RENEWABLE ENERGY: READY TO MEET ITS PROMISE?

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Presented August 20, 1998 (revised December 7, 1998)

Energy is the lifeblood of our society. It is essential to our quality of life and underpins all other elements of our economy. As we approach the dawn of the 21st century, renewable energy technologies offer a tantalizing promise: clean, abundant energy gathered from continuously self-renewing resources such as the sun, wind, earth, and plants. Research conducted over the past 20 years has been bringing this promise closer to fruition, and progress towards realization of the full potential of renewable energy is accelerating.

> "For years, the renewables business has wanted to reach the point where, as sales volumes grew, prices dropped, making renewables more attractive and stimulating demand. This holy grail at last seems to be in sight."
> *The Economist*, April 18,1998, p. 57

This paper will briefly review the technical status, cost, and applications of major renewable energy technologies in 1998, and also discuss some of the socioeconomic impacts of wide-scale adoption of renewables.

PROGRESS IN RENEWABLE ENERGY TECHNOLOGIES

The term "renewable energy" encompasses a broad spectrum of technologies, all of which are based on self-renewing energy sources such as sunlight, wind, flowing water, the earth's internal heat, and biomass such as energy crops, agricultural and industrial waste, and municipal waste. These resources can be used to produce electricity for all economic sectors, fuels for transportation, and heat for buildings and industrial processes.

Renewable energy today contributes as much today to U.S. energy consumption as nuclear power (7%) and contributes slightly more (8%) to worldwide energy consumption.[1] Each renewable energy technology is in a different stage of development and commercialization. Some technologies are already commercial, at least for some situations and applications.[2] Of the renewable energy consumed in the United States in 1997, hydropower comprised 55%; biomass, including municipal solid waste, 38%; geothermal, 5%; solar, 1%; and wind, 0.5%.[3] Detailed information on over 7,000 facilities that generate U.S. grid-connected electricity from renewable resources is available electronically.[4]

Renewable energy technologies offer important benefits compared to those of conventional energy sources such as fossil fuels or nuclear power.[5,6] Renewable energy resources are abundant; worldwide, one thousand times more energy reaches the surface of the earth from the sun than is released today by all fossil fuels consumed. Table 1 gives the energy delivered per square meter of land for four renewable resources.[7] Similar to fossil fuels, renewable energy resources are not uniformly distributed throughout the world. However, every region has some renewable energy resource. And, because different renewable energy resources complement each other, taken together they can contribute appreciably to energy security and regional development in every nation of the world, without dependence on foreign energy sources that are subject to political instability or manipulation.

Table 1. Comparison of Renewable Energy Delivery per Unit Land Area	
Resource	Annual Delivered Energy (kWh/m^2)
Wind Energy (intermittent)	11 (average wind speed) 18 (high wind speed)
Biomass (baseload)	15 (low efficiency) 45 (high efficiency)
Photovoltaics (intermittent)	50-100
Geothermal (The Geysers) (baseload)	160-200

Most renewable energy systems are modular, allowing flexibility in matching load growth. Today's markets for renewable energy technologies range from specialized energy niche markets, where they are already cost effective, to centralized energy production. For centralized energy production, renewable energy systems are relatively capital intensive compared to competing conventional technologies such as natural gas combined power plants. However, after the initial investments have been made, the economics of renewable energy technologies improve in comparison with conventional technologies because operating and maintenance costs are low compared with those incurred using conventional fuels. This is especially true in the regions of the world where world fuel prices are relatively high, and will be especially true in the future as fuel prices increase.

Renewable energy systems generate little if any waste or pollutants that contribute to acid rain, urban smog, and health problems, and do not require environmental cleanup costs or waste disposal fees. Potential global climate change, caused by excess carbon dioxide and other gases in the atmosphere, is the latest environmental concern; systems using solar, wind, and geothermal sources do not contribute any carbon dioxide to the atmosphere.[8] In fact, today renewable sources of electricity help the United States avoid about 70 million metric tons of carbon emissions per year that would have been produced had that electricity been generated by fossil fuels.[9] Biomass does release carbon dioxide when it is converted to energy, but because biomass absorbs carbon dioxide as it grows, the entire process of growing, using, and regrowing biomass results in very low to zero carbon dioxide emissions.

Renewable Electricity Cost Trends and Projections

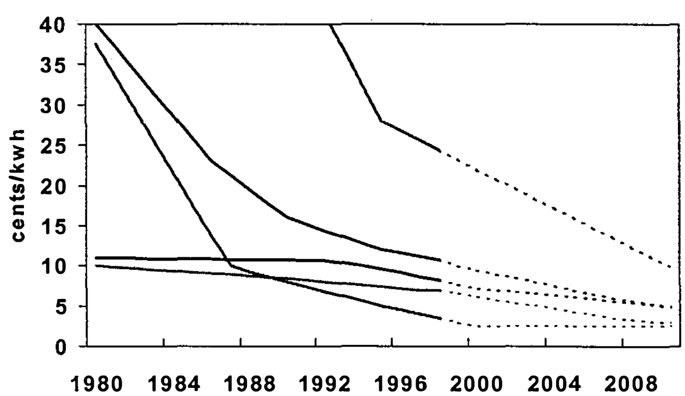

Figure 1

Although the energy of the sun and wind has been used by mankind for millennia, modern applications of renewable energy technologies have been under serious development for only about 20 years. In that period of research and development investment by industry and government (primarily the U.S. Department of Energy [DOE]), dramatic improvements have occurred in the cost, performance, and reliability of renewable energy systems (see Figure 1). A summary of these improvements is given below; many excellent reviews of the past two decades of progress in renewable energy technologies are available.[10,11,12,13,14,15,16,17,18,19]

