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# RENEWABLE ENERGY MARKETS IN DEVELOPING COUNTRIES*

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■ **Abstract** Renewable energy is shifting from the fringe to the mainstream of sustainable development. Past donor efforts achieved modest results but often were not sustained or replicated, which leads now to greater market orientation. Markets for rural household lighting with solar home systems, biogas, and small hydro power have expanded through rural entrepreneurship, government programs, and donor assistance, serving millions of households. Applications in agriculture, small industry, and social services are emerging. Public programs resulted in 220 million improved biomass cook stoves. Three percent of power generation capacity is largely small hydro and biomass power, with rapid growth of wind power. Experience suggests the need for technical know-how transfer, new replicable business models, credit for rural households and entrepreneurs, regulatory frameworks and financing for private power developers, market facilitation organizations, donor assistance aimed at expanding sustainable markets, smarter subsidies, and greater attention to social benefits and income generation.

## CONTENTS

## INTRODUCTION

Developing countries have 80% of the world's population but consume only 30% of global commercial energy. As energy consumption rises with increases in population and living standards, awareness is growing about the environmental costs of energy and the need to expand access to energy in new ways. Increased recognition of the contribution renewable energy makes to rural development, lower health costs (linked to air pollution), energy independence, and climate change mitigation is shifting renewable energy from the fringe to the mainstream of sustainable development. Support for renewable energy has been building among those in government, multilateral organizations, industry, and nongovernmental organizations (NGOs) pursuing energy, environment, and development agendas at local, national, and global levels. At the same time, commercial markets for renewable energy are expanding, shifting investment patterns away from traditional government and international donor sources to greater reliance on private firms and banks (1–12).

Changing investment patterns make it more important to think about markets for renewable energy, rather than simply about the technologies themselves and their economic characteristics (Figure 1). Changing investment patterns also elicit increased decision-making and participation from a wider variety of stakeholders—not just traditional donor agencies and governments, but also manufacturers, rural entrepreneurs, individual households, local technicians, NGOs, community groups, utility companies, and commercial banks.

Renewable energy commonly refers to both traditional biomass (i.e., fuelwood, animal wastes, and crop residues burned in stoves) and modern technologies based on solar, wind, biomass, geothermal, and small hydropower. Our definition here, also called new renewables by many others, excludes large hydropower because it is already a mature technology and treated well elsewhere. While traditional biomass provides about 7%–11% of global primary energy supply, the modern

| Old paradigm | | New paradigm |
|---|---|---|
| Technology assessment | ➔ | Market assessment |
| Equipment supply focus | ➔ | Application, value-added, and user focus |
| Economic viability | ➔ | Policy, financing, institutional, and social needs and solutions |
| Technical demonstrations | ➔ | Demonstrations of business, financing, institutional and social models |
| Donor gifts of equipment | ➔ | Donors sharing the risks and costs of building sustainable markets |
| Programs and intentions | ➔ | Experience, results, and lessons |

**Figure 1** Renewable energy: from technologies to markets.

forms of renewable energy provide about 2% (13). For developing countries, the traditional biomass share averages 30%–45%, although some developing countries approach 90%. Besides traditional biomass, small hydropower in China and transport ethanol in Brazil are among the largest single contributors to renewable energy supplies in developing countries. In fact, modern biomass represents 20% of Brazil's primary energy supply, aided by significant increases in the past 20 years in the use of ethanol fuels for vehicles and sugarcane waste for power generation. The largest developing country—China—gets about 2% of its primary energy supply from renewable energy, mostly from small hydropower generation. Globally, contributions from wind power and solar photovoltaics (PV) are still small, but applications of these technologies are growing fast—at annual rates of 10%–30% in recent years.

Most treatments of renewables in the literature are organized by supply technology (e.g., solar, wind, biomass). A large literature looks at technology options, comparative costs, resource potentials, environmental and social benefits, research and development, commercialization, and technical performance (11, 14–21). The literature that approaches renewable energy from a market or end-use perspective is much smaller but has grown rapidly in recent years. This literature is by no means well-defined because market-oriented elements appear in a variety of sources. But a market orientation focuses on what underlies a market—social conditions, consumer knowledge, demand for products or services (driven by the benefits they confer and affected by social structures and culture), product characteristics,

**TABLE 1** Renewable energy markets in developing countries[a]

| Application | Indicators of existing installations and markets (as of 2000) |
|---|---|
| 1. Rural residential and community lighting, TV, radio, and telephony | Over 50 million households are served by small-hydro village-scale mini-grids.<br>10 million households get lighting from biogas.<br>1.1 million households have solar PV home systems or solar lanterns.<br>10,000 households are served by solar/wind/diesel hybrid mini-grids. |
| 2. Rural small industry, agriculture, and other productive uses[b] | Up to 1 million water pumps are driven by wind turbines, and over 20,000 water pumps are powered by solar PV.<br>Up to 60,000 small enterprises are powered by small-hydro village-scale mini-grids.<br>Thousands of communities receive drinking water from solar PV-powered purifiers/pumps. |
| 3. Grid-based bulk power[c] | 48,000-MW installed capacity produces 130,000 GWh/year (mostly small hydro and biomass, with some geothermal and wind).<br>More than 25 countries have regulatory frameworks for independent power producers. |
| 4. Residential/ commercial cooking and hot water | 220 million households have more-efficient biomass stoves.<br>10 million households have solar hot water systems.<br>800,000 household have solar cookers. |
| 5. Transport fuels | 14 billion liters per year ethanol vehicle fuel is produced from biomass.<br>180 million people live in countries mandating mixing of ethanol with gasoline. |

[a]Figures are authors' estimates based on tabulations of country-level statistics from sources cited in the text and other sources. Very few of these indicators are summarized well in a single source. Figures are approximate.

[b]Agriculture and productive-use applications are difficult to estimate because little published data exists.

[c]A share of stated grid-based power capacity serves small village mini-grids.

sales volume, financing and credit, manufacturing, suppliers and distributors, technical skills, service networks, business models, regulatory frameworks, and public policies.[1]

Much of the market-oriented literature tends to cover selected end-use applications, projects, or countries. A global overview has been missing. In this paper we provide an aggregate review of past market experience, existing applications, and results of policies and programs, organized by end-use application rather than by technology (Table 1). We then review the emerging lessons suggested by these experiences for six key issues ranging from rural development impacts to subsidies to enterprise development. We believe that grouping lessons by issue proves more useful than a single group of renewable energy lessons.

[1]A large gray literature on renewable energy markets exists, with much experience unreported or distributed informally. Market participants or observers, particularly those in rural areas, may not publish or may lack the means to share their experience.

## FROM DONOR AID TO SUSTAINABLE MARKETS

In the 1970s and 1980s, many development assistance agencies attempted to promote small-scale renewable-energy technologies such as biogas, cooking stoves, wind turbines, and solar heaters in developing countries. From 1980 to 2000, official development assistance for renewable energy totaled about $3 billion [estimate based on donor statistics from the Organization for Economic Co-Operation and Development, which do not separate small from large hydro; see also (29)], most of which went for geothermal, wind, and small hydro technologies. Much of this, particularly aid for rural areas, focused on technical demonstrations or on projects that were narrowly self-sustaining but could not be replicated. Many projects were considered failures because of poor technical performance, and poor suitability to user needs and local conditions (stemming from lack of involvement of relevant stakeholders). Projects often did not demonstrate institutional and commercial viability and lacked mechanisms for equipment maintenance, sustainable sources of credit and expertise, and incentive structures for sustained operating performance (22–31).

Kozloff & Shobowale (29) concluded that "between 1979 and 1991, most official development assistance for renewable energy funded fixed capital assets. Much smaller amounts were used to meet such recurrent costs as maintenance, and less than 10 percent was spent imparting the technical and managerial skills needed to build national capacity." The United Nations Development Progamme (UNDP)/World Bank Energy Sector Management Assistance Program (23) reported that a large number of the early donor programs encountered a variety of technical problems; "many programs badly underestimated problems of repair and maintenance in the mistaken belief that PV systems were virtually maintenance free and could be cared for by untrained local people." As a result, by the late 1980s, donors had become disillusioned, and aid recipients had come to view renewables as second-class technologies that industrialized countries were unwilling to adopt themselves.

In reviewing its portfolio of solar home systems in the 1980s, the German aid agency GTZ, one of the most active donor agencies promoting PV since the 1980s, said: "there has not been a single project that was designed expressly to disseminate the technology .... Rather, the bulk of activities have taken the form of pilot projects or testing and demonstration projects ... frequently characterized by the diffusion of a small number of systems ... and public-sector counterpart institutions which showed little interest in promoting a commercial dissemination process" (26).

At the same time, however, many developing countries were busy with their own renewable energy programs. Large-scale initiatives by developing-country governments included ethanol use for transport in Brazil, household biogas for lighting and cooking in China and India, grid-connected wind power in India, and small hydro power in Nepal. Some success stories, such as the market for solar home systems in Kenya, began with donor assistance in the 1980s but then graduated to private sector–led markets in the 1990s. Common to these experiences is the fit between technologies and user needs and practices. For example, Hurst (28) argues that the success of solar hot water heaters in several countries, micro-hydro in Nepal, and wind-turbine water pumps in Argentina during the 1980s occurred because relatively little change of behavior was involved. Similarly, the ethanol vehicle fuel program in Brazil was successful partly because using ethanol required little change in consumers' attitudes or behaviors (32).

