throughout its lifetime. Not so for fossil fuels, where the cost of power will vary in the future with fuel prices (unless fuel price hedging is used, in which case hedging costs should be added to power costs).[9]

The International Energy Agency has portrayed the cost-competitiveness of renewables in this way:

> *Except for large hydropower and combustible renewables and waste plants, the average costs of renewable electricity are not widely competitive with wholesale electricity prices. However, depending on the technology, application and site, costs are competitive with grid [retail] electricity or commercial heat production. Under best conditions—optimized system design, site and resource availability—electricity from biomass, small hydropower, wind and geothermal plants can produce electricity at costs ranging from 2–5 cents/kWh. Some biomass applications are competitive as well as geothermal heat production in specific sites.*[10]

In regions where the technology is well established, solar water heating is fully competitive with conventional water heaters, although less so in cooler climates where the solar resource is poorer and heating demand is higher.

Two key points emerge from the above discussion: If renewables are not yet competitive, they are getting close; and cost comparisons can never be analytically precise, because they depend on assumptions about future fuel prices, interest rates, technology costs, treatment of external costs, and other conditions and thus leave room for analytical arbitrariness and bias. Aside from direct cost differences, many other market barriers have meant that most renewables continue to require policy support.[11]

Markets Accelerate

Renewable energy is now growing extremely quickly, in part due to strong policy support. The fastest growing energy

Table 1. Renewable energy costs and trends

Technology	Typical cost of energy in cents per kilowatt-hour (kWh)	Cost trends
Power Generation		
Large hydro	3–4	Stable
Small hydro	4–7	Stable
On-shore wind	4–6	Declining by 12–18 percent with each doubling of gloabal installed capacity
Off-shore wind	6–10	Market still small
Biomass power	5–12	Stable
Geothermal power	4–7	Declining modestly since the 1970s
Solar PV (module)	–	Declining by 20 percent for each doubling of global installed capacity
Rooftop solar PV	20–40	Declining due to lower solar PV module and balance-of-system costs
Solar thermal power	12–18	Declining from 45 cents per kWh for the first plants in the 1980s
Hot water/heating		
Biomass heat	1–6	Stable
Solar hot water/ heating	2–25	Stable or moderately declining due to scale, materials, quality
Geothermal heat	0.5–5	See geothermal power, above
Biofuels[a]		
Ethanol	25–50 cents per liter	Declining in Brazil (sugar) but stable in the United States (corn)
Biodiesel	40–80 cents per liter	Declining to 35–70 cents per liter post-2010 from rapeseed and soy, stable from waste oil at 25 cents/liter
Rural (off-grid) energy		
Mini-hydro	5–10	Costs generally stable to moderately declining with improvements in technology, scale, and delivery infrastructure
Micro-hydro	7–20	
Pico-hydro	20–40	
Biogas digester	n/a	
Biomass gasifier	8–12	
Small wind turbine	15–30	
Household wind turbine	20–40	
Village-scale mini-grid	25–100	
Solar home system	40–60	

[a] Costs for ethanol and biodiesel are in cents per liter diesel- or gasoline-equivalent, corrected for the lower energy content per liter compared to conventional fuel (about 68 percent for ethanol and 87–95 percent for biodiesel).

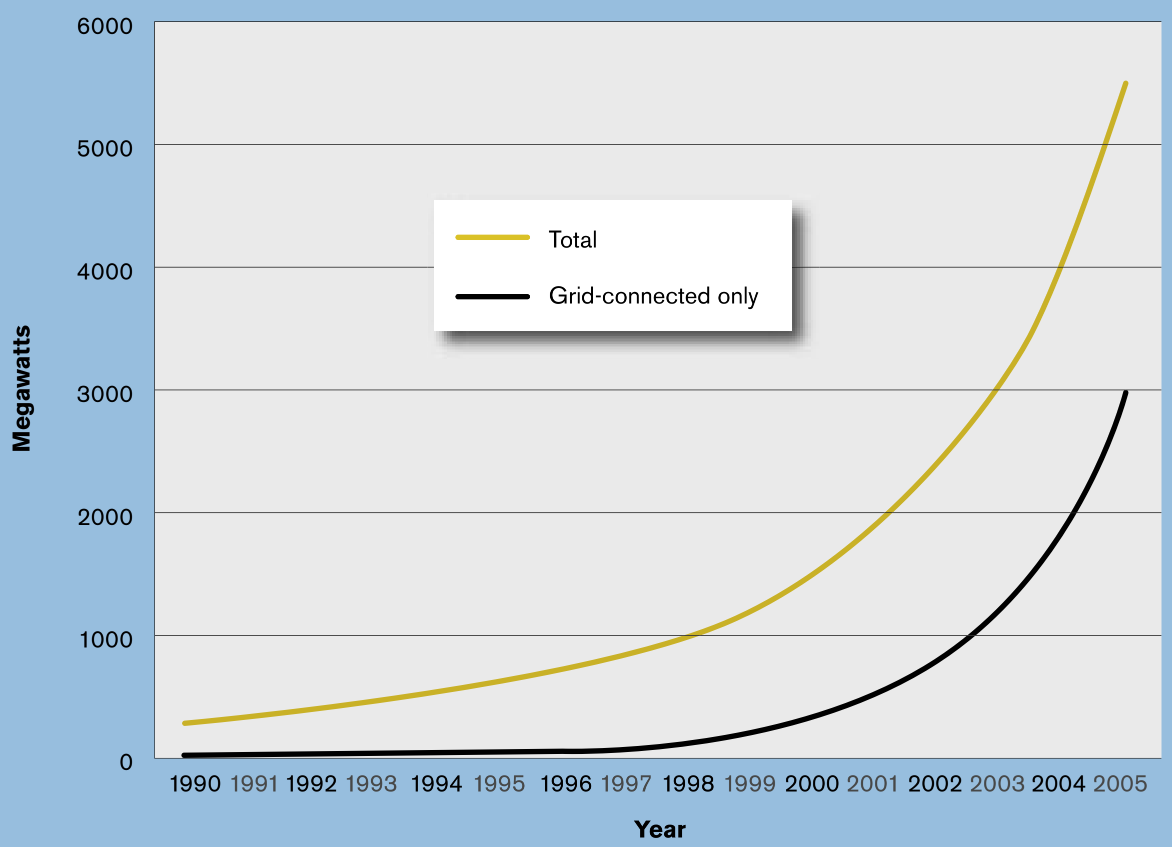
SOURCE: REN21, *Renewables 2005 Global Status Report* (Washington, DC: Worldwatch Institute, 2005).

technology in the world is grid-connected solar photovoltaic (PV), which grew by 60 percent per year from 2000 to 2004 (see Figure 1 below). During the same five-year period, other renewable energy technologies grew rapidly as well: wind power, 28 percent; biodiesel, 25 percent; solar hot water/heating, 17 percent; off-grid solar PV, 17 percent; geothermal heat capacity, 13 percent; and ethanol, 11 percent (all annual averages). Other renewable energy power generation technologies, including biomass, geothermal, and small hydro, are more mature and are growing by more traditional rates of 2–4 percent per year. Biomass heat supply is likely growing by similar amounts, although data are not available. These growth rates compare with annual growth rates of fossil fuel-based electric power capacity of typically 3–4 percent (higher in some developing countries), a 2 percent annual rate for large hydropower, and a 1.6 percent annual rate for nuclear capacity during the three-year period 2000–2002.

Renewable energy competes with conventional fuels in four distinct markets: power generation, hot water and space heating, transport fuels, and rural (off-grid) energy. In power generation, renewable power capacity reached 182 GW worldwide in 2005, more than 4 percent of the global power-generating capacity of 3,900 GW. This capacity is primarily from small hydro (66 GW), wind (59 GW), and biomass power (44 GW), with smaller amounts of solar PV (3 GW) and geothermal (9 GW). Solar thermal power (0.4 GW) and ocean power (0.3 GW) remain at low levels. Developing countries have almost half of the renewable power capacity at 80 GW (see Figure 2 on page 33). Hot water and space heating for tens of millions of buildings is supplied by solar, biomass, and geothermal. Solar thermal collectors alone are now used by an estimated 45 million households worldwide. Production of biofuels exceeded 37 billion liters in 2005, about 3 percent of the 1,200 billion liters of gasoline consumed globally. Ethanol provided 41 percent of all (non-diesel) motor vehicle fuel consumed in Brazil in 2005. The most active markets are as follows:

- *Solar PV, grid-connected*. Grid-connected solar PV installations are concentrated in Japan, Germany, and the Unit-

Figure 1. Solar PV, existing world capacity, 1990–2005 (MW)



SOURCE: REN21, *Renewables 2005 Global Status Report* (Washington, DC: Worldwatch Institute, 2005); and 2006 Update (forthcoming).

ed States. By 2005, more than 650,000 homes in these countries had rooftop solar PV feeding power into the grid. This market grew by about 1.1 GW in 2005, from 1.8 GW to 2.9 GW cumulative installed capacity.