Photovoltaic Energy

Photovoltaic devices use semiconductor materials such as silicon to convert sunlight to electricity. They contain no moving parts and produce no emissions while in operation. Extremely modular, photovoltaic devices can be used in small cells, panels, and arrays. Photovoltaic systems require little servicing or maintenance and have typical lifetimes of about 20 years. Through the National Center for Photovoltaics at NREL, researchers in government, universities, and industry are working together to lower production costs. Their efforts are focused on developing more efficient semiconductor materials and device designs, while expanding production capacity, increasing production rates, and improving product quality.[20,21,22,23]

Capital costs for photovoltaic panels have decreased from more than $50 per watt (W) in the early 1980s to about $5/W today; energy costs have declined from about 90¢ per kilowatt-hour (kWh) in 1980 to about 25¢/kWh. Although this is still higher than the cost of conventional baseload electricity, commercial markets are flourishing in developed countries for remote telecommunications, remote lighting and signs, remote homes and recreational vehicles, and in developing countries for remote power for village homes, clinics, and other uses (see Figure 2). Incorporating photovoltaic systems into roofing materials for generating power on buildings is another rapidly growing area.[24]

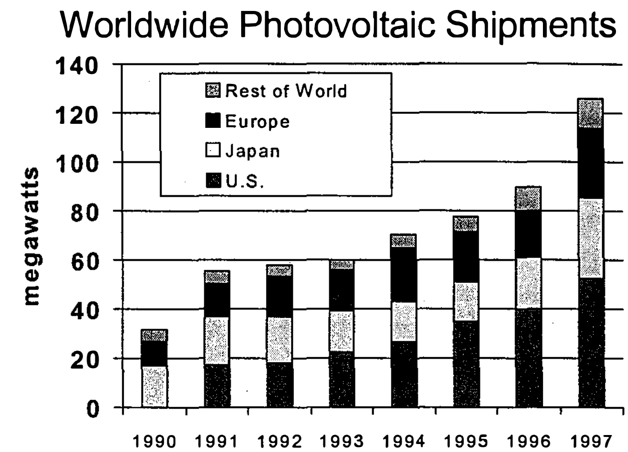

Figure 2

Photovoltaic markets, which have been growing steadily, experienced a large boost last year. In 1997, sales grew by 42% and are expected to do so again in 1998; the 1997 worldwide market for photovoltaic systems was about $1 billion. Worldwide shipments of photovoltaic systems in 1997 were 126 megawatts (MW); of this, 53 MW was exported from the United States, for a 42% share; Japan captured 26% and Europe (mostly Germany), 22%.[25] The surge in sales in 1997 came primarily from government programs in Japan and Germany that subsidize purchase of photovoltaics for residential use. In response to this growth, photovoltaic companies are expanding; considering only projects for which capital expenditures have been made, U.S. capacity is expected to grow from 50 MW in 1996 to more than 140 MW in 1998.

A new type of photovoltaics is now emerging, with the first commercial products now in development. Conventional solar photovoltaics, as discussed above, uses the energy of light to generate electricity. Thermophotovoltaics uses the energy of heat, or infrared radiation, to generate electricity, with the advantage that a generator can operate at night or when the sky is overcast, eliminating the need for batteries. Though it does need a fuel, such as natural gas, to provide the heat, using semiconductors for conversion rather than conventional diesel generators results in higher fuel-to-electricity conversion efficiencies, modularity, minimal pollutants, quiet operation, and high reliability. Applications under development include small power units to supply electricity in remote areas or for military troops; a U.S. company is also planning to market a thermophotovoltaic generator to run electrical equipment on sailboats. Ultimately, thermophotovoltaics could generate electricity from excess heat in hybrid electric vehicles or industrial processes.[26,27]

Wind Energy

Wind power systems convert the kinetic energy of the wind into other forms of energy such as electricity. Although wind energy conversion is relatively simple in concept, turbine design can be quite complex. Most commercially available wind turbines use a horizontal-axis configuration with two or three blades, a drivetrain including a gearbox and generator, and a tower to support the rotor. Typical sizes for a wind turbine range from 200–600 kilowatts (kW), with electricity produced within a specific range of wind speeds.

Rapid progress in this technology has reduced costs until they are almost competitive with those of conventional power.[28] Capital costs have declined from about $2.2/W in the early 1980s to less than $1/W today. Energy costs have decreased from about 40¢/kWh to as low as 4¢-7¢ /kWh today in areas with excellent wind resources. In the United States, cooperative research between DOE and manufacturing companies is aimed at increasing the aerodynamic efficiency and structural strength of wind turbine blades, developing variable-speed generators and electronic power controls, and using taller towers that allow access to the stronger winds found at greater heights. Projected energy costs for these advanced machines are 2¢-3¢ /kWh.[29,30]

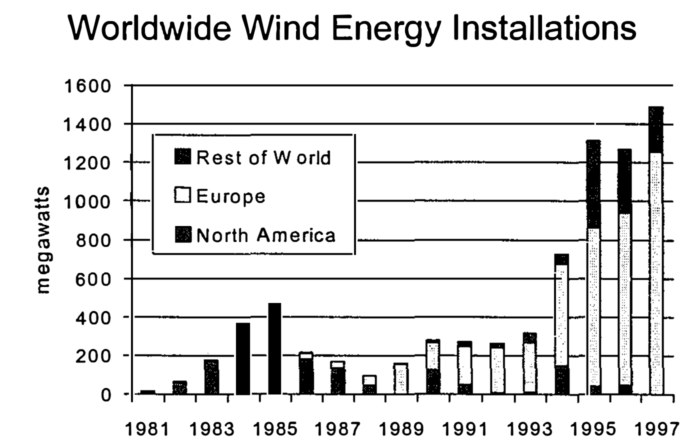

Figure 3

Wind resources are abundant throughout the world. In the United States, good resources can be found in 34 of the 50 states. For example, the wind resources in North Dakota alone could supply as much as 36% of all the electricity consumed by the lower 48 states.

