CHAPTER 9
RENEWABLE ENERGY SUPPLY

9.1 INTRODUCTION

Renewable energy can be defined initially as any energy source that is derived directly or indirectly from solar energy. In the broadest sense, however, almost all of the energy we use today, including fossil fuels, can be considered a form of solar energy. The most familiar forms of energy, such as wood, oil, gas, and coal, are embodied forms of solar energy gathered, stored, and transformed by natural processes.

Climate change due to emissions of GHGs, particularly CO_2, becomes an issue when stored solar energy is converted to useable forms of energy (heat, electricity, fuels, chemicals) at a rate far exceeding the rate of formation. For coal, oil, and natural gas, the ratio of time between formation and use is on the order of 1 million to one: that is, the world uses in one year what took natural processes one million years to create. Only biomass among these stored forms has a time ratio that is within a human time frame of years or decades. Renewable energy can now be defined as forms of solar energy that are available and replenished in time scales no longer than human lifetimes.

Given this definition of renewable energy, it becomes clearer why renewable energy is an important option for mitigating climate change. Because renewable energy creates little if any net greenhouse gas emissions, its use will not disrupt the radiative energy balance of the earth's atmosphere and will permit sustainable, long-term mitigation of climate change. The renewable energy option will allow climate change mitigation, energy use, and economic development to proceed in synergy rather than in opposition.

The remainder of this chapter will discuss what information, data, and analytic tools are needed to identify, screen, and characterize renewable energy options. The information and data needed include:

- economic and social development goals and needs
- energy end uses and tasks to be performed
- characteristics of energy needs
  - scale (total requirements, grid/off-grid, centralized/distributed, etc.)
  - timing of energy needs (duration, seasonality, diurnal, etc.)
- available energy resources
- technology characterization

Once energy needs are defined within the larger context of economic and social development needs and plans, renewable energy resources and technologies can be identified and evaluated for incorporation into this larger context. The analytical tools needed include systematic methods to inventory renewable energy resources and to evaluate the most appropriate applications of these resources.

This chapter presents an overview of renewable energy options and discusses resource assessment and characterization of renewable energy technologies. Methods for analyzing renewable energy options within an integrated framework are discussed in Chapter 3. Policy options for encouraging adoption of renewable energy technologies are briefly described at the end of this chapter.

9.2 MITIGATION TECHNOLOGY OPTIONS

Renewable energy supplies encompass a broad range of resources, and numerous technologies can be used to tap those resources. Table 9-1 lists the major technologies and the following discussion briefly describes each technology and its applications. Although many of these technologies are still under development, most have entered commercial markets around the world at some level. Some, such as hydropower and biomass technologies, have achieved sizeable market penetration, while others (e.g.,

Table 9-1. Renewable Energy Technologies

RESOURCE	TECHNOLOGY	END-USE APPLICATION			
		Electricity[a]	Industry	Buildings	Transport
Solar	Photovoltaics - Flat Plate	✓			
	Photovoltaics - Concentrator	✓			
	Solar Thermal Parabolic Trough	✓	✓		
	Solar Thermal Dish/Stirling	✓			
	Solar Thermal Central Receiver	✓	✓		
	Solar Ponds	✓	✓	✓	
	Passive Heating			✓	
	Active Heating			✓	
	Daylighting			✓	
Wind	Horizontal Axis Turbine	✓			
	Vertical Axis Turbine	✓			
Biomass	Direct Combustion	✓	✓	✓	
	Gasification/Pyrolysis	✓	✓		✓
	Anaerobic Digestion	✓	✓	✓	
	Fermentation				✓
Geothermal	Dry Steam	✓			
	Flash Steam	✓			
	Binary Cycle	✓			
	Heat Pump			✓	
	Direct Use		✓	✓	
Hydropower	Conventional	✓			
	Pumped Storage	✓			
	Micro-hydro	✓			
Ocean	Tidal Energy	✓			
	Thermal Energy Conversion				

[a] Electricity generated by any of these methods can be used in the remaining end-use applications either to meet power demands directly (e.g., industrial electricity inputs, buildings lighting demand, or electric vehicles) or as an input to end-use fuel production (e.g., hydrogen produced via electrolysis).

photovoltaics) are used in important but relatively limited applications today. Research and development activities continue to improve all of these systems to enhance their ability to meet future energy requirements, and new systems that are still in the early stages of development may provide additional opportunities.

9.2.1 Solar Energy

Solar technologies use the sun's energy directly to generate energy for industrial processes, buildings, and transportation as well as electricity for general consumption in all three of these end-use sectors. Given the large size of the solar resource, these technologies are not constrained by feedstock requirements but rather by costs and "institutional" obstacles such as performance (e.g., intermittent operation), perceived risks, and siting issues.

- **Photovoltaics**

  Photovoltaic (PV) devices convert the energy contained in sunlight directly into electricity-using modules composed of multiple PV cells. Two broad categories of PV devices exist: flat-plate and concentrating. Concentrator systems uses lenses to focus radiation onto just a few, highly efficient PV cells and only use direct beam sunlight, while flat-plates utilize the whole of the incident solar radiation, including diffuse (scattered) and direct insolation.