Many early programs were not successful, however, often because the factors for sustainability and replication were missing. For example, a Philippine government program for biogas-powered water pumping in the 1980s saw only 1% of the gasifiers in use after some years, while 16% went unused and 80% needed repair. Some of the reasons cited: the program agency coped with pressure to meet installation targets by circumventing technical standards and guidelines; individual farmers were not accountable for loan repayments in cooperative-based loan arrangements, which led to low repayment rates and lack of funds for program replication; the need for dual fuel supplies—both diesel and biogas—was inconvenient and required changes in behavior; and inadequate training and poor maintenance practices resulted in engine failures (33).

The 1992 UN Conference on Environment and Development (the Rio Earth Summit) along with the resulting UN Framework on Climate Change breathed new political life into donor assistance for renewables (7, 10, 18, 34–37). Linked to the Earth Summit in the 1990s were new forms of multilateral assistance for renewable energy, which included about $600 million in grant assistance by the Global Environment Facility, $2 billion in loans from the Word Bank (aided by its new Asia Alternative Energy Unit), and new initiatives by the UN Development Programme. Many of these projects were designed to promote sustainable technology diffusion and markets by removing key barriers related to skills, financing, institutional and business models, and policies. Project development and implementation progress has been slow, however, and substantial field experience from most of these multilateral programs is just now emerging. Still, the agencies themselves have learned and evolved in their approaches (38–42).

In the late 1990s, private multinational corporations such as Shell and British Petroleum also began to commit hundreds of millions of dollars to renewable energy investments, some of which was to go to developing countries. Many domestic firms in developing countries also entered the renewable energy business in the 1990s. But companies found such investments to be more difficult than they imagined in developing countries, and progress in fulfilling these commitments has been slow.

Among bilateral donors, the practice of simple equipment provision continues, although some donor programs have taken more market-oriented approaches that respond to local demand and user needs, promote enterprise development for sustained service, and create financing mechanisms independent of continuing donor aid. These market-oriented approaches were being recommended again and again in the 1990s by analysts and critics of historical donor assistance programs (6, 8, 24, 29, 39, 43–45). Most recently, a task force of the G-8 group of industrialized countries recommended market-oriented approaches and advocated a goal of serving 500 million people in developing countries with renewable energy within a decade (46). A growing body of experience shows that successful approaches to promoting renewable energy should expand and sustain markets for specific applications that offer the economic and social benefits most needed.

## EXPERIENCE WITH APPLICATIONS AND MARKETS

### Rural Residential and Community Lighting, TV, Radio, and Telephony

Roughly 350–400 million households, or 40% of the population of developing countries, do not have access to electricity (3, 4, 11). The proportions of rural populations served by electric power grids range from 98% in Thailand and 85% in Mexico to only 2%–5% in much of sub-Saharan Africa. In the middle are countries such as Brazil, Bangladesh, India, Morocco, and South Africa, with 20%–30% of rural populations electrified. In China, 94% rural electrification still translates into a large number of people (75 million) without access to power (3, 27, 47–51).

Household and community demand for lighting, TV, radio, and wireless telephony in rural areas without electricity has driven markets for solar home systems, biogas-fueled lighting, small hydro mini-grids, wind or solar hybrid mini-grids, and small wind turbines.[2] These technologies are not strictly comparable with one another; however, the level of service that households receive varies considerably by technology and by the specific equipment size used. Regardless of size, surveys and anecdotal evidence suggest that rural households highly value both electric lighting and television viewing. Development professionals often refer to so-called "willingness to pay," as measured by some household surveys, as proof of this demand (3). Growing numbers of individual equipment purchases, beyond government-driven programs, also point to the market "demand pull."

SOLAR HOME SYSTEMS A solar home system consists of a photovoltaic (PV) solar panel (typically 15–75 watts), battery, charging controller, and end uses like florescent lamps. Such systems can reduce the need for candles and kerosene. Typical purchase prices range from $200–$1200. Smaller solar lanterns (typically 10–20 watts) provide lighting only. An estimated 1.1 million solar home systems and solar lanterns exist in rural areas of developing countries, and donor approaches

[2]Many households without access to electricity routinely use dry cell and car batteries for small power needs. Central solar-powered battery charging stations have been driven by donor assistance but are not widespread. Thailand has achieved some success (52).

and markets have evolved in recent years. Most installations are individual household systems, but some serve public buildings such as schools, health clinics, and community centers—with thousands of such applications in some countries (27, 39–43, 53–64). An estimated 10%–20% of household systems are no longer operational, although equipment certification and standards have improved performance (59, 63). Battery replacement and disposal are serious problems.

The largest existing markets for solar home systems are India (450,000), China (150,000), Kenya (120,000), Morocco (80,000), Mexico (80,000), and South Africa (50,000). Kenya and China are probably the fastest growing markets, with annual growth rates of 10%–20% in recent years. Other notable emerging markets include Argentina, Bangladesh, Botswana, Bolivia, Brazil, Dominican Republic, Indonesia, Namibia, Nepal, Philippines, Sri Lanka, Tunisia, and Zimbabwe. Many of the components for solar home systems—such as batteries, controllers, and lights—are manufactured in these countries. Often local systems integrators adapt and match components to suit local conditions. PV module manufacturers now exist in India (23 firms), China (7 firms), Thailand (3 firms), and Namibia (1 firm). PV cells are manufactured in India (9 firms) and China (7 firms).

India's PV market has been driven by a long-standing government program of subsidy, tax, and financial incentives that began in the 1980s. Subsidies have accompanied most solar home systems installed, while loan and financing schemes have supported further private sector sales. As market volumes increased, policies began to favor commercial, market-oriented approaches rather than technology research and demonstration. Manufacturers became more active and invested in dealer and distributor networks, service centers, and credit schemes. Simultaneously, public agencies established local service centers and solar shops to help market growth, and NGOs also became involved. More recently, both public efforts and entrepreneurs have focused more strongly on after sales service. However, the number of installations by private entrepreneurs or other community organizations on purely commercial terms (without government subsidies) is still small (47, 65).

Most of China's market has developed in recent years on commercial terms, mainly in the northwestern provinces and autonomous regions of Qinghai, Xinjiang, Tibet, Inner Mongolia, and Gansu. In these isolated regions, a fairly developed solar industry and infrastructure now exist for installation, distribution, and maintenance. For example, a thriving network of dealers line a solar street in Xining—a dense concentration of stores selling a variety of solar and end-use equipment. Nearly all sales are for cash in these well-developed commercial markets, although many households in poorer regions are only able to afford smaller 10–25 watt systems. A number of small donor programs have helped to build these markets (49, 66–69).

Like China, private dealers have provided most solar home systems in Kenya, although the market was initially seeded by donor programs in the 1980s. "Donor programs allowed PV modules and system components to become known and available in Kenya . . . and provided a basis for the development of local capacities in component assembly and in the installation, repair and maintenance of PV systems" (23). Indeed, many of those trained through donor programs went on to build the private industry that followed. This private market was also spurred by an increasing supply of domestically produced components, which lowered costs, and by the slow pace of rural electrification that increased demand for alternatives like solar home systems (51, 70–74).

South Africa is an example of a volatile market, with a high number of company start-ups and closures. Beyond government programs, private sales have been slow due to affordability constraints, a hugely successful grid extension program, and consumer expectations of universal grid access (75–78).

BIOGAS FOR HOME LIGHTING AND COOKING Biogas digesters convert animal and plant wastes into a fuel usable for lighting, heating, cooking, and electricity generation. Digesters can be household scale, or community scale shared by many households. Biogas programs have been challenging because a variety of technical options are needed. Community and political issues have also created challenges, along with the need for rural sales and service businesses and consumer credit. China, India, and Nepal have conducted the main biogas programs; all three countries now have large manufacturing industries for biogas plants.

China leads the world with 7.5 million household biogas digesters installed and another 750 large- and medium-scale industrial biogas plants. However, the number of operational biogas plants may have declined considerably in the late 1990s. China's extensive biogas programs began in the 1950s and reached peaks in both 1960 and 1979. Inadequate education and training of households led to technical failures and declining use subsequent to each new program. Since the mid-1980s, however, a network of rural biogas service centers was established to provide the infrastructure necessary to support dissemination, financing, and maintenance (79–82).

India also has had a large program, with about 3 million household plants installed. Initial efforts focused on technology development and increased user awareness. Subsequent efforts trained grassroots-level engineers in technical and managerial skills for construction of biogas plants. After five years of the program, users became more familiar with biogas, and demand and acceptance increased. Programs emphasized quality to ensure that biogas maintained a good reputation. Still, up to 30% of installed systems were reportedly no longer operational. Problems have included lack of adherence to fuel specifications, frequent change of operating personnel, unskilled operators, inadequate user training, and unrealistic user expectations that suppliers should be responsible for all problems. Rural biogas businesses and manufacturers have also lacked sufficient business skills and finance to develop products and markets (65, 83, 84).