More than 1,500 MW of additional wind capacity, totaling $1.5 billion in sales, was installed worldwide in 1997.[31] This reflects a 25% annual growth rate in total installations for the last three years; international markets have been growing much more rapidly than U.S. markets (see Figure 3). Installed capacity in Europe, dominated by Germany and Denmark, has surpassed installations in the United States, and is rapidly increasing; the United States installed only 11 MW in 1997. China already has more than 100,000 wind turbines generating electricity and pumping water in rural areas far from existing power lines. India installed 385 MW of wind power in 1997, with another 2,500 MW slated for the near future. According to the American Wind Energy Association, as much as 13,500 additional megawatts of wind capacity may be installed worldwide in the next decade.

The U.S. wind industry is thinly capitalized, except for the recent acquisition of one major wind company by Enron; there have been two bankruptcy filings recently. Europe has twice as many wind manufacturing and developing companies; some have already established North American manufacturing facilities and are penetrating the U.S. market.[32]

Biopower

Biomass power plants generate electricity from biomass resources ranging from agricultural and forest product residues to crops grown specifically for energy production. Direct-combustion systems burn biomass in a boiler to produce steam that is expanded to produce power; cofiring substitutes biomass for coal in existing coal-fired boilers; gasification converts biomass to a fuel gas that can be substituted for natural gas in combustion turbines. Today's U.S. biopower industry — nearly 1,000 plants — consists of direct-combustion plants with a small amount of cofiring. Plant size averages 20 MW with efficiencies about 20% and electricity costs of 8¢-12¢/kWh. Grid-connected capacity has increased from less than 200 MW in 1978 to more than 7,300 MW in 1996. About 70% of this is in the forest products and sugarcane industries; municipal solid waste plants provide additional capacity of 3,300 MW.[33] Biopower capacity in the rest of the world is about 20,000–25,000 MW, and international markets are strong with at least six major multinational companies actively involved in the industry. Research focuses on doubling or tripling the conversion efficiency of commercial plants, reducing costs further, and resolving issues related to biomass residual ash.[34,35]

Geothermal Energy

Geothermal resources include dry steam, hot water, hot dry rock, magma, and ambient ground heat. Steam and water resources have been developed commercially for power generation and ambient ground heat is used commercially in geothermal heat pumps; methods of tapping the other resources are being studied. Research centers on lowering costs, improving methods for finding and characterizing reservoirs, and tapping broader resources.[36,37]

The Geysers steam power plant in California is the oldest and largest geothermal power plant in the world, with a capacity of 2,000 MW. Hot-water plants have been developed more recently and are now the major source of geothermal power in the world. Total U.S. capacity is about 2,700 MW, enough electricity for 3 million people, at a cost of 5¢-10¢/kWh. Hot water from geothermal resources is also used directly to provide heat for industrial processes, dry crops, or heat buildings, for a total U.S. capacity of about 500 thermal MW. Many developing countries have geothermal resources, and continue to be an attractive market.[38]

Geothermal heat pumps do not generate electricity, but they reduce the consumption of electricity by using heat exchangers and the constant temperature of the earth several feet under the ground to heat or cool indoor air. The market for geothermal heat pumps has been growing rapidly, and by 2000 expectations are that they will be installed on more than 400,000 homes and commercial buildings per year.[39]

Solar Thermal Energy

Solar thermal systems use the sun's heat to meet a variety of needs, such as generating electricity; heating water for industrial processes, domestic water supplies, or community swimming pools; preheating building ventilation air; and direct heating of building interiors.

In California, nine commercial solar thermal electric plants with a total generating capacity of 354 MW having been operating since the mid-1980s. These systems consist of rows of highly reflective parabolic troughs. Each trough focuses and concentrates sunlight on a central tube filled with heat-absorbing fluid, which is used to generate electricity. When combined with natural-gas-fired turbines, parabolic-trough systems can produce electricity for about 9¢/kWh.

Two other options for solar thermal electricity include "power towers" and dish-Stirling units. Power towers generate large amounts of electricity using a tall, fluid-filled tower located at the focal point of a large field of mirrors. This technology has been successfully demonstrated by DOE's Solar One and Solar Two projects near Barstow, California. Dish-Stirling units use a small array of mirrors to focus sunlight on a Stirling engine, which produces 5–50 kW of electricity for grid consumption or stand-alone applications. Dish-Stirling systems are currently being tested by several electric utilities in the southwestern United States as a way to add incremental capacity without constructing expensive new conventional power plants.[40,41]

One of the most widespread uses of solar thermal technology is solar water heating. Significant progress has been made in improving the reliability and durability of these systems since the 1970s. According to the Solar Energy Industries Association, more than 200,000 businesses and 100,000 pools in the United States now use solar thermal systems to reduce their utility bills. Flat-plate collectors are used on residences, while more costly parabolic-trough systems make this technology suitable for moving the large volumes of water used by hospital laundries, institutional kitchens, swimming pools, or industrial processes.[42,43,44]

The sun's heat can also be used to preheat building ventilation air using transpired solar collectors mounted on south-facing exterior walls. The first commercial systems were sold last year.