• *Wind power*. Wind power markets are concentrated in a few primary countries, with Spain, Germany, India, and the United States leading expansion in 2005. Other countries with active efforts include Australia, Canada, India, Nepal, and New Zealand.

• *Solar thermal power*. The concentrating solar thermal power market has remained stagnant since the early 1990s. Recently, commercial plans in Israel, Spain, and the United States have led to a resurgence of interest, technology evolution, and potential investment. New projcane waste (bagasse) is significant in sugar-producing regions, including Brazil, Colombia, Cuba, India, the Philippines, and Thailand.

• *Geothermal power and heat*. There are at least 76 countries with geothermal heating capacity and 24 countries with geothermal electricity. More than 1 GW of geothermal power was added between 2000 and 2005, including increases in

Jars of biodiesel, in varying stages of its production. 3.9 billion liters of biodiesel were produced globally in 2005.

2005 (see Figure 3 on page 34). India now has half of the wind power capacity of the United States and accounted for 15 percent of global installations in 2005. Several countries are now taking their first steps to develop large-scale commercial markets, including Russia and other transition countries, China, South Africa, Brazil, and Mexico.

• *Small hydropower*. More than half of the world's small hydropower capacity exists in China, where an ongoing boom in small hydro construction added 4 GW of capacity per year in 2004 and

ects were under construction in 2006 in Spain and the United States. Some developing countries, including India, Egypt, Mexico, and Morocco, have planned projects with multilateral assistance.

• *Biomass electricity and heat*. Biomass electricity and heat production is slowly expanding in Europe, mainly driven by developments in Austria, Finland, Germany, and the United Kingdom. Among developing countries, small-scale power and heat production from agricultural waste is common from rice or coconut husks, for example. Use of sugar

France, Guatemala, Iceland, Indonesia, Italy, Kenya, Mexico, New Zealand, the Philippines, and Russia. Geothermal heat capacity doubled from 2000 to 2005, with at least 13 countries using geothermal heat for the first time. Half of the heat capacity exists as heat pumps for building heating and cooling, with 2 million pumps in more than 30 countries.

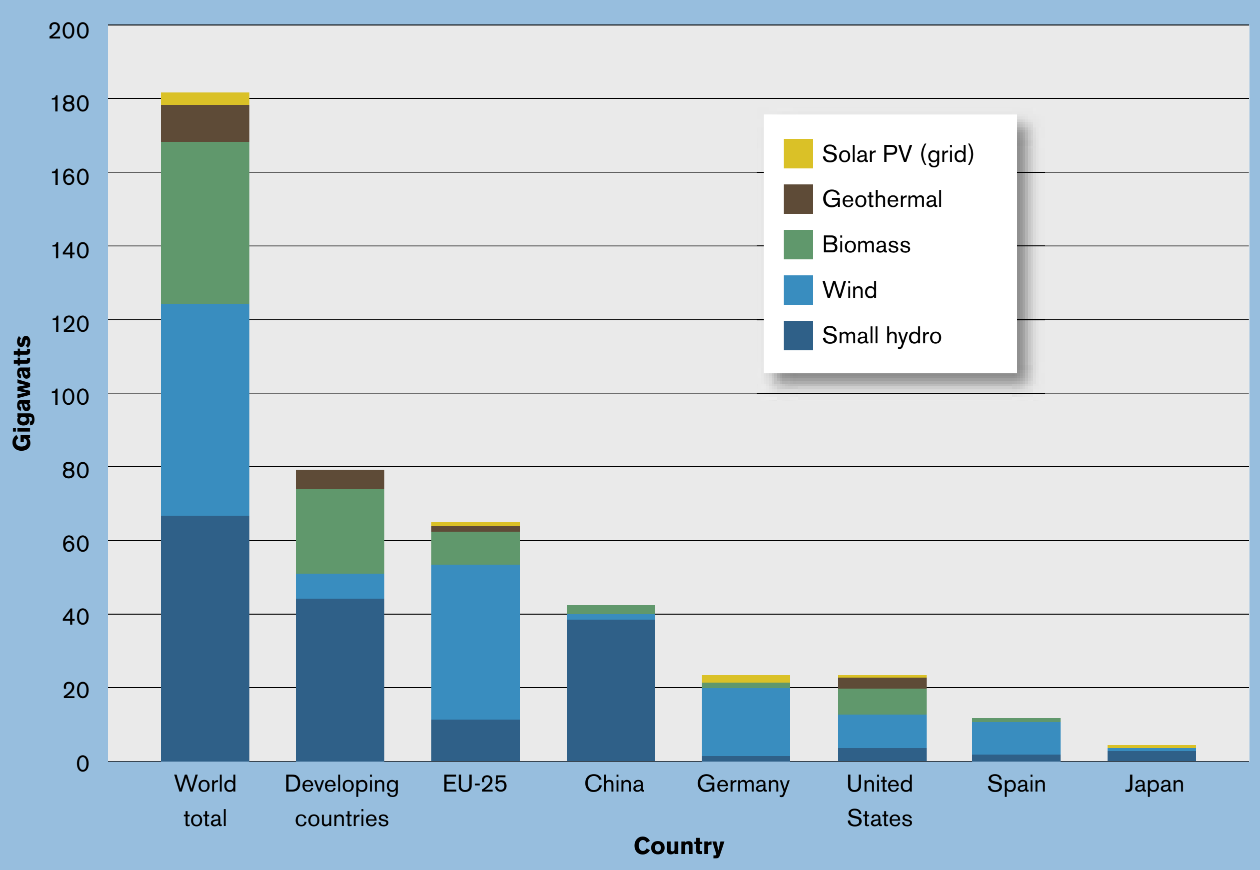
• *Solar hot water/heating*. Solar hot water/heating technologies contribute significantly to the hot water/heating markets in China, Europe, Israel, Turkey, and Japan. Dozens of other countries have smaller markets. Total installed capacity worldwide was 88 gigawatts-thermal (GWth) in 2005. China accounts for 60 percent of this total, followed by Europe (13 percent), Turkey (7 percent), and Japan (6 percent). Total sales volume in 2005 in China was 15 million square meters (10.5 GWth), a 23-percent increase in existing domestic capacity.

- *Ethanol*. Brazil has been the world's leader (and primary user) of fuel ethanol for more than 25 years, producing about 15 billion liters in 2005, slightly less than half the world's total. All fueling stations in Brazil sell pure ethanol (E95) as well as gasohol, a 25 percent ethanol/75 percent gasoline blend (E25). There were more than 340 sugar mills and distilleries producing ethanol in Brazil by 2005. The United States is the second largest producer of fuel ethanol—15 billion liters in 2005—with more than 95 ethanol plants operating. Other countries producing fuel ethanol include Australia, Canada, China, Colombia, the Dominican Republic, France, Germany, India, Jamaica, Malawi, Poland, South Africa, Spain, Sweden, Thailand, and Zambia.
- *Biodiesel*. Biodiesel production almost doubled in Germany in 2005 to about 2 billion liters, bringing total world production to 3.9 billion liters. Other primary biodiesel producers are France and Italy, with several other countries producing smaller amounts, including Austria, Belgium, the Czech Republic, Denmark, Indonesia, Malaysia, and the United States.

Renewable Energy Policies Multiply

Supporting these market changes, policies to promote renewable energy have multiplied around the world in recent years, often driven by environmental concerns. In a growing number of cases, these policies are also being driven by desires for energy security and fuel import substitution, industrial economic development, and rural development. Policies may be justified on many grounds, including market barriers and externalities. Policies may also be justified on the basis of "learning curves"—the idea that as cumulative production increases, costs decline and technologies become directly competitive so that public support is only

Figure 2. Renewable power capacities (in gigawatts) for developing countries, EU, and top five individual countries (excluding large hydropower), 2005



SOURCE: REN21, *Renewables 2005 Global Status Report* (Washington, DC: Worldwatch Institute, 2005); and 2006 Update (forthcoming).