The Nepal biogas program established over 35,000 biogas plants from 1992–1998. Investment subsidies and affordable financing made biogas plants attractive to small and lower-income farmers. A well-designed after-sales service program and joint responsibility by owners, installers, and program staff led to excellent operating performance. The program was also successful because the biogas plants were responsive to users' needs and because users rather than manufacturers received financial incentives (65, 85). In sub-Saharan Africa, most of the existing 2400 biogas units were installed through donor and demonstration projects. However, these experiences were not replicated due to inadequate feedstocks, intensive labor demand, high capital costs, poor technical performance, and lack of water (86, 87).

VILLAGE-SCALE MINI-GRIDS Village-scale mini-grids can serve tens or hundreds of households in settings where sufficient geographical density allows economical interconnections to a central power generator. Traditionally, mini-grids in remote areas and on islands have been powered by diesel generators or small hydro. Generation from solar PV, wind, or biomass, often in hybrid combinations, can replace or supplement diesel power in these grids (65, 88, 89).

Most village-scale mini-grids have developed in Asia on the basis of small hydro, particularly in China where more than 60,000 mini-grids exist, as well as Nepal, India, Vietnam, and Sri Lanka, each with 100–1000 mini-grids. In China, most mini-grids have resulted from government programs. More recently, rural entrepreneurs have built and run small hydro stations by borrowing from agricultural banks; revenue from just three years of electricity sales is apparently sufficient to repay such loans (48, 66, 90, 91). Standardization of the industry has also facilitated interconnection of multiple stations into county-level grids. In Nepal, most mini-grids have been installed and managed by rural entrepreneurs. This Nepali entrepreneurial success story of the 1980s and 1990s has been attributed to several factors, including availability of credit from a public-sector agricultural development bank, simplified licensing procedures to reduce transaction costs, unrestricted power tariffs, private financing from commercial banks, and capital cost subsidies from the government. Also, technical assistance by bilateral donors and NGOs led to technology development and manufacturing within Nepal's industrial base (92).

Very few hybrid mini-grids employing combinations of solar PV, wind, and diesel exist, perhaps on the order of 150 systems in developing countries. Such systems are still not yet economically competitive with conventional diesel power and must be financed at least partly with government or donor funds. China's roughly 80 PV/wind/diesel mini-grids (about half of which are PV-only systems), sized 10–200 kW, are installed mostly on islands along the coast and in the northern and western remote regions. In India, nine PV mini-grids (most 25 kW) and two biomass mini-grids serve 35 villages in West Bengal (48, 66, 69, 89–91).

HOUSEHOLD-SCALE WIND POWER Household-scale wind power (sized 100–5000 watts) has been piloted in a few countries, with most installations worldwide taking place in Inner Mongolia in China. Public programs were successful in disseminating more than 140,000 small wind turbines for household energy in this region. These programs were driven by local technology promotion agencies, development of local technology manufacturing, subsidies for purchase of locally manufactured wind turbines, and a government revolving credit fund offering repayment tied to the harvest season or future sales of cattle or wool. Performance of these systems has been good, except during the summer when winds drop and system output dwindles. Many households, spurred by government programs and demonstrations, are upgrading their systems with PV to complement the wind resource and provide all-season power (89, 93).

## Rural Small Industry, Agriculture, and Other Productive Uses

Although electricity provides improvements in the quality of life through lighting, entertainment, and increased conveniences, it is the productive uses of this electricity that increase incomes and provide development benefits to rural areas. As incomes increase, rural populations are better able to afford greater levels of energy service, which can allow even greater use of renewable energy. The major emerging productive uses of renewable energy are for agriculture, small industry, commercial services, and social services like drinking water, education, and health care (31, 65, 94).

AGRICULTURAL WATER PUMPING Wind-driven water pumps for irrigation and livestock historically have played a prominent role in rural areas, but these declined in the 1950s and 1960s as rural electrification and diesel-driven pumps took over (95). A resurgence of interest in wind pumps in the 1970s and 1980s did not lead to new large markets, however, with Argentina a notable exception. Between 500,000 and one million wind-powered water pumps are in use in Argentina, which follows decades of development of a local manufacturing base for small wind turbines there (13, 28). Other notable use of wind-powered water pumps is occurring in South Africa (100,000) and Namibia (30,000), with thousands more in Brazil, China, Columbia, India, Peru, and Thailand. Growing interest in solar PV powered water pumps (typical size 1 kW) has led to at least 20,000 installed, notably in India, Ethiopia, Thailand, Mali, Philippines, and Morocco (31, 51, 84, 96–98). However, many of the pumps are not operating due to poor maintenance and lack of technical information. Biogas for water pumping shows promise in dual-fuel diesel/biogas engines, but it was not adopted in India because government programs emphasized biogas for residential cooking and lighting rather than water pumping (65). The Philippine government did try a biogas power program in the 1980s, with more than 300 gasifiers installed, but the program suffered from poor sustainability (33).

SMALL INDUSTRY Mini-grid or stand-alone systems can power small industries and provide substantial local income and tens or hundreds of jobs. Indeed, communities with small industry connected to mini-grids value the grid much more highly than those with no industry. In fact, the economic viability of mini-grids often depends on the presence of industry because household lighting by itself may not provide the revenue base to pay for mini-grid investments (88). Examples of applications exist, but not systematically: On one Philippine island, a wind-solar-diesel hybrid provides 24-hour power for seaweed drying, woodworking, and sewing; in West Bengal in India, small local enterprises such as a cycle repair shop, a video cinema, and health clinics receive power from solar and biomass village-scale mini grids; in ten remote fishing villages in Indonesia, wind turbines power ice making to freeze fish, a chick hatching unit, corn grinding, and potable water supplies; in South Africa, women weave mats at night using the light from solar home systems; in Peru, carpenters and welders work off small hydro power; and in Bangladesh, a TV repair shop uses a PV-powered soldering iron (99).[3]

DRINKING WATER Use of renewable energy to provide clean drinking water is emerging as a potential major market. Applications include both mechanical pumping/filtering and ultraviolet (UV) disinfection. In areas where commercial or piped water is unavailable, villagers may walk several hours each day to obtain drinking water, or they may use hand pumps. Few examples of renewable applications yet exist. One example is in the Dominican Republic, where eight PV-powered village water systems provide daily water service to about 1000 people. The cost of this water over the system lifetime was estimated at about 1.5 cents/gallon, compared to 2.5 cents/gallon for water delivered by private truck in large drums. Users pay for water on a per-gallon basis and prefer the service to existing water supplies. Another example is in Swaziland, also based on per-liter fees and run by a village committee (51).

Other scattered examples of productive uses are emerging, albeit slowly and anecdotally. Longer retail shop hours are cited in a few countries as an income effect from solar PV; studies from Namibia and Bangladesh show solar-electrified retail stores operating for longer hours and generating higher incomes than unelectrified stores (99, 100). The organization Greenstar is developing "solar community centers" in villages with lighting, satellite links, computers, and video equipment to allow sales of local music and crafts over the internet. Other examples include paper making, building materials, wood and metal working, drip irrigation, greenhouses, electric livestock fences, sewing, distance education, and vaccine refrigeration.

## Grid-Based Power Generation

Total world electric power capacity stood at 3,400,000 MW in 2000, with about 1,500,000 MW (45%) of this in developing countries (see Table 2). Electricity consumption in developing countries continues to grow rapidly with economic growth, which raises concerns about how these countries will expand power generation in coming decades. According to some estimates, developing countries will need to more than double their current generation capacity by 2020 (101). Traditional options, such as coal and large hydro, have environmental and social repercussions that have increasingly taken on serious political and economic undertones.

[3]These and other examples can be found at http://rvsp.nrel.gov, http://solstice.crest.org, http://www.grameen-info.com/grameen/gshakti, and http://www.winrock.org.

**TABLE 2** Renewable grid-based electricity generation capacity installed as of 2000 (megawatts)[a]

| Technology | All countries | Developing countries |
|---|---|---|
| Total world electric power capacity | 3,400,000 | 1,500,000 |
| Large hydropower | 680,000 | 260,000 |
| Small hydropower[b] | 43,000 | 25,000 |
| Biomass power[c] | 32,000 | 17,000 |
| Wind power | 18,000 | 1,700 |
| Geothermal power | 8,500 | 3,900 |
| Solar thermal power | 350 | 0 |
| Solar photovoltaic power (grid) | 250 | 0 |
| Total renewable power capacity[d] | 102,000 | 48,000 |

[a]Figures are authors' estimates based on tabulations of country-level statistics from sources cited in this section, general statistics (5, 13, 50, 101, 112), and unpublished sources. Similar figures used in the G8 Renewable Energy Task Force report (46) were preliminary versions supplied by Martinot of the updated figures here.

[b]Small hydro is usually defined as 10 MW or less; the definition varies by country and sometimes extends to 30 MW.

[c]Biomass figures omit electricity from municipal solid waste and landfill gas; commonly, biomass and waste are reported together.

[d]Excludes large hydropower.

Small hydro power, biomass power, geothermal power, and wind farms are all competitive and viable technologies for grid-based power generation (5, 13, 102). Grid-connected installations can range in size from a few kilowatts to hundreds of megawatts. Given the right geographic resources and regional-specific costs of competing fuels, many of these technologies can produce electricity at costs competitive with conventional forms of electric power. If environmental externalities are factored into the market prices of competing fuels, a process which is still rare, then grid-based renewable energy becomes even more competitive.