Biofuels

Ethanol is frequently used as a gasoline additive, or converted to another additive called ethyl tertiary-butyl ether, to raise the octane level of gasoline and promote cleaner combustion. According to the U.S. Environmental Protection Agency, the use of ethanol blended with gasoline can reduce motor vehicle emissions of carbon monoxide by 25% to 30% and also reduce ozone levels that contribute to urban smog. In addition, the combustion of ethanol produces 90% less carbon dioxide than gasoline.

A blend of 10% ethanol and 90% gasoline has been widely used throughout the nation for many years. Stronger blends of 85% and 95% ethanol are being tested in government fleet vehicles, flexible-fuel passenger vehicles, and urban transit buses. Although there are less than 100 such vehicles in operation, their use is expected to grow as federal, state, municipal, and private fleet operators seek to comply with the alternative fuel requirements of the Energy Policy Act of 1992 and the Clean Air Act Amendments of 1990.

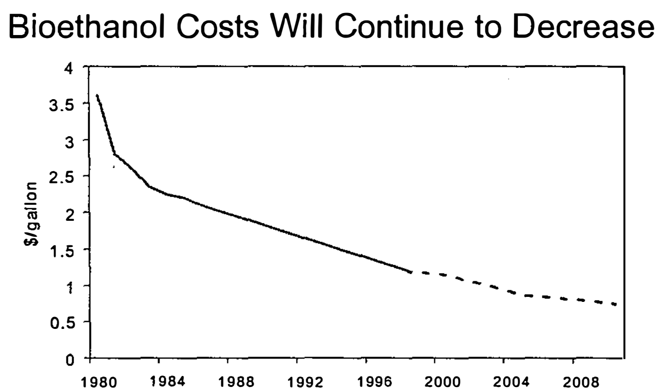

Figure 4

Ethanol sold today is produced from corn kernels using traditional fermentation technology to meet a market demand of more than a billion gallons of fuel a year. Because corn requires high amounts of energy (as fertilizer and farm equipment fuel) to grow, renewable energy research has focused on producing ethanol — termed bioethanol — from corn waste, waste newspaper, rice straw, and grasses and trees cultivated as energy crops.[45] Biological production of ethanol involves hydrolysis of fibrous biomass, using enzymes or acid catalysts, to form soluble sugars, followed by microbial conversion of sugars to ethanol. The cost of bioethanol production has decreased from $3.60/gallon in 1980 to about $1.20 today (see Figure 4) due to technical breakthroughs, including genetic engineering of specialized enzymes and microbes. Ultimately, the goal is for bioethanol to become competitive with gasoline in price.[46]

Research focuses on low-cost production of enzymes to break down cellulose, improve microorganism performance, produce suitable energy crops, and demonstrate ethanol production from a variety of biomass feedstocks.[47,48]

Ethanol is not the only fuel that can be produced from biomass. About 1.2 billion gallons of methanol, currently made from natural gas, are sold in the United States annually, with about 38% of this used in the transportation sector. (The rest is used to make solvents and chemicals.) Methanol can also be produced from biomass through thermochemical gasification. Diesel fuel, currently produced from petroleum, is also being produced in limited quantities from soybeans, but research has shown that diesel fuel can also be produced from less costly and more abundant sources, such as the natural oils occurring in algae and pyrolysis of biomass. Dimethyl ether is another fuel that can be produced from biomass as a diesel substitute. Federal support for research on biomass-derived methanol and diesel fuels has been de-emphasized recently to focus funding resources on ethanol.

Hydrogen and Fuel Cells

> "The new solar-powered water splitter...converts about 12.5% of the energy in sunlight to gaseous fuel—nearly double the previous record achieved by a conventional process."
> *Science,* April 17, 1998, p. 382

Hydrogen is today produced from natural gas for limited markets but it can be produced from renewable sources and promises substantial contributions to global energy supplies in the long term. Hydrogen is the most abundant element in the universe, the simplest chemical fuel (essentially a hydrocarbon without the carbon) that makes a highly efficient, clean-burning energy carrier. It has the potential to fuel transportation vehicles with zero emissions, provide process heat for industrial processes, supply domestic heat through cogeneration, help produce electricity for centralized or distributed power systems, and provide a storage medium for electricity from renewable energy sources. Some envision an entire economy based on hydrogen in the future.[49,50,51]

Research challenges include cost-effective, energy-efficient production technologies and safe, economical storage and transportation technologies. Major breakthroughs have occurred this year in both production and storage technologies for hydrogen. Researchers have doubled the previous efficiency of producing hydrogen from water and have made major advances in carbon nanotube storage technology.[52,53]

Fuel cells promise to be a safe and effective way to use hydrogen for both vehicles and electricity generation. Fuel cells convert hydrogen — as hydrogen gas or reformed within the fuel cell from natural gas, alcohol fuels, or some other source — directly into electrical energy with no combustion. Phosphoric acid fuel cells are already commercially available to generate electricity in 200-kW capacities selling for $3/W, using natural gas as the source of hydrogen; molten carbonate has been demonstrated at large (2-MW) capacities. Solid-oxide fuel cells are being demonstrated by major manufacturers for potential cogenerators in commercial and multifamily residential buildings. Proton exchange membrane cells using hydrogen (currently reformed from methanol) are being developed for both transportation and electricity applications.[54,55]

Although hydrogen fuel cells are used routinely by NASA for space missions, terrestrial applications are still in their infancy. The lack of an economical process for hydrogen production and suitable storage methods are two of the greatest obstacles to commercialization, especially in the transportation sector. Research goals include developing technologies to produce hydrogen from sunlight and water and biomass; developing low-cost and low-weight hydrogen storage technologies for both stationary and vehicle-based applications, such as carbon nanotubes and metal hydrides; and developing codes and standards to enable the widespread use of hydrogen technologies.