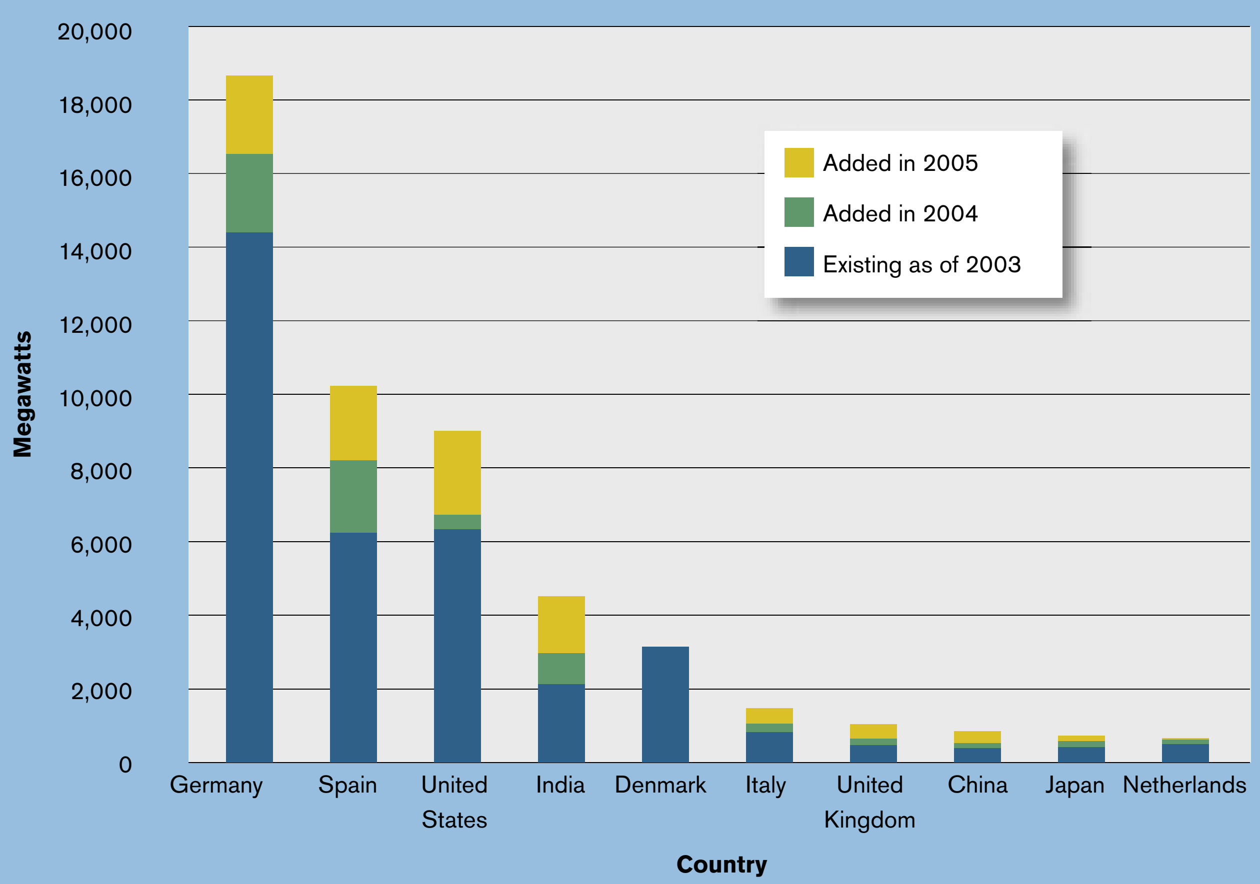
needed temporarily.[12] Around the world, countries, regions, states, provinces, and cities have enacted targets (goals) for future renewable energy development, power generation promotion policies, solar hot water/heating policies, biofuels policies, and policies to support green power sales.

Policy Targets for Renewable Energy

Policy targets for renewable energy exist in at least 48 countries. By 2005, at least 46 countries had a national target for renewable energy supply, including all 25 EU countries (see Figure 4 on page 36 and Table 2 on page 37). The EU has Europe-wide targets as well: 21 percent of electricity and 12 percent of total energy by 2010. In addition to these 46 countries, 20 U.S. states and 3 Canadian provinces have targets based on renewables portfolio standards (although neither the United States nor Canada has a national target). An additional 7 Canadian provinces have planning targets. Most national targets are for shares of electricity production, typically 5–30 percent, although even higher for some countries. Targets for shares of total primary energy supply include heat and transport fuels in addition to electricity. Some targets are for specific installed capacity figures or total amounts of energy production. Most targets aim for the 2010–2012 time frame.

The 46 countries with national targets include 13 developing countries. A few other developing countries are likely to announce targets in the near future. China's target of 10 percent of total power capacity by 2010 (excluding large hydropower) implies 80 GW of renewables capacity given projected growth. China also has targets for 2020: 15 percent of primary energy (including large hydro), 20 GW of biomass power, and 30 GW of wind power. Thailand is targeting 8 percent of primary energy by 2011. India is expecting 10 percent of added electric power capacity, or at least 10 GW of renewables, by 2012. The Philippines are targeting 5 GW total by 2013, a doubling of existing capacity.

Figure 3. Wind power capacity, top 10 countries, 2005



SOURCE: REN21, *Renewables 2005 Global Status Report* (Washington, DC: Worldwatch Institute, 2005); and 2006 Update (forthcoming).

Power Generation Promotion Policies

At least 48 countries—34 developed and transition countries and 14 developing countries—have some type of policy to promote renewable power generation. The most common policy is the feed-in law, which has been enacted in many new countries and regions in recent years. A feed-in law sets a fixed price at which producers can sell renewable power into the electric power network. Some policies provide a fixed tariff while others provide fixed premiums added to market- or cost-related tariffs. Some provide both. The fixed price is usually, although not always, higher than would be paid for conventional power, and this "cost gap" for renewables must be addressed through some type of cost-sharing mechanism. Often this simply means that all utility customers pay a very small surcharge or fractional rate increase to cover the "cost gap."

In 1978, the United States became the first country to enact a national feed-in law; Denmark, Germany, Greece, India, Italy, Spain, and Switzerland followed with their own feed-in policies in the early 1990s. By 2005, at least 32 countries and 6 states/provinces had adopted such policies, half of which have been enacted since 2003. Among developing countries, India was the first to establish feed-in tariffs, followed by Sri Lanka and Thailand (for small power producers only), Brazil, Indonesia, and Nicaragua. Three states in India adopted new feed-in policies in 2004, driven by a national law requiring new state-level policies. During 2005 and 2006, new feed-in policies were enacted in China, Ireland, Turkey, the Canadian province of Ontario, and the U.S. state of Washington. Many countries continue to adjust their policies as technology costs and markets change.

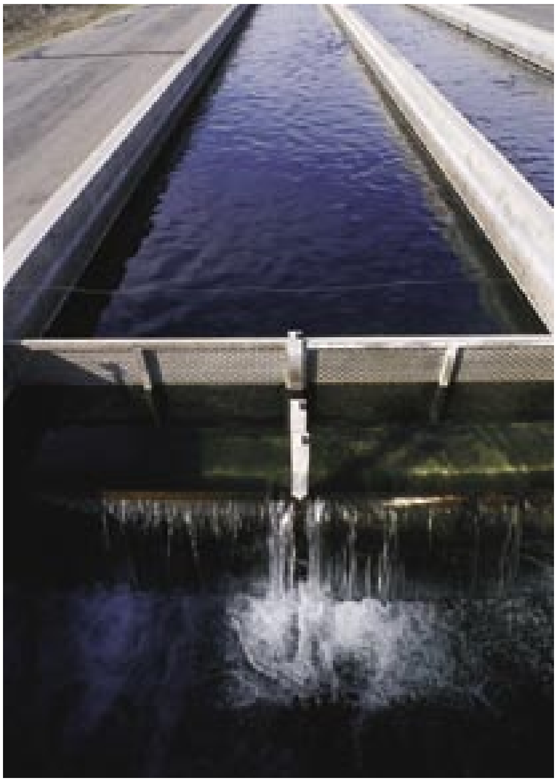
Renewables portfolio standard (RPS) policies are expanding at the state/provincial level in the United States, Canada, and India. At least 35 states or provinces in these countries have enacted RPS policies, more than half of these since 2003. A renewables portfolio standard requires that a minimum percentage of generation sold or capacity installed be provided by renewable energy. Obligated utilities are required to ensure that the target is met, either through their own generation, power purchases from other producers, or direct sales from third parties to the utility's customers. In India, five more states enacted RPS policies in 2004–2005. Most RPS policies require renewable power shares in the range of 5–20 percent, typically by 2010 or 2012. There are also six countries with national RPS policies, all enacted since 2001: Australia, United Kingdom, Japan, Sweden, Poland, and Thailand.

Energy production payments or tax credits exist in several countries, with the U.S. federal production tax credit most significant in this category. That credit is paid to producers for each kWh of generation and has applied to more than 5.4 GW of wind power installed from 1995 to 2004. That credit started at 1.5 cents per kWh in 1994 and increased over time, through expirations and renewals, to 1.9 cents per kWh by 2005, with expiration extended to 2007. Other countries with production incentives include Finland, the Netherlands, and Sweden.