SMALL HYDROPOWER Small hydropower harnesses small rivers and streams, typically with plants less than 10 MW size. Small hydropower has been a mainstay of rural energy development for many years in many countries. About 43,000 MW of small hydro are installed worldwide, about 60% in developing countries. China alone accounts for 21,000 MW of that capacity, driven by long-standing government rural electrification programs (13, 66, 68, 103).

BIOMASS POWER Biomass power technologies are diverse (17, 104). The most common is direct combustion of biomass feedstocks to produce power and often cogenerate heat. Others include anaerobic digestion, which produces biogas for use in engines, and gasification, which produces gas for use in combined-cycle gas turbines. In developing countries, most applications are direct combustion and biogas, although a few gasification plants in sizes up to 200 kW are operating in India, China, and Indonesia (105). Most biomass feedstocks come from agricultural and forest industry residues (i.e., pulp and paper, sugarcane, rice husks, and vegetable oils). Sugarcane waste, or "bagasse," is especially common in tropical countries. Power generation from biomass is roughly 32,000 MW worldwide, about half in developing countries. Brazil and the Philippines are the leading producers of biomass power (50, 103).

WIND POWER Wind power is generated by clusters of wind turbines, typically each 100–1500 kW in size, connected into wind farms. Wind power is now the fastest growing energy technology in the world. Total installed capacity worldwide stood at 18,000 MW in 2000, about 10% in developing countries. Global wind power capacity grew by more than 4,000 MW in the year 2000 alone. India, with 1,300 MW of installed capacity, leads the developing world. Starting with only 50 MW in 1993, India experienced a boom in wind power development during the 1990s, driven by special tax policies that allowed private power developers to recover the full investment costs of wind farms in the first year of operation (accelerated depreciation). However, these investment-based incentives have not encouraged high operating performance, and declining investment tax credits and changing utility policies moderated growth in the late 1990s. China is the second major market for wind power, with over 350 MW, mostly through a series of small projects with bilateral donor grants or concessional finance (106–110).

GEOTHERMAL POWER Geothermal power can be generated from hot water or steam captured from reservoirs below the surface of the earth. This power source is expanding in Indonesia, Philippines, Mexico, Kenya, and Central America. Global electricity generating capacity from geothermal stands at 8,500 megawatts, about 45% in developing countries (111).

Most grid-connected technologies, such as small hydro, biomass, and geothermal, are relatively straightforward and easily produced in a number of developing countries. Wind power technologies, however, are a rapidly evolving and high-technology product. Both India and China have been developing their own wind power industries. In India, over 30 domestic wind turbine manufacturers emerged in the 1990s, many of them joint ventures with foreign partners. After an industry shakeout, only 15 firms remained, but production capacity increased to 500 MW/year, or almost 15% of global production. Exports of components and whole turbines began in the 1990s as firms began to produce advanced turbine designs with variable-speed operation. The growth of the domestic industry was fueled by the government's aggressive wind power development incentives, concessional financing for wind power developers, and exemptions and concessions on import duties for wind turbine components (84, 108, 113, 114).

China has also been developing advanced wind turbine technology, both to ensure self-sufficiency and to lower costs. In the 1990s, several Chinese companies began to produce large-scale (200–300 kW) wind turbines as well, either as joint ventures or under license to foreign companies. Demand for these turbines declined, however, as imported 600 kW and larger units became more cost-effective and offered higher quality. In 1998, one Chinese firm purchased a license from a German manufacturer for an advanced 600 kW turbine design and became the first Chinese company to commercially manufacture this size turbine with mostly Chinese components. To further promote domestic manufacturing, the Chinese government has required that all new wind farms contain at least 40% local components (106, 109). China already had a thriving domestic industry of small wind turbine manufacturers as a result of market development programs in Inner Mongolia for household-scale wind power applications (93, 109, 115).

## Residential and Commercial Cooking and Hot Water

Residential and commercial cooking and hot water in rural areas of developing countries are supplied primarily by direct combustion of biomass—in the form of wood, crop wastes, dung, and charcoal. In recent decades, the alarming decline in forest resources in many countries called attention to more efficient household use of biomass, as well as solar cookers. Driven by public programs, household demand, and declining resources, markets for more efficient biomass stoves and solar cookers are found primarily in Asia and Africa, where resource constraints are greatest. In Latin America, resources are more plentiful and depletion less an issue (3, 4, 11, 104).[4]

Since 1980, many donor programs have developed and disseminated new technologies for efficient biomass cookstoves in developing countries, with close to 220 million improved biomass stoves disseminated (4, 8, 117, 118). The largest program is in China, where between 1982 and 1999, the Chinese National Improved Stoves Program disseminated 180 million improved biomass stoves (79, 82). This program established local energy offices to provide training, service, installation support, and program monitoring. It also fostered self-sustaining rural energy enterprises that manufactured, installed, and serviced the stoves. Users paid the full direct costs of the stoves (about $10), and government subsidies were limited to the indirect costs of supporting the enterprises. A parallel program in India initiated in 1983 resulted in more than 30 million improved stoves by 2000, through a centralized government program that subsidized half the cost of the stoves. Surveys suggest that only one third of the stoves in the India program are still being used. Reasons cited for the lack of sustained use were that stoves did not save energy, broke down, and were poorly constructed (4, 84).

In Africa in the 1990s, over 3 million improved biomass stoves were disseminated. Markets and technology adoption have proven easier for reducing charcoal

[4]Improved stoves and solar cookers have been fashionable strategies to address fuelwood scarcity. But they are actually coping rather than mitigation strategies. Earlier notions that household biomass use causes deforestation have been largely discredited, giving way to the realization that household biomass scarcities result from deforestation due to forest clearing for cultivation, timber sales, and commercial charcoal production (4, 11, 116).

consumption (as opposed to wood), and for urban markets to save purchased fuel (as opposed to saving collected fuel). Kenya has led this market, with close to one million improved stoves in that country alone. The Kenya ceramic jiko (KCJ) has been the most widely disseminated of all improved biomass stoves, notably with 90,000 stoves sold through private firms. The KCJ success is partly attributed to a piggyback strategy used for marketing and distributing stoves through existing sales networks. The KCJ has been replicated in Uganda, Rwanda, Tanzania, Ethiopia, Sudan, and Malawi (4, 87, 117, 119–121).

Solar cookers have also been disseminated in various countries. There were more than 800,000 solar cookers installed in developing countries in 2000, mostly in India and China. The solar box cooker has been the most effective, promoted in India through the All India Women's Conference. Cookbooks for box cookers have even been published. However, few real markets exist; most cookers have been provided free of charge or at subsidized prices through donor programs (65, 84).

Hot water for residential and commercial uses, both in rural and urban areas, can be provided cost-effectively by solar hot water heaters in many regions. An estimated 15 million domestic solar hot water collectors are installed worldwide, about two thirds of them in developing countries. China's solar hot water industry has mushroomed in the 1990s, with growth rates of 10%–20% and up to 10 million households now served with solar hot water (48, 122). (Households must be estimated from square-meter installation statistics. We used a range of 1.5–3 $m^2$/household depending on the country.) Markets with hundreds of thousands of households served include Egypt, India, and Turkey. In India, investment tax policies providing accelerated depreciation, together with low-interest loans, have stimulated a large market for commercial and public facility installations, which more than tripled from 1990 to 2000. Other emerging markets are Botswana, Kenya, Lesotho, Mauritius, Morocco, Namibia, Papua New Guinea, South Africa, Tanzania, Tunisia, and Zimbabwe (13, 28). Some markets have been driven by government requirements; for example, solar hot water heaters were required with new construction of government-owned housing in Namibia (123). Lack of consumer credit, supply and service networks, quality standards, and business finance have hindered solar hot water markets.

## Transport Fuels

Biomass-derived liquid fuels power motor vehicles in Brazil, Kenya, Malawi, and Zimbabwe. Two separate applications exist, one in which ethanol powers specially designed vehicles that run on pure ethanol and another in which ethanol is mixed with gasoline or diesel fuel to produce "gasohol" for use in ordinary vehicles. Market issues relate to ethanol production efficiency, cost competition with gasoline, the commercial viability and costs of specially designed ethanol-only vehicles, fuel distribution infrastructure, and ratios of ethanol to gasoline in gasohol blending. Global annual ethanol production from biomass is estimated at 18 billion liters, 80% of which is in Brazil (13).

The commercial viability of converting sugarcane to ethanol for motor vehicles has been demonstrated in the ProAlcool program in Brazil (13, 25, 32, 124, 125). Today, more than 60% of Brazil's sugarcane production goes to produce ethanol. Technological advances have continued to improve the economic competitiveness of ethanol and gasohol relative to conventional gasoline, although the price of oil and competitive forces in global automotive technology greatly affect ethanol's prospects.[5] In 2000, over 40% of automobile fuel consumption and 20% of total motor vehicle fuel consumption in Brazil was ethanol, displacing the equivalent of 220,000 barrels of oil per day. According to one estimate, about US$140 billion would have been added to Brazil's foreign debt if ethanol had not been used as a fuel over the past 25 years, although this significant benefit has gone largely unreported and unnoticed by policy makers (32).