TODAY'S TRENDS AND ISSUES AFFECTING RENEWABLES

As is evident from the preceding discussion, scientific and engineering advances continue to strongly influence the progress of renewable energy technology development, as do advances in information technology. Easily accessed World Wide Web sites relating to renewable energy technologies provide valuable and accurate information that is easily accessible by everyone. Real-time metering is opening up innovative electricity pricing;[56] sophisticated equipment and controls are improving the use of energy in buildings; and complex systems are being modeled in the laboratory, accelerating technology development.

But despite the excellent technical progress of the last 20 years, electricity and fuels from renewable energy are still generally more expensive than electricity and fuels from conventional fossil-fuel sources, with the exception of some niche markets. Table 2 summarizes the economic potential of major renewable energy electric systems. Although it is difficult to compare costs of electricity from renewable technologies to those of conventional grid electricity, it should be noted that the average retail price of electricity in the United States is 7¢/kWh, which is less than most renewables. The cost of electricity and fuels from renewable energy would easily be less expensive than fossil fuels if the true, hidden costs of fossil fuels — environmental costs, health costs, and energy security costs — were considered. But our society has not yet found acceptable ways to incorporate these hidden costs into the cost of our energy.

Table 2. Economic Potential of Renewable Electric Systems in the U.S.

Resource	Application or Technology	Current Cost[57] (¢/kWh)	Next Generation Cost[57] (¢/kWh)	Grid-connected Generating Capacity, 1996[57] (MW)	Timeframe for Major Market Penetration (years)[58]
Photovoltaics	All types	25-35	15 or less	10	5-15
Solar Thermal Energy	Dish-Stirling	10-15	4-6	0	5-10
	Trough	10-12	7-9	354	5-10
	Power Tower	6-9	3-5	0	5-10
Biopower	Direct Combustion	7-15	4-6	7,500	0
	Cofiring	2-3	2-3	500	0-3
	Gasification	8-10	4-5	0	3-8
Wind Energy	All types	5-10	2-4	1,850	0-5
Geothermal Energy	Steam and Hot Water	7-10	3	3,020	0-5

Although we have not yet incorporated hidden costs into our pricing structures, the support of the American public for renewable energy continues unabated. In surveys over the past 18 years, majorities of the public have chosen renewable energy and energy efficiency over other energy alternatives and expressed a desire for a national agenda of sustainable development with increasingly large portions of the nation's energy mix from renewables.[59] In addition, more than a dozen utilities in the United States and more in Europe are offering renewables as part of a "green" marketing campaign to attract consumers, with very positive results to date.[60,61,62,63] Renewable energy is also getting more attention as a valuable response to natural disasters to mitigate loss, aid in immediate relief, and promote rapid recovery.[64] Even the insurance community is paying greater attention to renewables as insurance companies take higher and higher losses from natural disasters that scientists suggest may be increasing due to the cumulative impact on the environment of mankind's use of energy.

The industrialized world, and particularly the United States, is currently undergoing rapid change in the fundamental structure of the electricity sector of our economies.[65,66,67] Following the experience of the airline, telecommunications, and other industries, regulated utility monopolies are giving way to a market-driven electricity industry. The challenges and opportunities of this restructuring affect utilities, independent developers, power marketers, energy users, investors — and the renewable energy community. The immediate effect has been to make it more difficult for renewable energy electric technologies to penetrate large U.S. markets, because of the newness and uncertainty surrounding investments in relatively new technologies, the expectation of stiff price competition, and the higher initial cost of renewable energy technologies. Although some opportunities have opened up because of consumer interest in "green" energy, wind energy companies in the United States have been hurt at a critical time for the industry.

To encourage the use of renewable energy electricity in the United States, policy measures will be needed.[68,69] The most prominent measure under consideration is the renewables portfolio standard, a market-based mechanism for ensuring a minimum level of renewable energy development in the electricity portfolios of power suppliers as determined by a state or other implementing entity. Electricity sellers could meet their obligation through direct ownership of renewable generation, contracts for power from renewable generating facilities, or purchase of credits for sufficient renewable electricity from another power supplier. The U.S. Department of Energy's proposed restructuring legislation[70] would establish a renewables portfolio standard which ensures that at least 5.5% of all electricity sales include generation from non-hydroelectric renewable energy sources by 2010.[71]