Net metering policies allow a two-way flow of electricity between the electricity distribution grid and customers with their own generation. When consumption at any given moment exceeds self-generation, the meter runs forward. When self-generation exceeds consumption, the meter runs backward. The customer pays only for the net electricity used. Net metering laws exist in at least 7 countries, 35 U.S. states, and several Canadian provinces (although some schemes employ two separate meters and might be called "net billing" instead). Net metering laws are being enacted regularly, with 6 new U.S. states passing such laws in 2004. Most recently, a 2005 U.S. law requires all U.S. electric utilities to provide net metering within three years.

Policies to promote rooftop grid-connected solar PV exist in a few countries, using either capital subsidies or feed-in tariffs. These policies clearly have been responsible for the rapid growth of the grid-connected market in recent years. Japan's rooftop solar PV policies, which ended in 2005 after subsidizing more than 200,000 installations, provided capital subsidies that started at 50 percent in 1994 but declined to around 10 percent by 2003. Germany, with more than 300,000 rooftop solar homes and 1,500 megawatts (MW) installed, provides a guaranteed feed-in tariff and, until 2003, also provided low-interest consumer loans. Continuing policies in California, other U.S. states, and several other countries provide capital subsidies (typically 30–50 percent) or favorable power purchase tariffs.

There are many other forms of policy support for renewable power genera-



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Hydropower provides energy for household electricity needs and small industrial technologies. Its costs have remained stable in recent years.

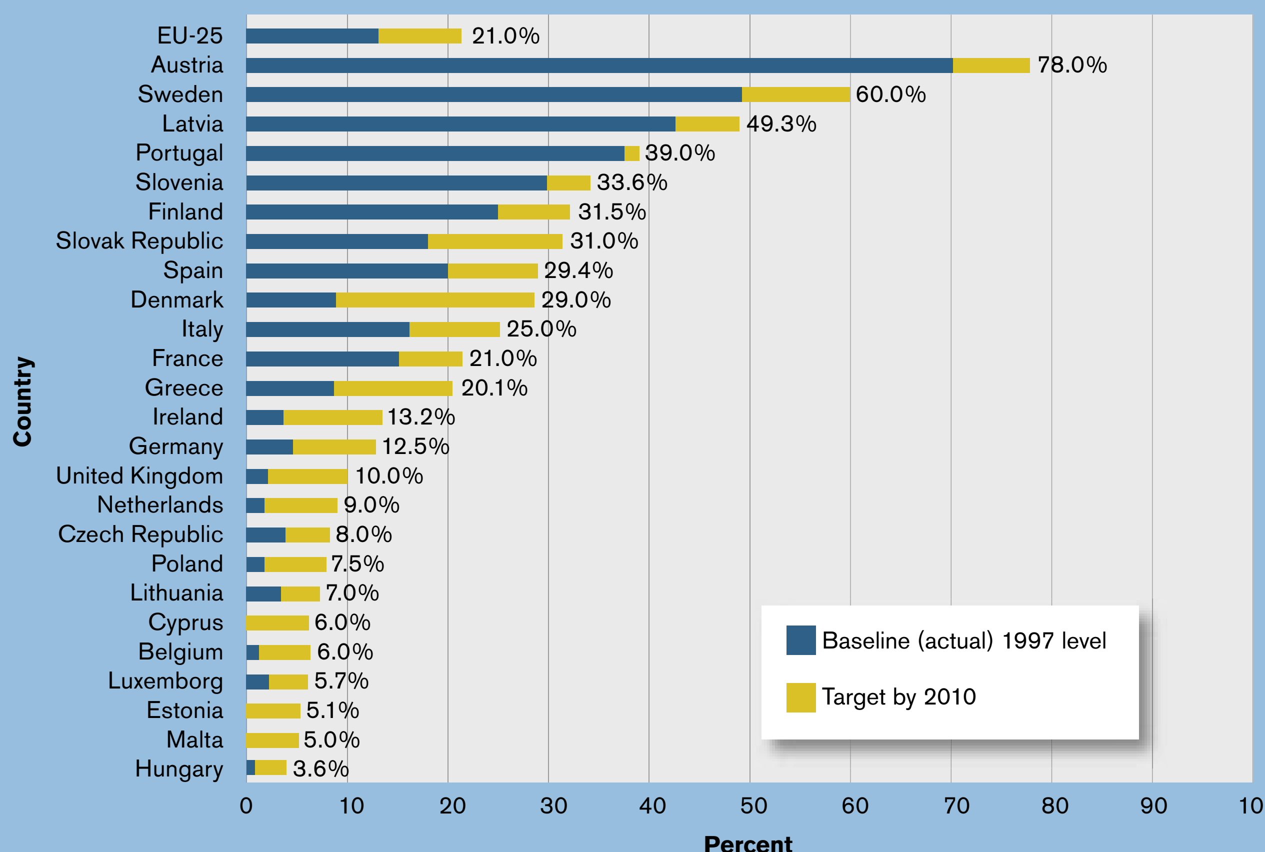
tion, including direct capital investment subsidies or rebates, tax incentives and credits, sales tax and value added tax (VAT) exemptions, green certificate trading, direct public investment or financing, and policies for competitive bidding of specified quantities of renewable generation capacity.

Solar Hot Water/Heating Promotion Policies

The world's largest market for solar hot water is China, with 80 percent of the global additions in 2005. China's national goal of 65 million square meters of solar hot water collectors by 2005 was met; the country is now reaching toward a new goal of 300 million square meters by 2020. With its origins in small towns and villages in the 1980s, the market has mainly been driven by unmet demand for hot water, economics, and systems that sell for a small fraction of prices found in developed countries. Although there are no explicit policies for promoting solar hot water in multi-story urban buildings, building design and construction has begun to incorporate solar hot water as energy costs rise and public demand increases, particularly during the current construction boom. There are also government programs for technology standards, building codes, and testing and certification centers to help the industry mature.

Beyond China, at least 20 countries and probably several more provide capital grants, rebates, or investment tax credits for solar hot water/heating investments. These include Australia, Austria, Belgium, some Canadian provinces, Cyprus, Finland, France, Germany, Greece, Hungary, Japan, the Netherlands, New Zealand, Portugal, Spain, Sweden, the United Kingdom, many U.S. states, and the U.S. federal government. Capital grants are typically 20–40 percent of system cost.

Figure 4. EU renewable energy targets for share of electricity by 2010



NOTE: There are also targets in some countries for shares of total energy by 2010: EU-25, 12 percent; Lithuania, 12 percent; Poland, 7.5 percent; Latvia, 6 percent; Czech Republic, 5–6 percent; and Germany, 4 percent.

SOURCE: REN21, *Renewables 2005 Global Status Report* (Washington, DC: Worldwatch Institute, 2005); and 2006 Update (forthcoming).

For many years, Israel was the only country with a national-level policy mandating solar hot water in new construction. Since 1980, most buildings in Israel have been required to have solar hot water collectors, with varying requirements by size and type of building. In 2006, Spain passed national legislation mandating solar hot water for most new buildings and renovations. This national legislation followed the local passage of municipal laws first in Barcelona and then in dozens of other Spanish cities over the past few years. According to the new national law, buildings must supply 30–70 percent of hot water energy demand from solar, depending on building characteristics and location.

Biofuels Promotion Policies

Brazil has been the world leader in promoting biofuels for 25 years under its "ProAlcool" program. Policies have included blending mandates, retail distribution requirements, production subsidies, and other measures. Since 1975, Brazil has mandated that ethanol be blended with all gasoline sold. Although the required blend level is adjusted frequently, it has been in the range of 20–25 percent. All gas stations are required to sell gasohol (E25) and pure ethanol (E100). Tax preferences have been given to vehicles that run on pure ethanol. The recent introduction and soaring sales of so-called "flex-fuel" vehicles by several automakers was assisted by a preferential vehicle licensing tax.[13] Brazil has more recently begun to target increased use of biodiesel fuels, primarily derived from soybean oil. A recent law in Brazil allowed blending of 2 percent biodiesel in diesel fuels starting in 2005.