  Today's annual PV market is only about 50 MW worldwide, but market growth during the last few years has been 25% per year. PV systems are currently cost-effective in some consumer products (e.g., watches and calculators) and distributed and remote power generation (e.g., village power). For example, over 2000 small residential PV systems have been installed in the Dominican Republic under a unique revolving credit system that permits rural clients to borrow funds to purchase these systems and pay the loans back as they save money from avoided kerosene purchases. Similarly, 15,000-20,000 systems have been installed in Mexico under the government's rural development program. As costs continue to decline in the next 5-15 years, opportunities for PV systems will expand, allowing them to compete with large-scale conventional power generation in the next century.

- **Solar Thermal - Electric**

  Solar thermal technologies collect the sun's radiant energy to create a high-temperature heat source that can be converted into electricity via a number of thermodynamic conversion cycles. Parabolic trough technologies employ a field of parabolically-shaped solar collectors that focus the sun's energy onto specially-coated metal pipes surrounded by glass tubes containing a heat transfer fluid (such as synthetic oil). Parabolic dish systems use a modular mirror system that approximates a parabola and creates a high energy flux at the focal point where an external combustion Stirling engine converts the heat into electricity. Central receivers use a large field of sun-tracking mirrors (heliostats) that reflect the incident radiation onto a tower-mounted thermal receiver. Finally, solar pond systems collect and store solar energy in a liquid medium (usually a large basin of water with a salt gradient to suppress heat loss), which can then be converted to electricity using a closed Rankine Cycle engine.

  Solar thermal technologies are currently in the development/demonstration phase, with projects designed to prove the reliability and operation of such facilities in numerous locations worldwide. Many systems employ thermal storage devices or energy backup (so-called "hybrid" systems) to overcome issues associated with the intermittent nature of the solar resource (e.g., power generation during cloudy weather). Likely applications for these technologies will be village power (especially the parabolic dish/Stirling systems) and centralized electricity generation in the late 1990s and early 21st century.

- **Solar Thermal - Industrial Process Heat**

  Solar thermal technologies for industrial process heat (IPH) utilize technologies and principles similar to solar thermal electric technologies in generating a high- or medium-temperature heat source. The heat generated from these systems can then be used to supply energy for general industrial processing needs or for specialty processes, such as the detoxification of hazardous wastes.

  Development and deployment opportunities for these technologies are closely tied to those for solar thermal electric systems since they employ similar thermodynamic and physical principles.

- **Solar Building Technologies**

  Solar building technologies include active and passive heating and cooling systems, as well as daylighting. Today, there are more than two million solar water heaters installed in Japan and 600,000 in Israel; significant numbers are also found in many other countries, notably the United States, Kenya, China, Turkey, and Papua New Guinea. Active heating systems provide hot water and space heating for residential or commercial buildings utilizing a collector that receives or absorbs the incident solar energy and transfers it to a working fluid (water, oil, or air) for direct use or storage. Active solar cooling technologies include solar desiccant systems that use a drying agent to adsorb water vapor in building circulation air; solar heat is then used to dry or regenerate the desiccant for re-use. Another cooling technology, the solar absorption system, is based on traditional refrigeration technologies but uses solar heat to provide much of the energy, although some mechanical assistance is typically required.

  Passive heating and cooling systems use little or no mechanical assistance, relying rather on the design of the building to achieve specific thermal requirement goals. Passive space heating uses natural heat transfer processes to collect, store, and distribute heat. Techniques in practice today include direct gain systems (e.g., south-facing windows), thermal storage walls, attached sunspaces (e.g., greenhouses), roof storage using water that collects heat and is distributed via convection, and convective loops based on a thermosiphon principle common in solar hot water heaters but using air as the working fluid.

  Conventional passive cooling techniques maximize natural ventilation, incorporate well-insulated and low-emissivity building materials, and utilize advantageous landscaping methods (e.g., shade tree planting). More advanced practices involve earth cooling tubes that use lower underground soil temperature to cool incoming air, evaporative cooling using water, and ice ponds (in which ice from the winter months is used to cool circulating air as it melts).

  Finally, daylighting simply involves the effective use of natural light to provide illumination. This is primarily achieved through building design although advanced optical switching materials and low-emissivity coatings for windows can further the effective use of daylighting.

9.2.2 Wind Energy

Wind technologies convert the energy of moving air masses at the earth's surface to rotating shaft power that can be directly used for mechanical energy needs (e.g., milling or water pumping) or converted to electric power in a generator. Two major types of turbines exist and are defined based on the axis of blade rotation: horizontal-axis (which currently dominate commercial markets) and vertical-axis turbines.