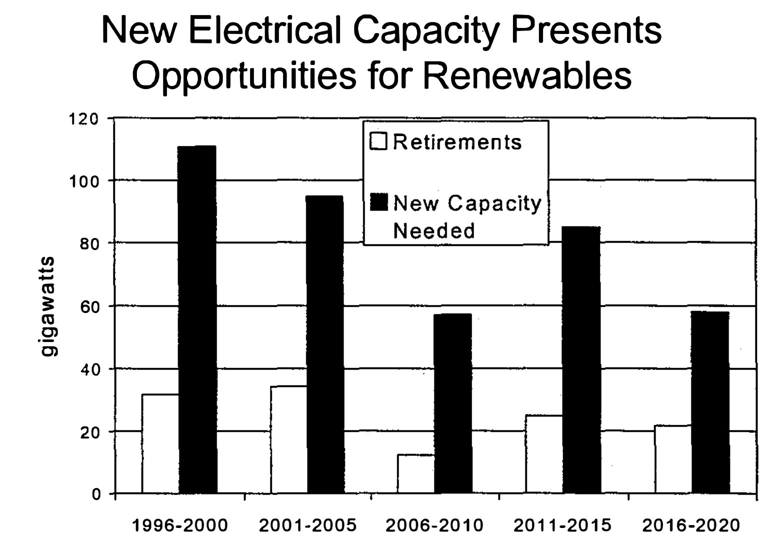

Figure 5

Because of the changing U.S. electricity marketplace, remote or distributed markets for renewable electricity, as noted in the individual technology discussions above, appear to be more promising today than centralized electricity markets.[72] Although central-station fossil and nuclear plants — which are, on average, 30 years old — supply 87% of the electricity used in the United States today, the Electric Power Research Institute expects that distributed markets will begin to emerge as early as 2000.[73] Figure 5 indicates the large requirements for capacity replacement expected during the next 20 years.[74] Renewable energy electricity technologies will be competing with gas and diesel engines, gas turbines, microturbines, and fuel cells. Intermittent renewable electric systems (wind, photovoltaics, and solar thermal) should be helped by recent advances in battery and other storage technologies.

The electricity sector is not alone in its challenges; the transportation sector also faces

> "Our analysis of the discovery and production of oil fields around the world suggests that within the next decade, the supply of conventional oil will be unable to keep up with demand."
> *Scientific American, March 1998, p. 78*

major challenges in meeting the ever-growing demand for transportation goods and services while minimizing adverse energy security and environmental impacts. The total U.S. transportation sector remains over 97% dependent on petroleum fuels and consumes about two-thirds of the nation's oil demand. Reliable energy supplies are essential to national security and economic well-being, yet America now depends on other nations for 52% of its oil. According to DOE, that figure will likely rise to 70% in little more than 20 years.[75] Oil imports represent a major transfer of wealth —$67 billion in 1997[76] — from the United States to oil exporting countries. And while the world rests comfortably, with many energy forecasters predicting 50 years or more worth of petroleum left to find and produce, a recent article in *Scientific American* suggests that the end of cheap oil we come much sooner.[77] However, despite the predictions of rapidly rising oil prices in the next decade or two, today's petroleum prices (especially in the United States) are the lowest in 20 years — presenting difficult challenges for bioethanol, biodiesel, hydrogen, renewable-powered fuel cells, and other alternative transportation fuels.

Most renewable fuels, as well as biomass power, depend on various forms of biomass as feedstocks.[78,79] Therefore, the availability and price of biomass become key factors in the economic viability of both technologies. Agricultural, industrial, and municipal wastes are attractive near-term sources of biomass for these end uses; they have zero or low value today. But it will not take much market penetration of these new technologies to deplete economically attractive waste products. The longer-term solution is energy crops — plants such as fast-maturing species of trees and grasses that are grown on farms[80] to be harvested specifically for burning, gasifying, or fermenting into electricity or fuel. Although energy crops can bring many advantages to the American farmer and rural development, the emergence of farms growing energy crops will require some changes to the traditional policies affecting the American agricultural community.

International Renewable Energy Markets are Increasing

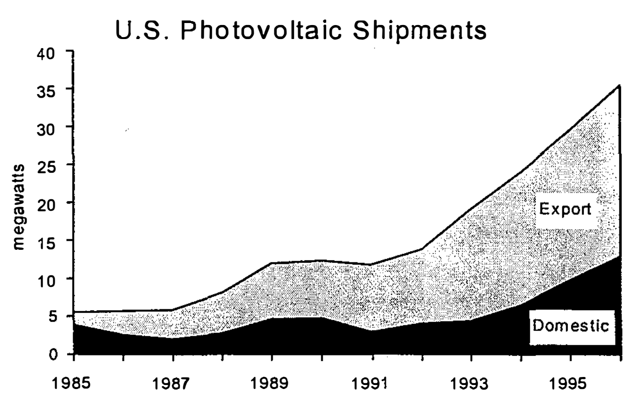

Figure 6

Demand for energy in developing nations has been increasing more rapidly than in the industrialized nations for the past 20 years or more, and is projected to increase even more rapidly, especially in China, India, and other growing economies in Asia.[81,82,83,84] In addition, this century has seen the dawning of the independence of individual nations all over the world, including the former Union of Soviet Socialist Republics. Independent nations are looking to develop indigenous sources of energy and their own energy infrastructure, in contrast to fossil-fuel-based energy systems ultimately controlled by a very few nations.[85] Developing countries are also looking to avoid the environmental problems created by conventional energy systems. In response, international lending institutions such as the World Bank have begun to target programs to environmentally friendly energy technologies such as renewables. All of these trends are quickly opening up strong international markets for renewables (see Figure 6).

Strong international markets mean strong international competition. Sweden's carbon tax led to a sharp increase in the use of biomass; Germany has underwritten a 15-fold increase in windpower since 1990. Both Japanese and German companies have invested heavily in photovoltaics. As reported in *The Economist* (April 18, 1998, p. 57), "Most of the rich countries in the OECD have programmes (supporting renewables) of varying degrees of compulsion, sense and utility." Some small U.S. renewable energy companies have suffered because of government subsidies for foreign renewable energy companies. But strong international competition has also served to spur on larger U.S. companies to move faster in developing new technologies, such as recent advances in hybrid vehicle developments in Japan that are encouraging U.S. auto companies to move more quickly.