Brazil's policies mandate the blending of ethanol with all gasoline sold in the country and also require that all gas stations sell pure ethanol. This last requirement made it commercially viable for the automotive industry to produce ethanol-only cars as early as 1980. In the scale-up phase of the program, the share of ethanol-only cars as a share of total car sales rose steadily from 27% in 1980 to 96% in 1985. However, by 1989 the sales share had declined to 51%, triggered by a temporary ethanol shortage. Ethanol use continued to decline in the 1990s, and by 2000 sales had declined to around 10,000 ethanol-only vehicles—compared to more than 800,000 in 1987. These declines were due in part to political uncertainties, lack of attention from policy makers, ethanol producers, and automobile manufacturers to the program, declining oil prices which made ethanol less competitive, and lack of confidence in supply. More recently, the annual decline in consumption of ethanol, as ethanol-only vehicles are retired from service and not replaced, has been balanced by significant growth in the number of vehicles using gasohol.

The ProAlcool program demonstrated cost reductions and economies of scale in ethanol production technologies, which achieved improvement in ethanol yield by factors of two or three from a given acreage of sugarcane. It also brought about policy changes in sugarcane pricing (from being based on weight to being based on sucrose, or energy, content) that changed the composition of the sugarcane crop and made ethanol production even more effective. Potential productivity improvements of 20% or more are still possible (126). Early government subsidies for ethanol production declined significantly but were not fully eliminated.

[5]Disagreement has existed about the commercial viability of ethanol fuels without subsidies, with past analyses showing higher costs for ethanol relative to gasoline (14). Significant progress in technology and management of ethanol production occurred in the late 1990s. Although oil prices declined during much of this period, ethanol production costs also declined. In many parts of Brazil, ethanol subsidies have now been entirely eliminated and some retail ethanol prices are almost half those of gasoline. Other countries are moving to ethanol vehicle fuels, including India, Japan, and Thailand. Growing interest in fuel cells could also stimulate ethanol demand.

Because some ethanol production is not competitive with gasoline at lower oil-price levels, the viability of the ethanol market continues to depend on subsidies, further efficiency improvements, and the economic value placed on externalities of fossil-fuel use. Future markets appear to favor use of gasohol rather than pure ethanol.

In Africa, ethanol is produced in Kenya, Malawi, and Zimbabwe for blending with gasoline (87). Zimbabwe is the only one of the three, however, to mandate that ethanol be blended with all gasoline sold. Due to its recent economic crisis, Zimbabwe increased the proportion of ethanol in gasohol to counter gasoline shortages. In Kenya, a gasohol plant continued to operate, but with annual financial losses due to government controlled retail prices (since liberalized), inadequate plant maintenance and operation, resistance from local subsidiaries of multinational oil companies, and unfavorable exchange rates that increased costs of servicing foreign loans (120). As in Brazil, in these countries ethanol markets have saved foreign exchange that would otherwise be needed to import gasoline.

## EMERGING LESSONS

### Impacts on Rural Development

After decades of renewable energy programs and investments in rural areas of developing countries, relatively little is known about the ability of renewables to deliver services that will raise incomes and provide other social benefits. Certainly there are social benefits from lighting, TV, and radio powered by solar home systems, mini-grids, and biogas, and even some economic benefits from reduced kerosene and candle use. Biogas for cooking and improved biomass stoves may also reduce expenditures for fuel wood, either in time or money, as well as create jobs. A clear result of the Nepal biogas program is that women spend less time and labor for fuelwood collection and cooking. In China, however, the direct financial benefits of biogas to households, beyond the social benefits of lighting, are not as clear. On balance, the literature does not offer a strong case that large rural development benefits have occurred from renewable energy (2, 31, 85, 87, 127).

Most insight on the economic benefits of rural electricity comes from literature on rural electrification through extension of central power grids. Studies clearly show the consumptive benefits and improvements in quality of life through electrification (2, 127, 128). For example, a study in Namibia indicates that electrification has improved household welfare, but almost exclusively as a consequence of electric lighting. Access to high-quality light is the major change reported, particularly the ability to study in the evenings (100, 129). But where rural electrification took place without other supporting economic infrastructure and skills, as happened in many development projects, productive economic development did not follow, acknowledged both the World Bank and the German aid agency GTZ (11, 26, 130).

The few examples mentioned earlier of rural small industry, agriculture, and other productive uses powered by renewable energy offer some promise of economic and development benefits. However, as just noted, economic benefits depend not just on the availability of energy but also on other conditions favoring small business in rural areas, such as access to markets, finance, communications, education, and health care. That is, economic benefits from rural renewable energy are more likely in areas where economic development is already taking place. Further, those who most benefit from the availability of energy are those who can afford the electrical equipment and other infrastructure needed to convert energy into useful services and productive activity (26, 127, 130).

There is little question that solar home and solar community systems provide benefits that increase household welfare and quality of life, which include improved lighting for children's education, adult study, evening cottage industry, as well as television and radio. Anecdotal evidence suggests that demand for television has been a major driver of some markets (with soccer often mentioned). Distance education via television is also cited for subjects like farming, health care, and language. But little research has measured or quantified these benefits. "So far, there is little evidence that SHS have an impact on poverty alleviation" wrote GTZ in a review of its experience (27). In fact, GTZ concluded that rural households do not buy solar home systems for reduced energy costs, but rather for improved services like longer TV viewing and better lighting quality. Other anecdotal evidence supports this view of increased services rather than decreased costs: Some households continue to use kerosene for lighting so that the electricity from solar home systems can be conserved for television viewing.

Research is emerging slowly. In Inner Mongolia, a socioeconomic assessment of small household-scale wind turbines found that households bought appliances such as refrigerators, washing machines, rice cookers, irons, and electric heaters to improve living conditions and save time, particularly for women. The study found that television and radio provide language instruction and information on commodity prices, weather, and new farming methods and practices. Electricity also increased income-generating activities, adding up to \$30–\$150/month to incomes (131). In Bangladesh, Grameen Shakti reports that community solar-powered cell phones, operated primarily by local women villagers in their homes, produce up to \$200/month in revenue for the operators. Villagers appear willing to pay per-minute connection charges for calls because of the financial benefits from learning about commodity prices, exchange rates, market trends, and from verifying cash deliveries made by relatives (64, 99).

On balance, it is not clear how welfare and quality of life benefits will drive demand for renewable energy systems beyond the wealthiest rural households. "Acquisition of SHS is often a lower priority for rural households than other basic needs and commodities; only after these other needs have been met do solar home systems become an option," which limits demand for consumer applications, wrote GTZ (27). We hypothesize that applications of renewable energy that provide income generation and social benefits, such as clean drinking water, cottage industry, distance education, and improved agricultural productivity, will appeal to increasing segments of rural populations (31).

Lessons suggested by experience are that: (*a*) Social benefits and quality of life, rather than income and economic benefits, have driven markets for renewable energy in rural areas; (*b*) experience with productive uses of renewable energy is still in its infancy and deserves much greater attention from donors, development agencies, and governments; (*c*) economic benefits from renewables are more likely in rural areas that are already undergoing development and can incorporate the additional energy dimension into existing development activities for water, health, education, agriculture, and entrepreneurship; and (*d*) published studies of income generation and economic benefits from renewable energy are still limited and call for further research.

## Affordability, Consumer Credit, and Sales Versus Rentals

In the rural energy and development literature, much has been made of affordability of rural household systems such as solar home systems, biogas digesters, and improved biomass stoves. For example, many argue that households can afford to substitute solar home systems for candles and kerosene lighting if the monthly costs for each are comparable (11, 53, 54). Based on affordability analyses, some donor programs for solar home systems began by offering large 100-watt sizes. Donors soon found these sizes too expensive for rural households and decreased sizes to 50 watts and even to 20 watts (40). This small-size approach to affordability also has occurred in the private markets in Kenya, Morocco, and China, where households often buy very small systems (i.e., 10–15 watts). In these cash markets, smaller systems may represent up to 80% of the market (27, 51). Even so, most buyers are among the wealthiest households in rural areas. Some households upgrade later to larger systems when they can afford them.

Consumer credit is another approach to affordability. Credit may be provided either by vendors themselves, by rural development banks, or by microcredit organizations (132). The Grameen Bank in Bangladesh is perhaps the best known and analyzed example of a microcredit organization, with many success stories (133). But some people question how relevant microcredit models are to consumer purchases like solar home systems. Consumer loans do not fit the traditional microcredit lending models, which tend to provide short-term (i.e., one-year) finance for income-producing activities only. "Most microfinance institutions and programs that deliver financial services to the low-income population do not fit the requirements of SHS finance," said GTZ (27). Reasons include credit size, dependence on savings (which in turn result from income generating activities), payment frequency, group-based lending, focus on women, and short lending terms (42, 64). In addition, microcredit organizations themselves need credit from banks or donors; the success of the Grameen Bank partly rests on early infusions of donor aid.