In addition to Brazil, mandates for blending biofuels into vehicle fuels have appeared in several other countries in recent years. In particular, at least 24 states/provinces and 8 countries now have mandates for blending ethanol and/or biodiesel with all vehicle fuels sold. In India, the government mandated 10 percent ethanol blending (E10) in 9 out of 28 states and 4 out of 7 federal territories (all sugar cane–producing areas), starting in 2003. In China, nine provinces currently mandate E10 blending, although only in cities in four of those provinces. The United States passed a national renewable fuel standard in 2005 that requires 28 billion liters by 2012. Three U.S. states also mandate E10 blending: Hawaii, Minnesota (increasing to 20 percent by 2013), and Montana. Minnesota also mandates 2-percent blending of biodiesel (B2). In Canada, the province of Ontario mandates E5 (average) blending by 2007, and Saskatchewan mandates E7 blending. Ger-

Table 2. Non-EU countries with renewable energy targets

Country	Target(s)
Australia	9.5 terawatt-hours (TWh) of electricity annually by 2010
Brazil	3.3 gigawatts (GW) added by 2006 from wind, biomass, small hydro
Canada	3.5 percent to 15 percent of electricity in 4 provinces; other types of targets in 6 provinces
Dominican Republic	10 percent of electric power capacity by 2010 (expected 60 GW); 5 percent of primary energy by 2010 and 10 percent of primary energy by 2020
Egypt	3 percent of electricity by 2010 and 14 percent by 2020
India	10 percent of added electric power capacity during 2003–2012 (expected 10 GW)
Israel	2 percent of electricity by 2007; 5 percent of electricity by 2016
Japan	1.35 percent of electricity by 2010, excluding geothermal and large hydro (renewables portfolio standard)
Korea	7 percent of electricity by 2010, including large hydro, and 1.3 GW of grid-connected solar photovoltaic systems (PV) by 2011, including 100,000 homes (0.3 GW)
Malaysia	5 percent of electricity by 2005
Mali	15 percent of energy by 2020
New Zealand	30 petajoules of added capacity (including heat and transport fuels) by 2012
Norway	7 TWh from heat and wind by 2010
Philippines	4.7 GW total existing capacity by 2013
Singapore	50,000 square meters (~35 megawatts-thermal) of solar thermal systems by 2012
South Africa	10 TWh added final energy by 2013
Switzerland	3.5 TWh from electricity and heat by 2010
Thailand	8 percent of total primary energy by 2011 (excluding traditional rural biomass)
United States	5 percent to 30 percent of electricity in 19 states and Washington, DC

SOURCE: REN21, *Renewables 2005 Global Status Report* (Washington, DC: Worldwatch Institute, 2005).

many will mandate B4.4 and E2 blends by 2007. France will require a 7 percent biofuels blend by 2010. National blending mandates have also appeared in Colombia (E10), the Dominican Republic (E15 and B2 by 2015), Malaysia (B5 by 2008), and the Philippines (B1 by 2006). Thailand has a target for biofuels as a share of total energy by 2011, for which it is considering E10 and B2 blending mandates. Japan is considering an E5 blending mandate.

Green Power Purchasing and Utility Green Pricing

There were more than 4.5 million green power consumers in Europe, the United States, Canada, Australia, and Japan in 2004. Green power purchasing—voluntary purchases of green power by a customer, either from a utility, from a third-party producer, or by purchasing "renewable energy certificates"—is growing, aided by a combination of supporting policies, private initiative, utility programs, and government purchases. With utility sales or third-party sales, a customer's actual electricity consumption is matched by an equivalent amount of renewable power fed into the power grid by the seller. Renewable energy certificates allow the renewable energy production to be located anywhere. More and more utilities offer "green pricing," in which they offer customers a variety of power "products," usually at various prices and degrees of renewable energy content.

In Europe, green power purchasing and utility green pricing have existed in some countries since the late 1990s. By 2004, there were almost 3 million green power consumers in the Netherlands, supported by a tax exemption on green electricity purchases. Other countries in Europe with retail green power markets include Finland, Germany, Switzerland, and the United Kingdom. Germany's green power market has grown steadily since 1998, with more than 600,000 consumers in 2004. In addition, 18 European countries are members of RECS, a renewable energy certificates system founded in the late 1990s to standardize and certify renewable energy certificates and trading.

The United States has an estimated half-million green power consumers. Green power purchasing began in earnest around 1999. By 2004, at least 2 GW of additional renewable energy capacity was built in the United States to accommodate this market. The federal government is the largest single buyer of green power. By 2004, more than 600 utilities in 34 states had begun to offer green-pricing programs. Most of these offerings were voluntary, but regulations were enacted in five states between 2001 and 2003 that required utilities to offer green power.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To offer green pricing and other incentives, power companies must monitor renewable energy use. With net metering, self-generating consumers can save on their energy bills.

Municipal-level Policies

Many local governments around the world are enacting their own renewable energy policies. For example, many cities are adopting future targets of typically 10–20 percent of electricity from renewables for all consumers in the city. Examples are Adelaide, Australia; Cape Town, South Africa; Freiburg, Germany; and Sacramento, California. In 2006, Tokyo proposed an ambitious target of 20 percent of total energy consumption in the city by 2020. Some cities have also proposed or adopted CO_2 emissions-reduction goals, typically a 10–20 percent reduction over a baseline level, consistent with the form of Kyoto Protocol targets. Examples are Freiburg, Germany; Gwangju, Korea; Sapporo, Japan; Toronto, Canada; and Vancouver, Canada.

A number of cities have decided to purchase green power for municipal government buildings and operations. Examples are Portland, Oregon, and Santa Monica, California, in the United States; each city already purchases 100 percent of its power needs as green power. Other U.S. cities purchasing 10–20 percent of municipal government power are Chicago, Los Angeles, Minneapolis, and San Diego. Some cities are also enacting policies to support solar hot water and/or rooftop solar PV, or modifying their urban planning methods or processes to incorporate future energy consumption.

Renewables for Rural Energy and Development

The most common applications of renewable energy for rural (off-grid) energy services are cooking, lighting and other small electric needs, mechanical processes (that is, for turning shafts) in light industry, water pumping, and heating and cooling. These applications are summarized in Table 3 (below). There is a growing literature on the economic development and social benefits of these renewable energy applications. Unfortunately, we are still far from understanding or achieving consensus on the magnitude or prevalence of such benefits.[14]

Aside from traditional biomass-fueled cooking stoves, the applications receiving the most attention in the literature are biogas and solar home systems. Sixteen million households cook and light their homes with biogas, displacing kerosene and other cooking fuel. More than 2 million households light their homes with solar home systems, primarily in India, China, Sri Lanka, Bangladesh, and Brazil.

Productive uses of heat and electricity for small-scale industry, agriculture, telecommunications, health, and education in rural areas are small but growing areas of research and practice.[15] Examples of industrial applications include silk production, brick making, rubber drying, handicraft production, sewing, welding, and woodworking. Examples of agricultural and food processing applications include irrigation (water pumping), food drying, grain mills, stoves and ovens, icemaking, livestock fences, and milk chilling. Health applications include vaccine refrigeration and lighting. Communication applications include community cinema, telephone, computers, and broadcast radio. Other community applications include school and street lighting and drinking water purification. Despite this diversity of potential applications, existing projects are still small demonstrations, with few large-scale developments on replicable terms. In particular, applications of modern renewables to rural heating needs, such as cooking and agricultural processing from advanced solar or biomass technologies, are just beginning to attract the attention of the development community.

National rural electrification policies and programs, together with international donor programs, have employed renewable energy as an adjunct to "access" strategies (serving increasing percentages of rural populations who don't have access to central electric power networks). An estimated 360 million households worldwide still lack such access. The main electrification options include power grid extension, diesel generators connected in mini-grids, renewable energy connected in village-scale grids (solar, wind, and/

Table 3. Common existing applications of renewable energy in rural (off-grid) areas

Energy services	Renewable energy applications	Conventional alternatives
Cooking (homes, commercial stoves and ovens)	• biomass direct combustion (fuel wood, crop wastes, forest wastes, dung, charcoal, and other forms) • biogas from household-scale digester • solar cookers	Liquefied Petroleum Gas (LPG), kerosene
Lighting and other small electric needs (homes, schools, street lighting, telecommunications, hand tools, vaccine storage)	• hydropower (pico-scale, micro-scale, small-scale) • biogas from household-scale digester • small-scale biomass gasifier with gas engine • village-scale mini-grids and solar/wind hybrid systems • solar home systems	Candles, kerosene, batteries, central battery recharging, diesel generators
Process motive power (small industry)	• small hydro with electric motor • biomass power generation and electric motor • biomass gasification with gas engine	Diesel generators
Water pumping (agriculture and drinking)	• mechanical wind pumps • solar photovoltaic pumps	Diesel pumps
Heating and cooling (crop drying and other agricultural processing, hot water)	• biomass direct combustion • biogas from small- and medium-scale digesters • solar crop dryers • solar water heaters • ice-making for food preservation	LPG, kerosene, diesel generators

SOURCE: REN21, *Renewables 2005 Global Status Report* (Washington, DC: Worldwatch Institute, 2005).

or biomass gasification, sometimes combined with diesel), and household-scale renewable energy (solar home systems and small wind turbines). Often the cost of traditional grid extension is prohibitive. Interest in using renewable energy technologies to provide electricity to rural and remote areas as a cost-effective alternative to grid extension is gathering momentum in many developing countries.