TOMORROW'S IMPACT OF RENEWABLE ENERGY ON THE WORLD

From the dawn of human civilization to about 100 years ago, the sources of energy used by mankind were predominantly human and animal muscle and wood, with lesser amounts of solar, wind, hydro, and geothermal. With the discovery of oil, the development of natural gas fields, and the widespread distribution of electricity from coal-powered central power plants, fossil fuels became the predominant sources of energy in the United States and the world. Is there another major transition ahead for energy? Can the renewable resources that sustained early civilization be harnessed with enough efficiency and availability and at a cost to meet a significant portion of the much higher energy needs of today's society?

Although there are always risks in predictions, the convergence of some of today's trends suggests interesting possibilities.[86] In summary, today's converging trends related to renewable energy include:

- Relevant scientific discoveries and engineering progress
- Emergence of a new economic structure in the electricity sector
- Trends towards decentralization and modularity
- Explosive advances in computers, information, and telecommunications
- Globalization of markets
- Persistent, pervasive support for a clean environment
- Limited future availability of inexpensive fossil fuels.

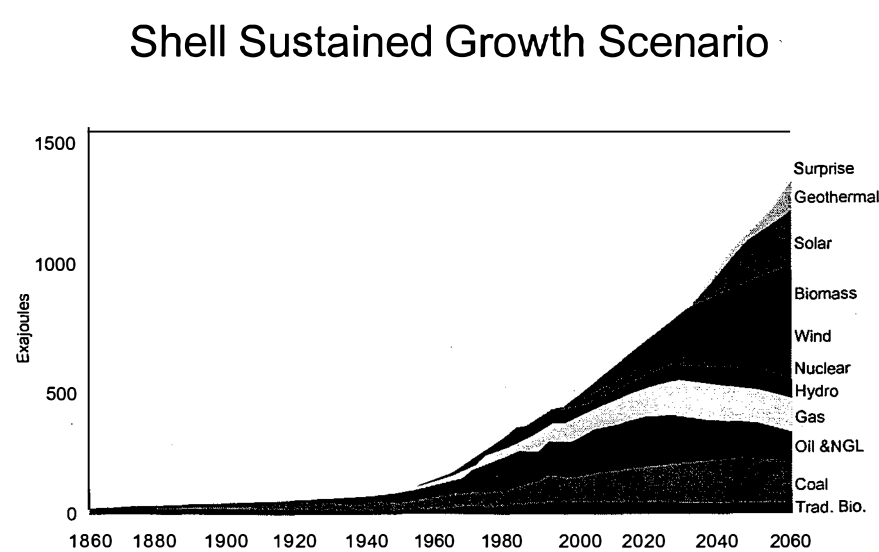

Figure 7

Do these converging trends mean that we are on the brink of a new energy transition from fossil fuels to renewables? Several independent entities have recently developed scenarios indicating that renewable energy will play a major role in the energy mix for the world, with increasing impacts beginning as early as 2000–2010 and major impacts by 2050.[87,88,89,90,91,92] In both of the Shell International scenarios, energy contributions from conventional energy resources begin to level off in 20–30 years, with petroleum consumption actually decreasing (see Figure 7).[93] According to these scenarios, the increases in world energy demand will be supplied by renewable energy technologies, which will provide 30%–50% of world energy by 2050.

Although these scenarios are important, and should be studied and debated, it may be even more significant that four international companies have recently made major investments in renewables. In October 1997, the Royal Dutch/Shell Group created Shell International Renewables with a $500 million investment, focusing on solar, biomass, and forestry.[94] In January 1998, British Petroleum (BP), through its BP Solar subsidiary, opened a 10–15 megawatt photovoltaics facility (its sixth in the world) in California.[95] Enron Corporation, one of the world's largest natural gas companies, entered into a joint venture with Amoco Corporation in 1995 to form the largest U.S.-owned producer of PV cells and the second largest in the world. Enron then acquired the largest U.S. wind energy company in 1997 and formed a new business unit, Enron Renewable Energy Corporation.[96] Most recently, Amoco and British Petroleum announced a merger. And Bechtel, the international engineering and project development giant, recently formed a joint venture with another U.S. firm to develop small, renewable energy systems including solar, wind, and hybrids.

Leaving aside the controversial question of *when* we might transition to an energy mix with significant proportions of renewable energy, but accepting the inevitability of the transition, what could be the impact on American and global society?[97,98] Although the topic is worthy of many pages of discussion, we will focus here on four areas relating most closely to the direct impact on human beings:

- U.S. rural economy
- Community planning and lifestyles
- International socioeconomic equity
- Environment

> "The restructuring of the electric industry is one of the most important, far-reaching policy debates of the decade. The decisions we make on the future of the electric industry will influence our economy, our environment, and our day-to-day lives in a way that doesn't even compare to the other major deregulation efforts of this century."
> *Federico Peña, then-Secretary of Energy, in remarks to the Edison Electric Institute, June 9, 1997*

U.S. Rural Economy

The rural economy in the United States continues in a state of change and uncertainty. The typical modern farm concentrates on the production of one or two major commercial products such as corn, soybeans, milk, or beef; the net income is vulnerable to fluctuations in market demand, the weather, and other factors. The addition of crops grown specifically for energy — such as poplar trees or native switchgrass — will expand the horizons of the American farmer, providing flexibility with a greater diversity of crops to improve the economic potential and stability of the farm. Because it is most economical to build the power plant or fuel facility near the source of biomass, the energy facilities themselves will add non-farm jobs in rural areas.