Four notable examples of consumer credit for solar home systems have emerged. In Bangladesh, Grameen Shakti, a nonprofit vendor, has offered consumer credit for terms up to 3 years with 15–25% downpayment (39, 64, 99). The Vietnam

Women's Union offered similar credit terms for systems sold by a private vendor in Vietnam (134). In Sri Lanka, Sarvodaya, a national microfinance organization, has offered 2- to 5-year credit with 20%–25% downpayment for purchases from any of three private vendors in that market (39, 43, 135). In Zimbabwe, vendors sold several thousand systems on credit provided by the Agricultural Finance Corporation.[6] The total number of systems sold for credit under these four cases is approaching 25,000, still small compared to the booming cash markets in countries such as Kenya, Morocco, and China.

In India, urban businesses were offered government incentives to provide credit to rural households for solar home systems, but the businesses proved too concerned about household creditworthiness and the transaction costs of loans and collections to act. Attention has turned to India's well-developed network of rural development banks and financing institutions, but these organizations first needed to become familiar with solar technologies, sometimes through direct demonstrations, and convinced that such loans are viable (134, 136).

The prospects for consumer credit are very specific to cultural, legal, and financial factors in each country. The Sri Lanka microcredit model appears sustainable but perhaps only because Sri Lanka has a strong and long-standing microfinance culture and set of institutions in rural areas, along with a well-developed commercial banking system. Still, banks have lent capital to only one microfinance organization, through a World Bank/Global Environment Facility (GEF) project, but have not deemed other microfinanciers creditworthy (39, 43, 57). In China, credit is an unfamiliar concept in rural areas, and the few experiments with rural credit have not yet been successful (67, 137). Credit in rural areas of Kenya is also minimal, but some solar PV purchases with credit are emerging, partly due to the interest of the Kenya Commercial Bank.

Another approach to affordability that is receiving much attention is the rental model. Typically, an energy service company supplies households with solar home systems for a flat monthly fee, which sometimes includes lights or other end uses. Under this arrangement, called "fee-for-service," the company retains ownership and provides maintenance. Monthly fees for a 50-watt system might be $15–$20 equivalent. However, rental models are employed in only three countries so far: In the Dominican Republic, the firm Soluz Dominicana has installed 2000 rental systems and is attempting to develop a viable business model (39, 58); in South Africa, Shell has installed 6000 rental systems (75, 78, 138); and a utility company in Argentina has installed 700 rental systems (39, 139). The Argentina and South Africa cases are a variation of the rental model called "concessions" (63). With a concession, the government selects one company to exclusively serve a specific geographic region, with an obligation to serve all who ask. The government also provides subsidies and regulates the fees and operations of the concession.

[6]Mulugetta et al. (62) question the effects of the credit provided in Zimbabwe. They argue some households went beyond their means in borrowing because solar home systems were perceived as a status symbol.

An ongoing debate is whether sales or rental models ultimately will prevail in rural markets. Some argue that rental models provide greater affordability to rural households because large capital purchases are not necessary. Others cite the difficulties of rental businesses, particularly the costs of monthly fee collections and the need to own large capital assets (26, 39, 63). There may be a natural progression from cash to credit/rentals in the evolution of a given market; some analyses estimate that up to 10% of rural households will pay cash and that once the cash market expands, larger but poorer segments of rural areas, perhaps up to 50%, will be able to afford credit or rentals (26, 60).

Lessons suggested by experience are that: (*a*) Historically, affordability of rural energy has been addressed through government subsidies, donor programs, and private cash sales of small systems; (*b*) new approaches to affordability are emerging, including vendor-supplied credit, microcredit, and rental models but are still largely untested; (*c*) credit risk is a serious concern of both financiers and dealers and makes credit sales challenging; (*d*) lower income rural households will need long-term credit or rental options; (*e*) even with credit or rentals, lower income groups will only benefit with targeted policies, including subsidy policies, justified by development goals.

## Equipment Subsidies and Market Distortions

Subsidies for renewable energy equipment have been driven by three interwoven factors: (*a*) donors using equipment installation as a visible and politically viable approach to development aid (particularly "tied aid" that requires the equipment to come from the donor country); (*b*) the need for subsidies to build market volume on the premise that costs will decline as volume increases, due to economies of scale and learning; and (*c*) government goals for addressing poverty and economic development in rural areas. Many expect renewable energy to compete with conventional fuels with few subsidies and also expect it to alleviate poverty—a heavy burden. Renewables must also compete against many hidden subsidies for conventional fuels—everything from subsidized kerosene and coal to government investments in power grid extensions not recovered by electricity rates. Many studies have lamented that if renewable energy received the same subsidies as fossil fuels and grid extensions, it would be more widely adopted (25, 45, 140). For example, biogas-powered water pumps for agriculture have been hindered in India due to subsidized rural electricity, free electric connections to water pumps, and subsidies for diesel fuel (65).

One important lesson emerging is that donations without any cost recovery destroy markets. Despite bad experiences with the unsustained use of donated renewable energy equipment in developing countries, donors are still undermining markets with large capital cost subsidies and donated equipment (141–143). An executive of Shell, remarking on Indonesia, noted that subsidies had left that market in disarray: "after only five years, most of the state-financed photovoltaic facilities are damaged . . . . People don't take care of things that they get for free" (144). This is symptomatic of the earliest donor projects, which simply provided equipment and left users on their own. Later came donor projects that still provided free equipment, but these also set up sustainable schemes for collecting small user fees to pay for ongoing maintenance and spare parts. However, such an approach is not replicable. Without more donor assistance, no more systems can be installed. Some donors have claimed that fees charged in some projects are set aside into long-term revolving funds to pay for future purchases, but most fees appear adequate only to pay for maintenance and component replacements (27, 63, 145).

Another problem is that these approaches can inhibit commercial markets because consumers come to expect more donor aid and will wait rather than pay market prices (142). Donor projects are still valuable—they can help familiarize governments with technologies and demonstrate market viability. But in doing so, donors need to understand existing private activities. In a recent example in Namibia, donor subsidies undermined a national program to develop the local solar home system industry, which featured a revolving low-interest consumer loan fund administered by a commercial bank. Households were unhappy about taking these loans because two neighboring villages were receiving free equipment through a donor program (146).

In China, bilateral donors have provided concessional loans for wind power projects. One example is Denmark's provision of zero-interest loans to Danish turbine manufacturers to gain access to the Chinese market. Such loans have helped the Chinese wind sector in the short run by facilitating installations. But over the long run, a commercial market is stifled because installations remain limited to those obtaining concessional finance. So far, only a handful of wind power projects have occurred on a commercial basis, despite the great interest of both domestic and foreign private developers. Continued donor-subsidized equipment has created perceptions among utilities that wind power is not commercial and requires continued donor aid. In fact, lack of commercial competition has contributed to higher wind power purchase prices, which further reinforces perceptions that wind power is too expensive (106, 109, 147).

Most recently, the use of "smart subsidies" has been advocated (141). These subsidies exist only for a limited program duration and are supposed to be self eliminating. The theory is that subsidized investments and business development eventually lower transaction and technology costs, through learning and economies of scale, to a point where subsidies become unnecessary. Smart subsidies also imply payments based on operational performance, rather than on capital investment. This was the case in the Nepal biogas program, where subsidy payments to individual projects were based on operational milestones over periods of up to three years (85). The Nepal program also set subsidies inversely related to income. Recent renewable energy projects utilizing grants from the GEF have adopted these approaches (41, 88, 139).

Lessons suggested by experience are that: (*a*) Subsidies are unlikely to lead to sustainable markets unless they explicitly create the conditions whereby they are no longer needed (i.e., smart subsidies); (*b*) subsidies can undermine private investments and business in new markets and should be applied with attention to private-sector conditions in a particular market; (*c*) subsidies can be used effectively to build up initial market volume, local expertise, user awareness, appropriate technology adaptation, quality standards, and entrepreneurial activities; (*d*) subsidies are more effective when tied to operating performance rather than investment; and (*e*) continuing subsidies may always be needed for poorer segments of the population.

## Rural Enterprise Development, Financing, and Business Viability

Rural entrepreneurship is neglected in much of the literature on rural renewable energy in developing countries. The track record of donor programs in creating and sustaining enterprises is particularly poor. No better illustration exists than Zimbabwe, where dozens of enterprises entered the market in the mid-1990s in response to a donor program but then went out of business after the program ended (51, 62). If businesses are not viable, the sustained provision of after-sales service suffers. Many households in Zimbabwe were left without local servicing once these enterprises collapsed. Similarly in South Africa, many solar home systems no longer work because maintenance service is not available, original equipment suppliers left the market, and replacement components are unavailable (75–78). "Most evaluations of solar home systems projects focus on technical performance and economics, rather than evaluating the long-term viability and sustainability of the business models and institutional dimensions," said GTZ (27).