Wind energy has proven the most cost-competitive renewable electricity technology for the bulk power market to date; however, its use is also very well-suited to remote and distributed applications. Hybrid applications, in which a wind turbine is coupled with another renewable energy source (e.g., PV) and/or a conventional back-up unit (e.g., diesel generator), are attracting much interest in the remote power market. For example, the fishing village of Xcalac in Mexico uses a hybrid system composed of six 10 kW wind turbines, an 11.2 kW PV array, and a diesel backup generator to provide 100% of its power.

As of 1994, there were over 1700 MW of installed wind turbines in the world, the majority of which are located in California in the U.S. Most of these are in the 50-150 kW size range and are providing power to the electric utilities in that state. Newer turbines being installed today for bulk power are closer to the 150-300 kW range, and systems in the future are expected to be much larger, reaching sizes over 500 kW.

9.2.3 Biomass Energy

Biomass energy is a term that includes all energy materials derived from biological sources, including wood wastes, agricultural residues, food industry wastes, sewage, municipal solid waste (MSW), and dedicated herbaceous or woody energy crops. The potential size of the biomass resource is quite large on a global scale, and the ability to utilize existing residue streams that may provide low-cost feedstocks offers attractive near-term opportunities for biomass use. In the longer term, the development of sustainable, dedicated biomass energy plantations may further expand the resource base and help reduce the costs of energy produced from biomass.

- **Biomass Electric Technologies**

  Cogeneration of biomass in the industrial sector provides the largest share of biomass-derived electricity today. Low-cost feedstocks are often critical to the economic viability of biomass energy use in these markets, and thus waste materials such as agricultural and forest products residues, food processing wastes, and MSW can be attractive feedstocks for direct combustion in boiler systems. Dedicated electricity generation also benefits from the use of waste materials although the development of dedicated biomass energy crops may provide low-cost feedstocks in the long term while simultaneously extending the resource base.

  The energy, environmental, and economic performance of biomass electric technologies can also be enhanced by moving to advanced conversion technologies, such as gasification/gas turbine technologies. Gasifiers convert biomass to a synthetic gasoline (syngas) containing chiefly CO and hydrogen, which can then be combusted in an aeroderivative gas turbine. The theoretical efficiency of such a process is much higher than that of the conventional direct combustion/steam turbine process, thereby reducing feedstock requirements and enhancing the economics of power generation.

Biomass energy systems are emerging as an economically viable option for satisfying power needs in both industrialized and developing countries (on-grid and off-grid). Where the resource conditions are favorable, power systems based on feedstocks grown on short-rotation forestry (SRF) plantations can produce electricity at costs that are comparable with conventional fossil-based alternatives (see Carpentieri *et al.*, 1993; Russell *et al.*, 1992; and Perlack *et al.*, 1991). Potential SRF biomass-to-electricity projects include:

- the conversion of agricultural processing facilities (e.g., sugar mills, rice mills, sawmills) to cogenerate heat and power for on-site processing needs and export of excess power to the local distribution grid using a combination of mill wastes and plantation grown biomass;

- the conversion of fossil-fired electric generation facilities to burn or co-fire plantation-grown biomass; and

- and the development of stand-alone biomass-based power generation relying exclusively on SRF plantation-grown feedstocks.

The interest in biomass-to-electricity projects comes not only from its potential as a low-cost supply of power but for its potential to mitigate a host of environmental concerns such as reducing the rate of CO_2 buildup in the atmosphere by sequestering carbon, by substituting for fossil fuels, and by replacing wood use from existing forests. When SRF feedstocks are grown renewably, biomass contributes no net buildup of atmospheric carbon because the carbon released during burning is extracted from the atmosphere during photosynthesis.

Direct combustion technologies can continue to improve and expand their market share in industrial cogeneration and utility markets, and the advanced power cycles discussed above are likely to move out of the demonstration phase and into commercial operation near the turn of the century.

- **Biomass Heating Technologies**

The most common use of biomass is direct combustion for residential space heating and cooking and for industrial process heating. In the residential sector, improved wood cooking and heating stoves can offer advantages in terms of reduced fuel requirements (thus, lower costs or less time spent collecting biomass) and improved emissions characteristics. In industrial processes (e.g., the sugar cane industry or pulp and paper industry), biomass wastes can be used more effectively by increasing boiler efficiencies and enhancing residue collection activities.

- **Biomass Transportation Fuels**

Fuels produced from biomass feedstocks for transportation applications include ethanol, methanol, and their ethers, ETBE and MTBE, as well as hydrogen, syngas, biodiesel, and jet fuels. Ethanol is produced from sugar (e.g., sugar cane), starch (e.g., corn), or cellulosic feedstocks (wood, herbaceous material, and MSW). The conversion process involves the biochemical conversion of the feedstock into its constituent glucose chains, which are then fermented to produce alcohol.

Methanol is produced from biomass by first gasifying the feedstock to form a syngas, a subsequent gas-shift reaction to adjust the chemical composition of the gas, cleaning, and finally the conversion to methanol in the presence of a catalyst. Hydrogen can also be manufactured via the gasification of biomass followed by gas-shift reactions and separation of the hydrogen component of the syngas.