Multilateral, bilateral, and other public financing flows for renewables in developing countries have reached about $500 million per year in recent years. The three largest sources of these funds have been the German Development Finance Group (KfW), the World Bank Group, and the Global Environment Facility (GEF). Other sources of public financing include bilateral assistance agencies, United Nations agencies, and recipient country governments. Financing for renewable energy in developing countries comes from an increasing number of local players, for example Grameen Shakti in Bangladesh, the Development Bank of Uganda, and Canara and Syndicate Banks in India.

Conclusion

Renewable energy shows strong growth trends and increasing significance relative to conventional energy. Installed capacity is growing at rates of 20–60 percent annually for many of the technologies, aided by a multiplying series of promotion policies at national, state/provincial, and local levels. The industry employs on the order of 2 million people worldwide and invested $65 billion in 2005, if large hydro capacity and new manufacturing facilities are counted. Perhaps there is no better indicator than the diversity of public and private financing sources. Increasing numbers of large commercial banks and investment houses are taking notice of renewables and "mainstreaming" investments, such as HypoVereins, Fortis, Dexia, Citigroup, ANZ, Royal Bank of Canada, Triodos, Goldman Sachs, and Morgan Stanley. Investments by traditional utility companies are also increasing. Financing by public banking institutions is led by the European Investment Bank, whose renewables financing averaged $630 million per year during 2002–2004.

The short-term future of renewable energy continues to depend on policy development. Policies like feed-in tariffs, investment subsidies, sales tax exemptions, and net metering have done much to spur markets over the past decade. In addition, setting future targets appears to be an important means of political expression and commitment. The effectiveness of other policies—such as renewables portfolio standards, public competitive bidding, utility green power pricing, and renewables certificates—is less certain but potentially also promising as more experience is gained. The federal production tax credit in the United States has supported wind power growth but in a repeatedly start-stop (expire-wait-renew) manner than has hindered sustained industry development, underscoring that policies need to be sustained and long-term to be effective. Ethanol tax credits in the United States have been responsible for an upsurge in ethanol production but at high subsidy cost (on the order of $2 billion in 2005). Similarly, the German 100 percent sales tax exemption for biodiesel has led to recent growth. Policies to support renewable energy at the city government level are emerging worldwide and show huge promise.[16]

In the longer term (2010–2030), declines in the costs of renewables should make them closely competitive with conventional energy even without counting externalities, especially if fossil fuel prices continue to rise. This should be the case even without any major technology breakthroughs. For example, ethanol from sugar cane is now cheaper in Brazil than gasoline, and grid-connected solar PV is still growing in Japan even after investment subsidies declined to zero in 2004. Some published scenarios show renewables growing to 40–50 percent of global primary energy by 2050, although conservative scenarios envision much lower levels. The conservative scenarios seem less and less plausible given the level of capital investment and sustained industry growth and given that more and more people are weighing the huge external costs (and potential geo-political costs) of fossil fuels against marginally higher direct costs of renewables.[17]

With concerted effort, renewables could realistically comprise more than half of global primary energy by 2040 (with the rest perhaps coming mostly from natural gas and coal-to-liquids). This view includes much greater use of electricity for transport, likely through advances in battery storage technology and plug-in hybrid-electric vehicles; widespread solar heating; a much greater share of power generation via distributed renewables with local energy storage, akin to today's distributed internet; and finally, perhaps a "wildcard" technology making great strides, such as solar thermal power generation or cellulose-to-ethanol. In any case, we can expect cost reductions of existing technologies through economies of scale as well as technology improvements. Further views in terms of individual technologies:[18]

- *Solar hot water and space heating* shows the greatest future potential among all renewable technologies. The key will be integration into building codes and design practices, including passive solar architecture, along with quality standards and a trained maintenance industry. The market is already huge in China, with costs just a fraction of those in Europe. Low-cost exports could push expansion globally. Policies such as those in Spain requiring solar hot water for all new construction and renovation are at the forefront of global market development.
- *Wind power* should continue to grow at 15–30 percent annually through at least 2020. The industry and technology have become mature and costs have declined by 12–18 percent with each doubling of global installed capacity. Virtually all development has been on-shore, but off-shore wind could play a larger role in the future. If overall growth continues at 22 percent annually, the "Wind Force 12" scenario by Greenpeace and the European Renewable Energy Council would be achieved. This scenario envisions 12 percent of global electricity from wind power by 2020, against the backdrop of a

projected two-thirds increase in electricity demand. More than 1,200 GW of wind power would be required, up from 60 GW in 2005, costing perhaps $600–800 billion in cumulative investment.[19]

• *Solar PV* has the most potential to "surprise" us with cost reductions, performance improvements, and materials breakthroughs, which could lead to tens of millions of solar PV rooftops worldwide by 2020. Until then, grid-connected solar PV is still expensive and likely to flourish only where substantial subsidies or feed-in tariffs are in place, such as Germany and California, or where retail electricity rates are extremely high, such as Japan. In any case, most expect the solar PV industry to continue to grow by more than 30 percent annually over the next several years. At a 30 percent annual growth rate, cumulative production would reach 300 GW by 2020, up from 5.5 GW today, equivalent to 100 million rooftops.

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Some new policies require solar hot water systems for all new construction and renovation. If these policies gain more momentum, more houses will be built like this one.

• *Solar thermal power* at small and large scales also has great potential for cost reductions driven by technology research and development and manufacturing innovation, although the market has essentially been dormant for more than a decade. Subsidies or feed-in tariffs are important, and Spain appears to be leading a resurgence of this market now, based on favorable feed-in tariffs.

• *Biofuels* have great potential where dedicated energy crops (such as corn, sugar cane, and a variety of oil seeds) are possible or waste cooking oils are available. Recent annual growth has been in the 10–20 percent range. The long-term future of biofuels is uncertain, however, given competing demands for land and crops, especially if agricultural disruption from climate change becomes serious. Still, many are optimistic. If cellulose-to-ethanol technology becomes commercial, a significant breakthrough that some expect by 2015, the ubiquity of wood and agricultural wastes could greatly enhance the prospects for ethanol production.[20]

• *Other renewable energy technologies*, like biomass power and heat via combustion, biogas, biomass gasification, geothermal power and heat, small hydropower, and wave and tidal power, should all continue to grow but probably at slower rates and decreasing significance relative to the other technologies mentioned above.

High-growth markets in the coming decade are likely to include Europe, the United States, Brazil, China, India, Japan, Korea, the Philippines, and Thailand. All these countries have ambitious targets and active policies in place. Europe, particularly Spain and Germany, continues to lead the world in most categories, although the achievement of EU 2010 targets is in question. China, in contrast, should meet its renewables development targets for 2010 and 2020 without difficulty, with continuing growth expected in solar hot water, small hydro, wind power, and biomass power. Brazil should continue to lead in biofuels, for domestic consumption and export, and Brazil's emerging markets for biomass power, wind power, and solar hot water are likely to grow. India should continue to be a world leader in wind power, especially given the success of Suzlon, an Indian wind turbine manufacturer, which went public in 2005 and was soon valued at $8 billion in market capitalization. India—along with China, Brazil, Sri Lanka, and Bangladesh—is leading in rural energy development employing biomass gasification and/or solar household systems. The United States lags well behind Europe overall but should continue to lead in wind power and biofuels.

The many recent U.S. state-level policies could do much in the coming decade. Japan should continue to lead in rooftop solar PV. The next decade is uncertain for renewables in Japan, although much is happening at the local level, such as an April 2006 announcement by the Tokyo government that renewables should become 20 percent of total energy consumption by 2020.[21]

The *Renewables 2005 Global Status Report* was written because there was no comprehensive picture of where renewable energy stood globally. The literature on renewable energy has emphasized technologies rather than policies, markets, and industries. These later categories tend to be covered more informally, through proprietary reports and unpublished sources. Furthermore, each technology and industry tends to be researched separately. Global coverage of policy development and markets was lacking, in part because the leading multilateral institutions that understand policy developments are segregated into developed versus developing countries. Also, policy information is often kept in highly detailed databases without good summaries or country-by-country profiles. Although there are good policy and market summaries for the EU and United States, no overall "landscape" existed for the whole world.[22]

Research priorities continue to be for market and policy research. Given the fast pace of growth, it is crucial that such research work toward understanding and documenting business, policy, and development lessons from existing activities and investments worldwide. Such lessons can help foster more effective private decisionmaking and policy development. There is still little consensus in the literature on which policies are most effective under which circumstances or on the direct or indirect costs of individual policies. The relative costs of different policies, both direct and indirect, need analysis. Further work should also consider renewables more realistically in the future energy picture of the world given current trends, building on existing scenarios, and with attention to existing scenarios that may draw from outdated circumstances of the 1990s. Research should also ask "what if" questions based on future technology developments and economic conditions, both plausible and surprising.