Some have estimated that tens of thousands of rural enterprises offering renewable energy-based products and services would be required to meet the needs of hundreds of millions of households. The number of such enterprises today is in the hundreds. The challenges are large: Entrepreneurs often face high business costs in rural areas because of long travel distances, poor transport infrastructure, low literacy rates, poor communications, and a lack of trained personnel. Fortunately, promising approaches are emerging that support rural entrepreneurs with training, marketing, feasibility studies, business planning, management, financing, and connections to banks and community organizations (39, 40, 43, 55, 99, 148–150). These experiences highlight four key dimensions to rural entrepreneurship:

1. MARKETING Marketing can be challenging and expensive, especially in dispersed rural areas where literacy is low. Grameen Shakti in Bangladesh, for example, has found that the high costs of marketing and consumer education critically affect prospects for profitability (39, 99). Many are trying innovative approaches. The Vietnam Women's Union demonstrates solar home systems at health camps. Sri Lanka vendors demonstrate products at village fairs and community gatherings. Chinese vendors promote solar lighting through testimonials read on the radio (134). An Indian vendor employs local technicians for marketing because they can speak customers' local languages and best understand user concerns (151).

2. BUSINESS FINANCING The lack of rural business financing is often cited as one of the primary factors hindering the development of markets. Credit may be unavailable, too expensive, or too limited in time to be usable (75). Entrepreneurs first face one-time business development costs, such as market surveys, personnel training, establishing sales and service networks, and writing a business plan. Then they must convince a bank that the business plan is sound—difficult if bankers lack familiarity with renewable energy technology and applications. Financial intermediaries may help—if they can package smaller loans into blocks of financing from larger banks and find ways to mitigate risks.

3. BUNDLING RENEWABLE ENERGY WITH EXISTING PRODUCTS Costs may be lower if vendors of existing products and services add renewable energy to their activities—and use their existing networks of sales outlets, dealers, and service personnel. Dealers of farm machinery, fertilizers, pumps, generators, batteries, kerosene, liquid propane gas (LPG), water, electronics, telecommunications, and other rural services can bundle renewable energy with these services. Of course, dealers must still develop new technical expertise and train their staff. Kenya is an example where market growth was rapid because existing electronics and other retail businesses added solar home systems to their offerings (71).

4. RURAL ELECTRIFICATION POLICY FRAMEWORK Experience also suggests that rural electrification policies and planning have a major influence on market growth and sustainability in specific locations. Unrealistic political promises or plans for rural electric grid extension can be serious barriers to solar-home-system market expansion because households expect to be connected soon. Subsidies for kerosene also undermine markets. “Our main competition is the false promise of the grid and kerosene, not other companies,” said one supplier in Sri Lanka when asked about competition (39).

Lessons suggested by experience are that: (*a*) A few donor programs have effectively assisted rural renewable energy-based enterprises to build a sustainable and viable business; (*b*) rural energy enterprises face a high-risk, low-margin business with high transaction costs; (*c*) commercial banks and financial intermediaries are key decision makers, who must understand the technologies and manage risks; (*d*) demonstration of viable business models that eventually show sustained profits for the enterprise is key to achieving market sustainability.

## Policies and Financing for Private Power Producers

Ongoing power sector restructuring in many developing countries greatly affects the prospects for grid-connected renewable energy. Six key trends occurring are competitive wholesale power markets, self-generation by end users, smaller-scale generation technologies, privatization and/or commercialization of utilities, unbundling of generation from transmission and distribution, and competitive retail sales. With these changes, particularly as utilities become privatized and/or rely on other parties to construct generation, utilities increasingly may have little interest in renewable energy themselves (152–157).

These trends leave a growing share of the power generation field to private power developers. Of the roughly 100,000 MW of electric power capacity added worldwide in 2000, about 40% was installed by private power developers (the share is lower for developing countries). More than 25 developing countries now have regulatory frameworks that allow "independent power producers" (IPPs) to generate and sell power to utilities under "power purchase agreements" (PPAs). These include Argentina, Brazil, Chile, Columbia, Costa Rica, Dominican Republic, Guatemala, India, Indonesia, Jamaica, Kenya, Malaysia, Mauritius, Mexico, Morocco, Pakistan, Philippines, Sri Lanka, Tanzania, Thailand, Turkey, Uganda, Zambia, and Zimbabwe. Some countries, for example India and Brazil, have more sophisticated policies that further facilitate grid-connected renewable energy, such as power transmission "wheeling" (selling power to a third party via the utility's transmission lines), "banking" (generating power for later consumption), and direct power sales from producers to end users. Still, renewable energy power developers in developing countries have faced problems, particularly with financing and with regulatory frameworks that define power purchase tariffs and transmission access (158).

A number of policies to promote grid-based renewable energy have been enacted in developed countries, notably "non-fossil-fuel obligations," "electricity feed laws," and "renewable energy portfolio standards" in Europe and the United States. These policies are either "quantity-driven" (mandating a certain quantity at undetermined prices), or "price-driven" (mandating a certain price at undetermined quantity). Similar policies are being considered but have not yet been enacted in any developing countries (159, 160).

Investment and production tax credits have also been employed in developed countries. So far, India is the only developing country to follow suit. India's investment tax policies spurred the largest wind power industry among developing countries. But these investment-based incentives for wind power led to large investments without sufficient regard to long-term operating performance and maintenance. Firms received large economic gains for installation of wind farm capacity regardless of the electricity generation from that capacity. Capacity factors have been lower than for wind power installations elsewhere. Many wind turbines were reportedly not operating at all, with no efforts made by their developers to repair them. Partly based on experience in India, many now advocate that investment-based incentives should be rejected in favor of production-based incentives related to actual energy output (108, 114).

India's regulatory frameworks for independent power producers have included long-term tariffs, transmission wheeling, and power banking (107, 108). The decline in wind farm development in Tamil Nadu, which had been at the center of wind power development in India, illustrates the dependence of power developers on regulatory frameworks. In 2001, the Tamil Nadu electric utility set power purchase rates for new wind turbines substantially lower than for existing turbines, did not provide automatic annual increases in rates to adjust for inflation, and did not allow power wheeling and banking for new wind power generation. These changes by the utility may have effectively halted new wind power development in Tamil Nadu, according to an industry association there.

Besides India, several other countries have adopted electric power policies that are leading to greater renewable energy, notably China, Costa Rica, Morocco, Sri Lanka, and Thailand. Thailand approved a policy in 1992 that allows small independent power producers to supply excess power to the grid. When the initial response to that policy by private biomass power developers was small, the national utility announced a special round of biomass power contracts with subsidies, which have successfully spurred power development within the sugar industry. The Sri Lanka power market opened to third-party mini-hydro developers for the first time in 1997. New regulatory frameworks for independent power producers include standardized nonnegotiable power-purchase tariffs and contracts. These regulatory provisions, together with other incentives, spurred private small hydro developers to install 20 MW in 1997 and 1998. However, subsequent declines in power purchase tariffs, which were tied to short-run avoided costs based on the price of oil, stalled the market. Tariffs dropped from 5 cents/kWh equivalent in 1998 to just 3.5 cents in 1999, and all development essentially stopped. This fluctuation has seriously hurt the longer-term interest of private mini-hydro developers (135, 161, 162).

Brazil recently adopted several policies to promote the use of grid-connected renewable energy. Utilities are allowed to purchase renewable power at higher prices than conventional electricity, with the cost difference spread among the whole customer base [this issue—who pays the cost difference—begs resolution in many countries, e.g., a World Bank/GEF project for 200 MW of wind power in China was mostly canceled in 2000 because utility restructuring left Chinese utilities unwilling to pay the cost difference (155)]. Independent power producers may supply electricity on a competitive basis to any third party and receive open access to the transmission and distribution system based on wheeling fees. Energy resellers can intermediate between buyers and sellers. Small hydro producers receive 50% discounts on transmission wheeling fees (163).

In addition to policy frameworks, availability of financing for renewable power projects is a key aspect of market development. Commercial banks must be familiar with and confident in the technology, and they must consider power purchase contracts secure enough to guarantee that power developers maintain revenues and can repay loans. But many PPAs with utilities in developing countries cannot be "taken to the bank" because of risks that the utility will renege on the contract at some point over a typical 15–20 year contract period. Tariffs may be subject to annual or short-term adjustment, which increases revenue risk. Or the currency devaluation risk may limit foreign financing if revenue streams are in local currency but loan repayment must be in foreign currency. The availability of commercial financing for wind power in India in the 1990s, through the Indian Renewable Energy Development Agency, was one of the key factors facilitating the market expansion that took place (6, 107, 155). Another example of innovative private financing is occurring in Morocco, where a 50-MW wind farm is being financed by a consortium of foreign investors, spurred by foreign government export credits. The 19-year contract between investors and the utility is a build, transfer, operate (BTO) scheme (164).

Lessons suggested by experience are that: (*a*) Policies that promote production-based incentives rather than investment-based incentives are more likely to spur the best industry performance and sustainability; (*b*) power-sector regulatory policies for renewable energy should support IPP/PPA frameworks that provide incentives and long-term stable tariffs for private power producers; (*c*) regulators need skills to understand the complex array of policy, regulatory, technical, financing, and organizational factors that influence whether renewable energy producers are viable; (*d*) financing for renewable power projects is crucial but elusive.

## Market Facilitation Organizations

Market facilitation organizations (MFOs) are public-private entities that support the growth of particular markets through a variety of means. MFOs may provide networking, partner matching, information dissemination, market research, user education, business-deal identification and facilitation, technical assistance, consulting services, financing, and policy advocacy or advice. Common and historical forms of MFOs are industry associations and government agencies. The highest level government agency serving in this capacity is the Ministry of Non-Conventional Energy Sources (MNES) of India, which has undertaken many market facilitation programs, in partnership with the India Renewable Energy Development Agency (114).