Synthetic hydrocarbon fuels (gasoline, diesel, and jet fuel) can be created from biomass by pyrolizing the feedstock to form an intermediate biocrude liquid product and then catalytically converting the biocrude to a traditional hydrocarbon fuel formulation. Alternative methods convert the oils extracted from certain plant seeds to diesel fuel by isolating the hydrocarbon portion of the carbon chain.

Currently, ethanol is the only biofuel that has achieved noticeable market success, particularly in Brazil and, to an extent, in the U.S. The advanced technologies associated with producing ethanol from low-cost feedstocks (i.e., lignocellulosic biomass) may help enlarge the ethanol market after the turn of the century. Similarly, biomass-methanol production technologies might be commercially available in the first decade of the 21st century, particularly if gasification technologies continue to advance in the electric power sector. Finally, current research experience indicates that cost-effective hydrogen and synfuel production might also reach commercial levels sometime in the first decade of the 21st century.

- **Biomass Energy Systems: General Considerations**

In addition to the direct power and environmental benefits, biomass energy systems offer numerous other potential benefits, especially for developing countries. Some of these benefits include off-season employment of underutilized labor (tree planting and maintenance, use of tree co- and by-products); increased agricultural productivity through soil stabilization, reduced water runoff, and improved microclimates; and increased opportunities for industrial development through the availability of peak (wet season) and base load (dry season) power. In power deficit areas, the availability of power can encourage the development of small-scale industries and rural commerce, increase the productivity of agriculture through irrigation and post-harvest processing, make modern conveniences (e.g., lighting and potable water pumping) available to many more rural residents, and promote general well-being.

What separates the evaluation and implementation of biomass energy projects apart from other renewable and conventional energy systems is that resource or feedstock management is an integral part of a total energy, environmental, and economic system. Moreover, the complexity of the evaluation and possible implementation is further compounded by a high dependency of the biomass energy system on adaptation to local environmental, economic, social, and institutional considerations. Evaluation of this option must address a complex array of issues: competitiveness with other sources of energy supply, costs, emissions, financing, energy regulatory policies, food and fiber production, employment and impacts on agriculture, biodiversity and habitat, land ownership and tenure, flood and erosion control, pollution remediation, plantation sustainability, and logistics of resource supply and distribution.

9.2.4 Geothermal Energy

Geothermal energy systems tap the heat originating from the earth's molten interior and the decay of radioactive materials in the crust. The potential size of the resource is very large although conversion technologies for fully accessing the estimated 100 million quads of available worldwide resource are yet to be proven. Geothermal energy is currently being used in various locations around the world to produce electricity at costs competitive with conventional sources and provide energy directly for space heating, food and industrial processing, refrigeration, and aquaculture.

- **Geothermal Electric Technologies**

  Hydrothermal resources, consisting of water and/or steam trapped in fractured or porous rocks, are currently the only type of geothermal energy being accessed on a commercial scale. Electricity is produced via one of three major routes: dry steam, flash steam, and binary conversion. Dry steam systems use the geothermal steam directly to drive a turbine-generator while flash steam technologies first convert hot geothermal liquids to steam by quickly reducing its pressure. Finally, binary cycle systems are used for generating power from lower-temperature liquids by using the hot geothermal waters to vaporize a secondary working fluid which then drives a turbine-generator unit.

  The state of California in the U.S. currently receives 6% of its electricity from geothermal energy, and installed units exist in the Philippines, Mexico, Italy, Japan, New Zealand, and other countries. Advances in methods for locating, drilling, and extracting geothermal energy coupled with improvements in conversion technologies can help geothermal electricity expand its current market share further, effectively competing with fossil-powered sources in the baseload power market.

- **Geothermal Heating Technologies**

  In some regions of the world, low-temperature geothermal energy is being used directly for space heating, such as in several cities in Iceland where steam/hot water lines carry geothermal fluid through the district heating system. Another promising technology is the geothermal heat pump (GHP). GHPs operate like a conventional heat pump (a refrigerator, for example, is a one-way heat pump) and use the heat gradient between the earth's surface and groundwater or soil several hundred feet below the surface to power the pump. Because GHPs are reversible, they can provide space heating in the winter and space cooling in the summer as well as supplement domestic hot water needs year-round. More than 100,000 of these systems have been installed in the U.S. to date and sales continue to grow at significant rates.

9.2.5 Hydropower

Hydropower facilities exploit the kinetic energy in flowing or falling water to generate electricity. Conventional hydropower facilities use water from a river, stream, canal, or reservoir to continually produce electrical energy, and water releases from single-purpose reservoirs (i.e., dedicated to power production) can be quickly adjusted to match electricity loads. Multipurpose reservoirs are not capable of following load as closely; however, they can be simultaneously used for irrigation, flood control, navigation, recreation, and water supply.