National policies and international environmental agreements have underscored concern about the environmental impacts of fossil fuels for many years. More recently, concerns about energy prices, energy security, and international conflict over fossil-fuel resources have added to the sense of urgency and importance of alternatives to fossil fuels. Fuel switching from coal to natural gas offers many environmental benefits, particularly using modern combined-cycle gas turbines. Nevertheless, the main alternatives to fossil fuels are energy efficiency, nuclear power, and renewable energy. Energy efficiency improvements are the most important short-term measures and offer large reductions in energy use. Nuclear power offers our children a severe environmental legacy of wastes to be safeguarded for thousands of years, with questionable economic competitiveness if all costs are considered. In many international discussions, with varying political agendas, renewables continue to be marginalized. Renewables should be taking the spotlight.

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NOTES

1. There is no universally accepted definition of "renewable energy." Common definitions sometimes include large-scale hydropower ("large hydro"), traditional use of biomass for heating and cooking in rural areas of developing countries, and energy from municipal solid waste. Statistics, research, and policy discussions often do not specify clearly which of these categories are included or excluded, which can be confusing. The use of "renewable energy" in this article excludes all three of these categories, but covers solar, wind, "modern" biomass, geothermal, and small hydro. This coverage is similar to the meaning of the term "new renewables" found in the literature. The distinction "new renewables" is useful for a variety of reasons, including the fact that new renewables are growing at annual rates of 10–60 percent and present unique market and policy considerations, while large hydro is growing at rates of 2–3 percent and reflects more traditional power sector investment and policy. Referring to "new renewables" as "renewable energy" is common practice. British Petroleum (BP), in its annual *Statistical Review of World Energy* (London, 2005), excludes large hydro from its renewable energy statistics. Similarly, the International Energy Agency book *Renewables for Power Generation* (Paris, 2003) excludes large hydro. Common practice is to define large hydro as more than 10 megawatts (MW) capacity, although small hydro statistics in this article include plants up to 50 MW in China and 30 MW in Brazil, as these countries define and report small hydro based on those thresholds. In 2004, there were 720 gigawatts of large hydro installed worldwide, and annual investment was about $20–25 billion.

2. This article is based primarily on E. Martinot et al., *Renewables 2005 Global Status Report* (Washington, DC: Worldwatch Institute, 2005); and an update for 2006 (forthcoming) by the same authors. The report was sponsored by the REN21 Renewable Energy Policy Network and is available at http://www.ren21.net/globalstatusreport and http://www.martinot.info/re2005.htm. Full references for the material presented in this article, along with detailed analytical notes, are in the *Notes and References Companion Document* available on the same Web pages.

3. The 182 GW of renewable electric power capacity generates about one-fifth the power of nuclear because of much lower average capacity factors, meaning that renewables do not produce full power all of the time, while nuclear has very high capacity factors. For detailed calculations, see Martinot et al., *Notes and References Companion Document*, note 2 above, pages 3–4.

4. For general references on renewable energy markets, policies, and barriers, see International Energy Agency, *Renewable Energy: Market and Policy Trends in IEA Countries* (Paris, 2004); European Renewable Energy Council, *Renewable Energy in Europe: Building Markets and Capacity* (Brussels, 2004), http://www.erec-renewables.org/documents/RES_in_EUandCC/ExecutiveSummary.pdf; F. Beck and E. Martinot, "Renewable Energy Policies and Barriers," *Encyclopedia of Energy* (San Diego, CA: Academic Press/Elsevier Science, 2004), http://www.martinot.info/Beck_Martinot_AP.pdf; P. Komar, *Renewable Energy Policy* (New York: Diebold Institute for Public Policy Studies, 2004); W. Turkenburg et al., "Renewable Energy Technologies," in UN Development Programme (UNDP), UN Department of Economic and Social Affairs, and World Energy Council, *World Energy Assessment* (New York: UNDP, 2000), http://stone.undp.org/undpweb/seed/wea/pdfs/chapter7.pdf; T. Johansson and W. Turkenburg, "Policies for Renewable Energy in the European Union and its Member States: An Overview," *Energy for Sustainable Development* 8, no. 1 (2004): 5–24, http://www.ieiglobal.org/ESDVol8No1/04overview.pdf; J. Sawin, *Mainstreaming Renewable Energy in the 21st Century*, Worldwatch Paper 169 (Washington, DC: Worldwatch Institute, 2004); J. Sawin and C. Flavin, "National Policy Instruments: Policy Lessons for the Advancement and Diffusion of Renewable Energy Technologies Around the World," thematic background paper for Renewables 2004 Conference, Bonn, Germany, June 2004, http://www.renewables2004.de/pdf/tbp/TBP03-policies.pdf; H. Geller, *Energy Revolution: Policies for a Sustainable Future*, (Washington, DC: Island Press, 2003); L. Fulton, T. Howes, and J. Hardy, *Biofuels for Transport: An International Perspective*, (Paris: International Energy Agency, 2004); and E. Martinot, R. Wiser and J. Hamrin, "Renewable Energy Markets and Policies in the United States" (San Francisco, CA: Center for Resource Solutions, 2005), http://www.martinot.info/Martinot_et_al_CRS.pdf. For renewable energy markets in developing countries, see E. Martinot et al., "Renewable Energy Markets in Developing Countries," *Annual Review of Energy and the Environment* 27 (2002): 309–48, http://www.martinot.info/Martinot_et_al_AR27.pdf.

5. Depending on the methodology for how large hydropower and other renewable power generation technologies are counted in the global energy balance, renewables' total contribution to world primary energy can also be reported as 13–14 percent rather than 17 percent, and fossil fuels as 80–81 percent rather than 77 percent. This point can also be confusing, and there is no international consensus on the methodology. The basic issue is whether to count the energy value of equivalent primary energy or of the electricity. In the figures used here, primary energy attributed to electricity supply is adjusted to reflect fossil fuel energy required to produce an equivalent amount of electricity. This type of adjustment is made in some but not all published global energy statistics. The adjustment is made in BP's annual *Statistical Review of World Energy*, note 1 above. In BP statistics, "the primary energy value of hydroelectricity generation has been derived by calculating the equivalent amount of fossil fuel required to generate the same volume of electricity in a thermal power station, assuming a conversion efficiency of 38% (the average for OECD thermal power generation)." Statistics by the International Energy Agency make this adjustment for nuclear power but not for hydro, which puts nuclear power's share of global primary energy three times higher than hydro, even though both forms of energy provide roughly the same useful electric power on a global basis. That methodology distorts the relative useful contribution of

these two energy sources. BP (2005) suggests that hydropower was 634 million tons of oil equivalent (MTOE) in 2004, 6.2 percent of global primary commercial energy. Other statistics not using this methodology may claim that hydropower was only 2.4 percent of global primary commercial energy. In addition, this correction makes total primary energy higher, with BP's figure of 10,224 MTOE commercial primary energy in 2004 higher than some other published figures. In addition, most figures for global primary energy exclude traditional biomass. Martinot et al. (2005), note 2 above, used a figure of 1,010 MTOE in 2004 for traditional biomass (see the report for further details on sources). Using that number, total world primary energy in 2004 was 10,224 MTOE (commercial) + 1,010 MTOE (traditional biomass) = 11,234 MTOE (total). Renewables share of 1,876 MTOE is 16.7 percent, including large hydropower and traditional biomass.

6. Data on environmental insults for this section come from J. Goldemberg and T. Johansson, eds., *World Energy Assessment Overview: 2004 Update* (New York: UNDP, UN Department of Economic and Social Affairs, and World Energy Council, 2004), Table 4, page 41, available at http://www.undp.org/energy/docs/WEAOU_full.pdf. A good comparison of environmental impacts between renewables and fossil fuels can found in A. Serchuk, "The Environmental Imperative for Renewable Energy: Update," (Washington, DC: Renewable Energy Policy Project, 2000), http://repp.org/repp_pubs/pdf/envImp.pdf. The Executive Summary has the most useful comparison tables, which are not found in the main report: http://www.crest.org/repp_pubs/articles/envImp/earthday.exec.summ.pdf.

7. European Commission, *External Costs: Research Results on Socio-Environmental Damages Due to Electricity and Transport*, (Luxembourg: Office for Official Publications of the European Communities, 2003), http://europa.eu.int/comm/research/energy/pdf/externe_en.pdf.

8. All costs are economic costs, exclusive of subsidies and other policy incentives. Typical energy costs are under best conditions, including system design, siting, and resource availability. Some conditions can yield even lower costs, for example, down to 2 cents per kWh for geothermal and large hydro and 3 cents per kWh for biomass power. Less optimal conditions can yield costs substantially higher than the typical costs shown. Typical solar PV grid-connected costs are for 2,500 kWh per square meter per year, typical for most developed countries. Costs increase to 30–50 cents per kWh for 1,500 kWh per square meter sites (such as Southern Europe) and to 50–80 cents for 1,000 kWh per square meter sites (such as the United Kingdom).