In the past decade, a new generation of MFOs has emerged to support renewable energy markets in developing countries—supported by both international donors and domestic sources. These new MFOs operate with a business interest in the industry but also with a public interest in seeing the technology widespread for a variety of public benefits. As a result, MFOs, even if initially supported entirely from public funds, usually end up obtaining a share of their funds from private sources in exchange for services. MFOs are usually unable to operate entirely on private revenues, however, because much of the public-interest aspects of their work cannot be billed to private clients. MFOs may be nonprofit and nongovernmental—but their purpose is different than traditional NGOs, which have historically focused on public policy advocacy. Experience shows that some traditional NGOs have operated successfully as MFOs by adopting a greater private-sector orientation.

Much of the success of China's dissemination of household-scale renewable energy technologies comes from organizational infrastructure and capacity in rural areas, including MFOs. The Ministry of Agriculture has established rural energy offices at county, district, and township levels that provide a variety of services, which include information, subsidies, and technical support. Biogas and small windpower "service stations" in China have also served as MFOs. These stations are responsible for profit and loss as any commercial business but are public agencies. In 1990, there were more than 700 such service stations in China, employing roughly 10,000 people. These service centers build digesters, provide training, sell materials, and offer management and technical consulting. In addition, some 40,000 "biogas doctors" have been trained and certified to manage thousands of biogas digester construction, operation, and maintenance teams at the village level (48, 81, 89, 93).

NGOs have often served as MFOs for renewable energy, frequently with a development motivation. Micro-hydro power is a good case in point. After looking at micro-hydro project cases in Sri Lanka, Nepal, Peru, Zimbabwe, and Mozambique, Khennas & Barnett (88) concluded that intermediation and related transaction costs were high relative to project costs, in part due to remote locations and low installation densities. Because commercial banks were unwilling to pay these transaction costs, NGOs led most of the micro-hydro programs, driven by a commitment to marginalized people. In India, the success of rural biogas and improved wood stove programs can be linked to market facilitation efforts by the All India Women's Conference (114).

More recently, private power developers have also served as MFOs, using both private and public funds. In looking at small hydro development, Khennas & Barnett (88) conclude that project developers "perform a crucial role in undertaking the various forms of intermediation. The availability, skills, and other capacities of project developers probably sets a limit on the extent to which micro hydro programs can expand in any country . . . . The extent of project developers is largely a function of whether there is enough work for them . . . and how their costs can be met, either as fee-for-service from plant owners or from specific allocations of 'soft' [public] money."

Other organizational forms can serve as MFOs. For example, the network of renewable energy project support offices (REPSOs) funded through Winrock International have established MFO-like entities in Brazil, Guatemala, India, Indonesia, and the Philippines. These offices facilitate project development, information exchange, partner matching, expertise among local firms, market and technology assessments, policy development, and technical innovation. As another example, five Asian countries have formed the Council on Renewable Energy in the Mekong region (CORE), a network of government agencies, NGOs, research institutions, and private sector companies that exchange information and implement joint projects. And in China, a new breed of renewable energy industry association has formed to facilitate expanded markets, improved capabilities of local firms, financing, and partner matching (48, 165).

Lessons suggested by experience are that: (*a*) MFOs can be powerful market stimulants but very few exist; (*b*) public-private MFOs most likely need full public funding to begin but eventually can become partly self-supporting through private contracts; (*c*) very few people are thinking about the power of MFOs to stimulate renewable energy market development.

## CONCLUSIONS

Based on our examination of renewable energy markets, along with expected future cost reductions, and the shift of renewable energy from the fringe to the mainstream of sustainable development, which was noted in the introduction, we conclude that several markets described below show promise of greatly expanding.

RURAL RESIDENTIAL LIGHTING Some national programs are poised to greatly expand solar home systems and solar lantern markets. India and China have proposed over 10 million additional systems in the next 10 years (66, 166). New business/policy models for regulated rural energy concessions employing solar home systems are emerging in several countries, including South Africa, where concessions would install 300,000 systems, and Argentina, with plans for 60,000 new systems (75, 139). Approved projects by the GEF could result in another 600,000 systems once completed (39).

GRID-BASED POWER PRODUCTION A few countries such as India and China are developing policies for mandated shares of renewable energy in power generation. India has proposed that 10% of new capacity additions through 2012 come from renewable energy, which would mean an additional 10,000 MW. China's latest five-year plan calls for a fivefold increase in wind power to 1500 MW by 2005. The plan also proposes to require 5% of new power generation from renewables, which could mean an added 20,000 MW by 2010 (66). However, such policies must overcome political and institutional hurdles, fit into utility-sector restructuring, and resolve who will pay for any extra costs of renewables in the shorter term until costs decline. In the longer term, renewables may integrate with "distributed generation" markets that include microturbines and fuel cells, while new technologies like biomass gasification and solar thermal power may become commercially viable (20, 167–171).[7]

[7]Four solar thermal power projects proposed in Egypt, India, Mexico, and Morocco, and a biomass gasification project in Brazil, all supported by the GEF, are designed to move technologies toward commercial viability through design research, business consortia, performance experience, and cost benchmarks (155). These first-of-a-kind projects in developing countries have generated new interest in these technologies. Supportive policies and cooperation among businesses, donors, and governments are needed to further stimulate investments (171).

PRODUCTIVE AND COMMUNITY APPLICATIONS Applications for income generation and social benefits are growing markedly but remain underreported. India now has 40,000 solar street lights, which are also appearing in Brazil, Indonesia, and the Philippines. Solar PV appears poised to increasingly pump, purify, and distribute drinking water in isolated villages. Community-based cell phones, satellite phones, and internet connections for distance education appear set to accelerate; Mexico, Bangladesh, and South Africa are notable examples, with some 12,000 PV-powered rural telephones in Mexico, 4,000 in Bangladesh, and 1,500 in South Africa (63). Small biogas plants and wind/PV/diesel hybrid systems powering village-scale mini-grids could aid an upsurge in rural small industry and service jobs.

The growth of these markets and others will require increased technical know-how in developing countries—including local capabilities to adapt, install, operate, and maintain technologies and to build local manufacturing industries. Large renewable energy industries exist in some countries already, notably Argentina, Botswana, Brazil, China, India, Nepal, South Africa, and Thailand. Despite the rhetoric about public technology transfer, commercially oriented technical know-how transfer takes place primarily between private entities through licensing, production agreements, joint ventures, or subsidiaries—each with well documented costs and constraints (6, 172). Public policies must facilitate technical know-how transfer while guarding against "technological imperialism"—a term used to question the effects of local industry being pushed aside by foreign firms (173). Some stress the need for "national systems of innovation"—interwoven networks of firms and public institutions (6, 174).

New sustainable and replicable business models for both consumptive and productive uses of renewable energy in rural areas will also be needed. In addition to new solar home systems business models, other models that promote long-term economic and social benefits show great promise, such as building mini-grids around income-generating microenterprise and incorporating renewable energy into water, agriculture, education, and telecommunications. Insights into successful approaches and models are still far from adequate. "The history of alternative energy research, development and dissemination reads as a litany of models of the dissemination of new technologies . . . . The great majority of these efforts, however, have yielded very little insight into how to foster a truly different energy future," lamented Acker & Kammen (70). Small entrepreneurs and larger firms are starting to blaze new trails and should be encouraged to take new risks and create new renewable-energy–based businesses.

Even though many donor efforts have not been sustainable or replicable, donor assistance for renewables is still vital for improving environmental conditions and incomes. However, donor projects must avoid an equipment demonstration mentality where the main objective is installation and maintenance of a certain number of systems. By project completion, the amount of hardware installed is much less significant than whether the business, delivery, and credit models are viable, sustainable, and being replicated, which requires donors to rethink traditional development assistance patterns (39).

One must not forget that many renewable energy efforts are directed at improving energy for the poor. Most renewable energy markets first succeed because the richer segments of society are able to afford the benefits or have the means to generate income from increased access to energy. Thus some argue that purely market orientations are going to leave behind large segments of the poor—over one billion people still subsist on less than $1 per day (12). Effective policy approaches for reaching the poorest may combine private sector involvement with targeted public subsidies linked to development goals and strategies for increasing incomes. Such policies must not lose sight of the real goal—meeting the basic needs of the poor—and must weigh the cost and benefits of renewables against all options for water, agriculture, health, education, transport, and small business development. For this reason, energy authorities are less relevant to good policy—which is properly the domain of authorities in these other sectors.

Governments need to foster the appropriate conditions for viable rural entrepreneurship and grid-based power investments that incorporate renewable energy. Commercial banks, multilateral organizations, and other public lenders need to provide business finance to entrepreneurs, credit to consumers, and project finance to grid-based power developers. National governments and international donors should support the creation and strengthening of innovative market facilitation organizations (MFOs). Finally, further research is needed on successful experiences and business models, social benefits and income generation, technology applications that meet user needs, and sectoral policy lessons from emerging policy successes and failures—grounded in the specific culture, politics, institutions, and history of each country.

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