Pumped storage plants operate similarly, but instead of tapping free-flowing water, the facility uses recycled water. During off-peak hours, water is pumped to an upper reservoir using low-cost resources, where it can be re-used to provide peak power on demand. Pumped hydropower facilities are net energy consumers (typically 1.25-1.40 kWh is required to pump the water to the upper reservoir for each kWh generated); however, they provide significant economic and operational benefits to utilities because of their ability to meet transient peak power demands.

Finally, mini-hydro facilities (30 MW or less in size) offer opportunities for distributed or remote power generation with minor environmental impacts, low operating costs, and high reliability. Installation of these systems is usually quite rapid and can use local labor.

Hydropower technology is currently mature and widely available. Almost 15% of the world's electrical energy comes from hydroelectric facilities operating in over 80 countries (Moreira and Poole 1993). Only a fraction of the available resource has been exploited to date, in large part because of siting constraints, environmental pressures against large-scale systems, and competition with other interests for water resource use. The increased development and use of micro-hydro technologies may permit additional resources to be accessed without encountering the barriers that have traditionally constrained conventional hydropower development. In Nepal, for example, the Agricultural Development Bank has financed the purchase of more than 650 small hydro systems by farmers, who use income from milling operations and electricity sales to pay back the loans.

9.2.6 Ocean Energy

Numerous systems have been conceived of for capturing the energy of the ocean's waves, tides, and temperature gradients. Of these, ocean thermal energy conversion (OTEC) and tidal power systems have received the greatest attention to date. OTEC uses the temperature difference between the surface of the ocean and depths of up to 1000 meters to generate electricity in either a closed-loop (using a secondary working fluid) or open-loop cycle (using seawater as the working fluid).

Tidal power uses the same principle employed in hydroelectric power generation to extract energy from a difference in hydrostatic head created by the rising and falling tides. A minimum difference of 5 meters between low and high tides is often cited as the limit required to effectively produce electricity, although developments in micro-hydro technology may permit additional resources with lower ranges to be accessed.

OTEC and tidal power are still primarily in the development stage, and technical, cost, and siting constraints continue to limit the progress of these systems.

9.2.7 Screening Mitigation Options

The first step in screening renewable energy options for further analysis is to conduct a preliminary resource assessment. For many countries, such an assessment may have already been conducted with sufficient accuracy to allow a screening out of those options that are unlikely to be of interest because adequate resources are lacking, or are too small to make a significant national contribution. Alternately, the study team can conduct its own preliminary assessment, drawing on appropriate experts in the country. For assessment of biomass resources, the energy sector analyst should work together with the forestry and agricultural analysts.

For those technologies for which exploitable resources appear to be available, a screening should be conducted using the criteria listed in Table 2-1 in Chapter 2. It is particularly important to consider the potential for indirect economic benefits such as local employment creation and foreign exchange savings.

9.3 RESOURCE ASSESSMENT[1]

Use of renewable energy requires careful matching of conversion technology to resource availability and to energy demand. Although it is usually obvious to the inhabitants of an area that one form of renewable energy is more plentiful than another, it is important to conduct an inventory of renewable energy resources before selecting technologies that may be deployed to convert these resources to usable energy forms. Some countries may have progressed beyond what is discussed below on resource assessment, while others may not have.

Resource assessment requires determination of the quantity and quality of resources found in a given region at a given time. It may involve exploration and monitoring to determine whether a particular site is suitable for a particular renewable energy technology.

An inherent difference between renewable and conventional energy resources is that renewable sources are determined by their "flow" whereas conventional sources are "fixed" in stock. Renewable energy resources vary by time of day, and some of them, such as solar radiation and wind, vary by night and day. Most renewable energy sources vary seasonally, and all of them vary from year to year. Sunlight and wind are variable in place, also. The rate at which renewable energy resources can be expended is generally fixed by the flow and not, as with conventional resources, by demand. These inherent resource characteristics make it essential to carefully evaluate energy needs when considering renewable energy systems. Some renewable energy resources, such as biomass resources, have competing uses that must be considered. Furthermore, crops can be grown for energy as well as agricultural uses, and in cases such as bagasse from sugar cane, there are mutual benefits in using a biomass resource for both agricultural and energy applications.

Data availability for renewable energy resources varies widely. Furthermore, most of the data available have been collected primarily for other purposes such as agriculture, airline operations, flood control, timber harvests, waste management, and the protection of life and property (weather forecasts). Such data are valuable for those purposes, but they do not always provide the information required to make accurate assessments of renewable energy resources. The collection of data specifically for assessing renewable energy resources is quite limited. In addition, data that are available for renewable energy resources are generally lacking in accuracy and spatial (geographic) and temporal (time) resolution. The poor spatial resolution (lack of data at most locations) is the direct result of the small number of locations at which resource measurements have been made. The lack of temporal resolution means that it is not possible to accurately estimate the flow characteristics of renewable resources on time scales capable of resolving hourly, daily, monthly, and annual variations.

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[1] The discussion on resource assessment is taken from Maxwell and Renne (1994).