9. Of course, just as renewables' technology costs can decline, so can fossil fuel technology costs. For example, improvement in gas turbine technology lowers equipment costs and improves technical efficiency. Two good references on incorporating fossil-fuel price risk into economic comparisons with renewables are S. Awerbuch, "Determining the Real Cost: Why Renewable Power is More Cost-Competitive Than Previously Believed," *Renewable Energy World* 6, no. 2 (2003): 53–61, http://jxj.base10.ws/magsandj/rew/2003_02/real_cost.html; and M. Bolinger, R.H. Wiser, and W. Golove, "Accounting for Fuel Price Risk: Using Forward Natural Gas Prices Instead of Gas Price Forecasts to Compare Renewable to Natural Gas-Fired Generation," LBNL-53587 (Lawrence Berkeley National Laboratory, Berkeley, CA, 2003), http://eetd.lbl.gov/ea/EMS/reports/53587.pdf.

10. IEA, note 4 above, page 61.

11. See the references in note 4 above for discussion of market barriers.

12. See International Energy Agency, *Experience Curves for Energy Technology Policy* (Paris, 2000).

13. Brazil's transport fuels and vehicle markets have evolved together. After a sharp decline in the sales of pure-ethanol vehicles during the 1990s, sales were climbing again in the early 2000s, due to a significant decline in ethanol prices, rising gasoline prices, and the introduction of so-called "flexible fuel" cars by automakers in Brazil. These cars can operate on either pure ethanol or ethanol/gasoline blends. By 2003, these cars were being offered by most auto manufacturers at comparable prices to pure ethanol or gasohol cars. Sales increased rapidly, and by 2005, more than half of all new cars sold in Brazil were flex-fuel cars.

14. For further background see D. M. Kammen, "Bringing Power to the People: Promoting Appropriate Energy Technologies in the Developing World," *Environment* 41, no. 5 (1999): 10–15 and 34–41; and Martinot et al., 2002, note 4 above. After fossil fuels, traditional biomass comprises some 9 percent of global primary energy. Traditional biomass means agricultural waste, waste from forestry and forest products, fuel wood collected manually by households, and animal dung. These sources are typically burned in stoves or furnaces to provide heat energy for cooking, heating, and agricultural and industrial processing. In rural areas of many developing countries, particularly in Africa, traditional biomass represents the primary energy source. The environmental impacts of traditional biomass use are also very significant; see M. Ezzati and D. M. Kammen, "Household Energy, Indoor Air Pollution, and Health in Developing Countries: Knowledge Base for Effective Interventions," *Annual Review of Energy and the Environment* 27, (2002): 233–70. Ezzati and Kammen state that "conservative estimates of global mortality as a result of exposure to indoor air pollution from solid fuels show that in 2000 between 1.5 million and 2 million deaths were attributed to this risk factor, accounting for 3–4 percent of total mortality worldwide." Although traditional biomass use is clearly a form of renewable energy, most literature on traditional biomass concerns environmental impacts or ways to displace consumption with more modern fuels or improve the efficiency of resource use, in contrast to literature on new renewables, which focuses on cost comparisons, technology development, and market acceleration.

15. See R. A. Cabraal, D. F. Barnes, and S. G. Agarwal, "Productive Uses of Energy For Rural Development," *Annual Review of Environment and Resources* 30 (2005): 117–44; in addition to a number of good references posted at http://www.martinot.info/productive_uses.htm.

16. For more details on subsidies for renewable energy, see Martinot et al., *Notes and References Companion Document*, note 2 above, 24–25. The Earthtrack Web site (www.earthtrack.net) has a comprehensive set of references on energy subsidies. Total energy subsidies/support for fossil fuels on a global basis are suggested in the range of $150–250 billion per year, and for nuclear, $16 billion per year, according to the UN Environment Programme and the International Energy Agency, "Reforming Energy Subsidies" (Paris, 2002), www.uneptie.org/energy/publications/pdfs/En-SubsidiesReform.pdf. Many advocate subsidies for renewables as "leveling the playing field" in the absence of political viability for removing subsidies to fossil fuels and nuclear.

17. See J. J. C. Bruggink, "The Next 50 Years: Four European Energy Futures," ECN-C-05-057 (Petten, Netherlands: ECN Policy Studies, 2005); EUREC Agency, *The Future for Renewable Energy: Prospects and Directions* (London: James and James, 2002); Global Wind Energy Council and Greenpeace, *Wind Force 12: A Blueprint to Achieve 12% of the World's Electricity from Wind Power by 2020* (Brussels, 2005); International Energy Agency, *Energy to 2050: Scenarios for a Sustainable Future* (Paris, 2004); D. J. Treffers, A. P. C. Faaij, J. Spakman, and A. J. Seebregts, "Exploring the Possibilities for Setting Up Sustainable Energy Systems for the Long Term: Two Visions for the Dutch Energy System in 2050," *Energy Policy* 33, no. 13 (2005): 1723–43.

18. S. Dunn, "Micropower: The Next Electrical Era," Worldwatch Paper 151 (Washington, DC, 2000); A.–M. Borbely and J. F. Kreider, *Distributed Generation: The Power Paradigm for the New Millennium* (New York: CRC Press, 2001); and National Renewable Energy Laboratory, *Plug-In Hybrid Electric Vehicles*, (Golden, CO, 2006), http://www.nrel.gov/vehiclesandfuels/hev/plugins.html.

19. See Global Wind Energy Council and Greenpeace, note 17 above, and Martinot et al., note 2 above. GWEC and Greenpeace calculate $634 billion cumulative investment from 2001 to 2020 (2002 dollars), but the per-unit costs cited are not turn-key costs and would need to be increased by 30 percent to compare with turn-key investment costs presented elsewhere in this article. See also M. J. Pasqualetti, "Wind Power: Obstacles and Opportunities," *Environment* 46, no. 7 (September 2004): 22–38.

20. See L. Fulton, T. Howes, and J. Hardy, *Biofuels for Transport: An International Perspective*, (Paris: International Energy Agency, 2004), and Worldwatch Institute, "Biofuels for Transportation: Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century," (Washington, DC, forthcoming in 2006).

21. Many other countries are, of course, active. For a full breakdown of policies for all countries, see Table 4 of Martinot et al., note 2 above. For current China development targets for 2010 and 2020, see E. Martinot, *Renewable Energy in China*, http://www.martinot.info/china.htm.

22. Sources of information for Martinot et al., note 2 above, are highly diverse. The report drew from over 250 published references, plus a variety of electronic newsletters, unpublished submissions, personal communications, and Web sites. There is generally no single source of information for any fact globally, as most existing sources report only on developed (OECD) countries or on regional or national levels, such as Europe or the United States. Thus, global aggregates were built from the bottom up, adding or aggregating individual country information for most indicators and statistics. Developing countries in particular required country-by-country sources, as very little material exists that covers developing countries as a group. All of the information, graphs and tables in the report are built from multiple sources, often involving triangulation of conflicting or partial information using assumptions and growth trends. However, some key sources exist for certain topics. Solar PV data comes primarily from the newsletter PV News by Paul Maycock and annual summary articles, including P. Maycock, "PV Market Update—Global PV Production Continues to Increase," *Renewable Energy World* 8 no. 4 (2005): 86–99. Solar hot water data comes from Chinese sources plus the IEA Solar Heating and Cooling Programme, most recently W. Weiss, I. Bergmann, and G. Faninger, "Solar Heating Worldwide: Markets and Contribution to Energy Supply 2006" (Paris: IEA, 2006), http://www.iea-shc.org/welcome/IEASHCSolarHeatingWorldwide2006.pdf. Wind power capacity data come from Global Wind Energy Council, *Record Year for Wind Energy: Global Wind Power Market Increased by 43% in 2005*, http://www.gwec.net. A key source of material for installed capacity statistics for OECD countries comes from the International Energy Agency's Renewables Information and Electricity Information reports (updated annually). Other key sources include the U.S. Energy Information Administration's International Energy Annual, http://www.eia.doe.gov/iea, various UN agencies, the World Bank, the EurObserv'ER information series contained in the bulletin Systemes Solaires, (http://www.energies-renouvelables.org); and other industry associations. Key sources of information for policies include the International Energy Agency's online databases; see "Global Renewable Energy Policies and Measures Database," (Paris: IEA), http://www.iea.org/textbase/pamsdb/grindex.aspx. For the United States, the DSIRE database of state-level policies is the best source; see "Database of State Incentives for Renewable Energy," (New York: Interstate Renewable Energy Council), http://www.dsireusa.org. Martinot's "Renewable Energy Policy References" page at http://www.martinot.info/policies.htm contains more sources.