These businesses will bring other businesses, encouraging rural development and redirecting money spent on oil imports into local economies.[99]

Community Planning and Lifestyles

Rural communities are only one type of community that will be radically affected by the advent of significant renewable energy usage. Urban and suburban communities are likely to be affected by two major changes: the restructuring of the electric industry and changes in the way people move about. The restructuring of the electric industry means that people will have much more choice than in the past about how they provide electricity, heating, and cooling for their homes. Consumers will be able to generate electricity on their own property and buildings using wind, photovoltaic, or micro-fuel-cell technology, or purchase electricity from a local network of small, interconnected generators. Local businesses will be able to use microturbine, fuel cell, or gasifier technologies. Heating and cooling options will increase as geothermal heat pumps and preheating solar collectors become commonplace among major builders. Energy requirements will decrease as the majority of builders respond to consumer awareness of energy's financial and other costs and incorporate widespread whole-building approaches to reduce energy requirements. Meanwhile, computers and information technology will allow customers to pay the lowest possible prices for electricity as suppliers institute real-time pricing. The convergence of advances in information technology, energy-efficient building equipment, and renewable energy technologies will result in "smart" buildings with sophisticated control systems that will optimize the use of energy while providing telecommunications, information services, and entertainment.

New generations of vehicles will increase fuel economy to three or four times today's levels — and dramatically lower or eliminate air pollution emissions — by taking advantage of lighter materials; new fuels; advances in gas turbines, fuel cells, and flywheels; and sophisticated computer technology for integration and control. Information and telecommunications technology will help reduce the miles traveled per day by controlling and directing traffic to avoid congestion, allowing people to work and shop from home, decreasing business travel, and suggesting the most efficient route and transportation mode for people when they do travel.

International Socioeconomic Equity

Changes in communities and lifestyles arising from widespread use of renewable energy will be even more profound in the developing world. Two billion people today are without access to electricity and efficient cooking fuels, contributing to a lack of medical services, lack of education, hunger, thirst, and environmental degradation. Women suffer more from the current energy system than men.[100] Women and children spend long hours in energy-related activities — cooking, collecting fuelwood, carrying water, processing food — and expend more energy in work than men. Home by home and village by village, renewable energy technologies such as wind turbines, photovoltaic panels, and modular biomass gasifiers, will bring the benefits of electricity to disadvantaged people. The small, modular nature of these systems will also open up opportunities for individual entrepreneurs — including women — to manufacture, sell, and service the renewable energy systems, giving them valuable experience in business and economics. Lastly, by choosing renewable energy systems rather than centralized fossil-fuel systems, developing nations have the opportunity to avoid the environmental problems and costs that have plagued the industrialized world and take advantage of the window of economic opportunity as these technologies begin to expand rapidly throughout the world.

Environment

Energy production and use already does more environmental damage in the world than any other economic activity. Although the United States has made substantial progress in improving the environment since the mid-1970s, power plants are still responsible for 72% of all sulfur dioxide emissions and 33% of all nitrogen oxide emissions.[101] The public health implications of energy-related pollution present a serious challenge; recent studies link health problems with particulate matter, sulfur dioxide, nitrogen oxides, ozone, and carbon monoxide.[102] And, with respect to global warming, the burning of fossil fuels contributes three-fourths of the carbon dioxide emissions in the United States today. Meeting the rapidly growing demand for energy, while also maintaining a clean global environment, requires clean energy to power the economy (see Figure 8).[103] Higher oil prices and environmental and security concerns will eventually prompt the transition from oil-based fuels to renewables-based fuels and fuel cells. Restructuring, international markets, continuing technical advances, and public opinion will increase the use of renewable electric technologies, replacing coal-based, nuclear, and perhaps natural gas power plants. The advent of the substantial use of renewable energy will finally herald a time when energy production and use will no longer be so harmful to the environment.

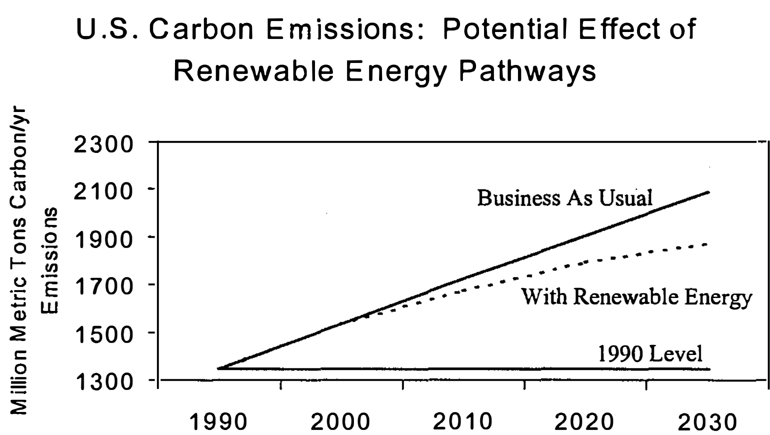

Figure 8

CONCLUSIONS

Is renewable energy ready to meet its promise? The answer is a resounding "Yes!"[104] Within the broad variety of technologies that constitute renewable energy, some are already making large inroads in the marketplace. Other technologies, perhaps those most beneficial to a sustainable future, are further from commercialization. Most, however, are progressing more quickly than ever; there are no technical stumbling blocks for renewable energy. Renewable energy *will* be a major force in America's future — the only question is when. The answer will depend only on the will of the American people for a clean environment and sustainable economy — or the next major political disruption in the Middle East.

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