9.3.1 Solar Radiation

Most measures of solar radiation resources are given in terms of the total energy received (in Btu, kWh, or megajoules) each hour and/or day at the measurement location. Monthly and annual averages are computed from the hourly or daily data, and these are used to prepare tabular data sets and maps of average daily energy. These data tables and maps provide a first-level indication of resource availability. More detailed assessment requires resolving the temporal characteristics of solar radiation changes that take place over time scales ranging from minutes to decades. Experience has shown that short-term changes in the flow of solar energy requires measurement intervals of 5 minutes or less. Monitoring long-term changes associated with climate change, volcanic eruptions, and atmospheric pollution requires a continuous measurement program. Typically, solar radiation data have been collected at intervals from one minute to one day, with the most common interval being one hour. Hourly data are adequate for most applications. The short-term (e.g., five-minute) variability of solar radiation at a given site can usually be determined from one to three years of data.

For initial screening of solar radiation resources and to produce solar resource maps at the national level, monthly average daily totals of the global horizontal radiation are available on Internet from a database at NASA-Langley at a resolution of 280 km by 280 km grids. These data are available for all locations. These data can be processed to obtain finer spatial (to 30 km grids) and temporal resolution, but such work will require specific effort by experts. These data should be validated by ground-based observations before they are applied to evaluate the suitability of solar energy technologies or projects to meet specific end uses or needs. International solar radiation data are available from the World Radiation Data Center (WRDC) in St. Petersburg, Russia, and from the World Radiation Monitoring Center in Zurich. Data from the WRDC will be available in the near future from The National Renewable Energy Laboratory (NREL) on Internet.

9.3.2 Wind Energy

Because the power of the wind is proportional to the cube of the wind speed, a small change in wind speed can represent a large change in wind power at any given time. Wind power density is calculated by summing the average wind power of several ranges of wind speed over a specified period of time (month, season, or year). The power for each range is multiplied by the frequency of occurrence of wind speeds within that range, and the results are summed over all ranges to obtain the wind power density. Maps based on such wind speed ranges to define wind power classes are available but at such large scales that even initial screening at the national level for most countries will be difficult. Wind atlases for many parts of the world are available but vary in quality and consistency. Grubb and Meyer (1993) survey data availability at the national and continental levels. Since wind speed is highly variable and is affected by surface roughness and topography, regional or local data are desirable for screening purposes.

Similar to solar radiation, wind speed has not generally been measured for the purpose of assessing wind energy resources. For these reasons and others, most of the wind data available today are not as reliable as one would like for estimating wind energy resources. Wind resources, including the turbulence characteristics of the resource, can vary significantly over small distances, particularly in very mountainous terrain or in coastal or lake-shore regions. When no wind data are available, topographic and vegetative indicators, or numerical models, might be used to estimate wind resources.

9.3.3 Hydropower

The hydropower resources for a given river basin or catchment area can be estimated from three sources of information: hydrographic records, which define the rate of flow of water at a certain point within the river basin, measurements or estimates of precipitation falling on the catchment area, and the topographic characteristics of the catchment basin. Recording rain gauges are standard for virtually all weather service stations around the world.

The prospects of developing any site also depend on numerous engineering, environmental, and economic considerations which have not been fully assessed and which can change over time. In those areas of the world with rapid population growth or areas that are prone to periodic severe droughts, there can be intense competition for the available freshwater supply. As with other renewable resources, the cost of energy derived from a hydropower project can vary considerably, even within regions where the resource is generally abundant.

9.3.4 Geothermal

Geothermal energy resources fall into four categories: hydrothermal (hot water and steam), hot dry rock, geopressured hot water with dissolved CO_4, and magma. Only hydrothermal resources have been commercially developed to date. Palmerini (1993) provides an overview of global geothermal resources and extraction technologies.

The main characteristics of a geothermal reservoir that determine the usefulness of its energy are its volume, the water state (liquid and/or steam), temperature, pressure, depth, water chemistry, and recharge rate. High-temperature steam sources are of greatest value for generating electricity. Lower temperature liquid sources ($T < 90°C$) are typically used for heating buildings and for process heat. The depth and pressure, particularly for liquid resources, will affect the cost of getting the resource to the surface. The chemistry of the liquid or steam will affect construction and operational costs, according to the measures required to remove harmful minerals or mitigate their effects. The rate at which the hot water or steam is replenished (naturally and by injecting spent fluids) determines the quantity of energy that the source is capable of supplying on a continuous basis.

9.3.5 Biomass

Biomass is by far the most complex of the renewable energy resources and presents the most difficult assessment problems. This complexity is due primarily to the multiple sources of biomass including energy crops (e.g., trees, corn, sugarcane, microalgae); standing crops (mostly forests) grown for other purposes; litter and dead or non-commercial trees (standing waste) in forests; and forest and agricultural wastes (field and mill or factory) and to the many energy conversion processes that are possible, including direct combustion, gasification, liquefaction, and biochemical processing. The first step (after determining end-use needs) is to inventory sources of biomass and their availability. Hall, *et al.* (1993) reviews biomass resources at the national and continental levels.

Once the sources and availability are identified, harvesting rates, transportation, storage, and conversion issues must be considered. For example, microalgae might be harvested on a daily basis, agricultural crops and agricultural waste from one to three times per year, trees grown for energy use every three to five years. It may be economical to harvest litter and standing waste only in conjunction with a timber harvest, which may occur as infrequently as once every 10 to 50 years. Given the variety of biomass resources, several resource assessment methods will be needed. Assessment of biomass resources for the energy sector should be coordinated with the non-energy part of the mitigation assessment.

Biomass resources are also difficult to assess because they consist of both flow and fixed stock components. Standing crop and litter in a mature forest represent a fixed stock waiting to be harvested. Annual growth in young forests, agricultural crops, and harvesting and production wastes all represent flow resources that are subject to change seasonally and from year to year. With the exception of crops grown for energy use, there is little consensus regarding the proportion of most biomass resources that is available for energy use. Competing uses of biomass for food, clothing, and shelter also complicates resource assessment. Competition for many biomass waste products is also important to consider. Wastes from both forest and agricultural crops are essential to stabilize and replenish soils. Straw and wood chips are used for bedding material for animals, and some waste products, such as bean pods and sugar beet pulp, are used as animal feed. In general, the amount of waste that could be diverted to sustainable energy production is not well known.

9.3.6 Municipal Solid Waste

Municipal solid waste (MSW) can be defined as the post-consumer solid waste generated by residential, commercial, and institutional (schools, hospitals, offices, etc.) sources (OTA 1989). Industrial sources are not included because industrial wastes are usually discarded separately from municipal wastes. Some of these solid wastes are combustible and are being used in some areas as a renewable source of energy. The feasibility of using MSW for energy production in a given area depends on a number of factors, including population, availability of landfills, the general economy of the area, and the demand for thermal or electrical energy.

An estimate of the national resource base requires an estimate of the materials flow of paper and paperboard, plastics, yard trimmings, rubber and leather, textiles, wood, food wastes, and other categories of MSW that could be used as an energy resource. Estimates of MSW resources for individual municipalities requires measurements of the MSW at the dump site or the point of generation. At the dump, the total weight could be determined by weighing the trash collection trucks before and after dumping. Measuring the composition of the MSW is more costly and time-consuming. A certain percentage of the trash trucks must be randomly selected and their contents dumped and sorted into categories such as paper and paperboard, plastics, wood, metal, etc. Each category must then be weighed separately. Similar to any other measurement process, the accuracy and reliability of MSW sampling is dependent on the design of the sampling program (e.g., number of samples, distribution in time, and length of sampling period) and its execution. Currently, there is no standard method for collecting such data; in fact, there is no general agreement on the categories to be used to define MSW (Kahn and Sable 1988).

9.4 TECHNOLOGY CHARACTERIZATION

After renewable energy resources are assessed to the degree possible with the available data, the next step is to characterize technologies that can convert the resources to usable forms. Renewable energy technologies are as varied as the resources they convert to electricity, heat, and fuels, and the information required to evaluate them differs somewhat among technologies. In general, however, the types of data listed in Table 8-11 for conventional energy supply technologies (engineering performance, economic parameters, environmental impacts) also apply for renewable energy technologies.

The National Renewable Energy Laboratory (NREL) in the U.S. has prepared technical and economic descriptions (technology characterizations) of selected renewable energy technologies for the IPCC that include performance and cost data. These technology characterizations include those renewable energy technologies considered by the Energy and Industry Subgroup of the IPCC to be commercially available in the near-term (<10 yrs) and suited for limiting the levels or growth rates of greenhouse gas emissions in developing and transitional economies. The technologies characterized and their applications are:

- flat-plate photovoltaics (electricity)
- solar thermal (heat, electricity)
- salt-gradient ponds (electricity, space and process heat, desalinization)
- wind turbines (electricity, water pumping)
- small-scale hydro (electricity)
- geothermal (electricity)
- MSW (electricity, heat)
- biomass: direct-fire steam turbine, gasification-gas turbine cycles (electricity)
- pelletized wood (space and process heating).

Additional cost information on photovoltaics, solar thermal electric, and biomass energy (electricity and liquid fuels) is available in Ahmed (1994).

An important set of technologies not included in the IPCC work so far is that to produce liquid fuels from biomass. Technology characterizations of these and other energy systems listed in Table 9-1 are available from NREL.

9.5 CONSTRUCTING BASELINE AND MITIGATION SCENARIOS

After potentially applicable renewable energy technologies are identified, a method to select the most suitable technologies is needed. There are two general ways to make this selection. One way is to use optimization or other models that can integrate renewable energy technologies into the overall energy supply system once assumptions on costs and performance are made.[2] The second way is to use a decision analysis tool that explicitly accounts for subjective and non-quantifiable factors. An example of such a tool is the Analytical Hierarchy Process (AHP), which has been applied for evaluation of renewable energy technologies in Mexico (Corbus *et al. 1993)*.

Specific options can be further analyzed by identifying market opportunities and exploring market penetration options. In doing so, attention should be paid to some of the unique characteristics of

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[2] Many models assess the availability of resources (e.g., oil, gas, coal) through pricing. As the resource becomes more scarce, the fuel price of a technology increases and the deployment of the technology is therefore constrained. For many renewables, fuel price does not exist (i.e., solar or wind technologies) and there is no way for the model to automatically limit deployment based on resource availability. In these instances, a "cap" may need to be applied to the model.

renewable supply technologies. Renewables offer important benefits in terms of reduced environmental impact beyond climate change mitigation, energy independence and diversity, and economic and social development. These benefits are often not readily modeled but are essential elements of a comprehensive assessment.

A particularly promising area for renewables deployment is distributed or off-grid power generation. Accounting for these opportunities requires a way of evaluating the trade-off between grid extension and off-grid remote power generation. In many instances, a utility line extension can be more costly than deploying a renewable technology as a stand-alone system.

For on-grid applications, a key issue for renewable energy is integrating the technologies into the existing energy network. Many of the renewable technologies operate intermittently, which is to say that they only produce power part of the time (when the sun is out or the wind is blowing). Some of the outages can be predicted (e.g., the time that the sun will set is known), while others cannot (e.g., a large bank of clouds passing overhead). As a result, electric utilities consider most solar and wind technologies as non-dispatchable since they cannot be turned on whenever they are required. Considerable research and experience has been devoted to assessing how utilities can deal with this uncertainty. One method has been to increase the knowledge of the resource through resource assessment to reduce the uncertainty about when the resource is available (i.e., "predict" when the wind will come up). Other techniques include the use of backup and storage systems, promoting system diversity, and load management.

9.6 MITIGATION POLICIES

Policies to promote adoption of renewable energy options and examples of their application are briefly described in Table 9-2. These are loosely aligned with the policy options listed in Chapter 8 on conventional energy supply since many of the same types of policies will serve to enhance renewable energy supply. Table 9-2 only lists policies and examples that might directly promote the use of renewable energy; however, most of the options discussed in Chapter 8 can have indirect effects on the use of renewables. For example, taxes or restrictions on the use of carbon-intensive fuels (e.g., coal) will increase opportunities for renewable energy. Finally, integrated resource planning offers opportunities for incorporating renewable energy technologies into utility planning as part of a formal process.

In addition to the policies in Table 9-2, technological transition strategies should be part of an implementation plan for renewable energy. Hybrid systems such as diesel generator/wind, hydro pumped storage/wind, and co-firing of renewable and conventional fuels (e.g., biomass and coal) are ways of integrating renewable and conventional technology options.

Table 9-2. Policies to Promote Use of Renewable Energy

OPTION	DESCRIPTION	EXAMPLES
Emissions Controls	Limits on emissions of GHG or other pollutants - caps by technology - caps by region/sector	- Emissions cap on new power plants, transportation vehicles, etc. - Emissions cap from regional utilities, urban zones (e.g., clean cites), or segments of the industrial sector
Input Controls	Require uses of renewable energy feedstocks	- Set-asides for renewable utility technologies in future capacity expansion plans - Payments to operators using renewable energy for industrial processes
Price Controls	Price subsidies for renewable energy fuels and technologies	- Federal/local subsidies on cost of electricity from renewable utility technologies - Payments to operators using renewable energy for industrial processes
Rate-of-Return Regulation	Requirements on the rate-of-return calculation for energy supply companies	- Permit owners/operators of renewable electric technologies to achieve higher rates of return
Permitting	Conditions placed on energy supply operations	- Preferential siting of renewable energy supply facilities; reduce siting constraints
Tradeable Emission Permits	Require the acquisition of GHG emission rights by trading with other sources	- Renewable energy supply technology used to offset emissions from non-renewable sources
Taxes	Tax credits/levies for GHG control - on products - on firms - on land and facilities	- Tax credits for renewable energy use (fuels, electricity, etc.) - Taxes on GHG-emitting technologies
Tariffs	Reduced tariffs for importation of non-GHG emitting technologies	- Reduced tariffs on foreign renewable energy supply technologies (e.g., wind energy systems) or demand tech-nologies (e.g., alcohol-fueled vehicles)
Research, Development, and Deployment	Government funding of RD&D in the area of renewable energy	- Government-sponsored research, including demonstration activities
Government Purchase	Government purchase of renewable energy technologies	- Purchase of alternative-fueled vehicles for government fleet use - Cost-sharing with industry and in purchase of industrial renewable energy technologies
Information Dissemination	Promote renewable energy technologies with the general public, specific industry groups, and energy planners	- Creation of one-stop shopping information clearinghouses for renewables - Sponsorship of technical conferences with industry

Cooperatives	Promote cooperatives that aggregate demand for renewable energy technologies	- Rural electric cooperatives (with focus on village power) - Industry-sponsored cooperatives (e.g., pulp and paper industry)

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