RENEWABLE ENERGY SOURCES: AN UNAVOIDABLE REQUIREMENT FOR THE FUTURE

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Summary

If we expect to sustain life on this planet, it will be necessary for us to use renewable energy resources rather than depleting nonrenewable energy resources. The only questions left are: what types of renewable energy resources are better and less expensive, and how soon and how rapidly do we make the transition from nonrenewable sources. The sections below contain a brief description of all of the potential renewable energy resources, and the methods used to collect and convert them to useful energy for humanity. Solar energy is the most important renewable energy resource for our planet. Its energy can be captured directly as either heat or electricity. Solar energy captured as heat can then be converted into electricity. Using wind, biomass, or hydroelectric

energy is an indirect method of capturing solar energy. Added to the above are ocean and geothermal energy, not directly from the sun, but still extensive enough and benign enough to be considered renewable energy.

As important as understanding the potential for generating renewable energy understands the barriers that keep us from immediately making the transition from nonrenewable to renewable energy. Understanding these barriers will be necessary before renewable energy can be implemented on a large scale. This treatise concludes with some ideas that would enable and facilitate this transition.

1. Introduction

The concept of "renewable" energy sources (or resources) is often referred to when discussing the problems and directions of sustainable development. Yet when one uses the term "renewable" there is often an implied understanding of an appropriate timescale, waste-stream contents and rate, and density of application, all of which can turn a nonrenewable energy resource into a renewable energy resource or vice versa. For example, early use of wood-burning fires for heating dwellings would probably fit into most current definitions of a "renewable energy source". However, today, in many locations, such as the cities of New York or Tokyo, wood-burning fires for heating dwellings cannot be considered a renewable energy source.

The reason for this dilemma has to do with many factors, the more important ones being deforestation on a massive scale, the number of people needing to use this resource, the need to transport it over long distances, and the density of the by-products of combustion, both solid and gaseous. Let us briefly here examine the context in which we will be defining energy sources as being "renewable". For this we must consider:

- the rate of income relative to the rate of use;
- the amount and toxicity of by-products;
- the safety of the systems used in converting the resource;
- the location of the resource relative to its uses;
- the practicability of extracting the resource; and
- the impact of large-scale production/conversion of a resource on other aspects of a sustainable world.

First, a renewable energy resource must be very large relative to current and expected future rates of use. Certainly the amount of solar energy intercepted by the earth in a day is much greater than the worldwide demand for energy today or in the expected future, whereas the amount of easily extracted petroleum is not expected to be adequate to meet our energy needs for many more decades. On a small scale, a farmer can place a dam along a stream running through his property and produce renewable electricity. However, if there are many farmers and just one stream, the resource will rapidly become depleted and no longer provide a renewable source of energy for anyone.

Second, in order to be considered a renewable energy resource, the by-products of the capture and conversion processes must be minimal and benign. This includes both conditions of normal operation and under abnormal and failure conditions. For example, the use of nuclear fission as a source of energy, as practiced today, is considered by most to produce too great a threat to the environment with its waste stream. In addition, the danger of abnormal occurrences during the energy conversion process is considered too great as well; therefore nuclear fission will not be considered by the authors as a renewable energy resource.

Further qualifications for a renewable resource relate to the processes required to extract, store, and convey the energy. An energy source may be plentiful and benign in its conversion, but makes large impacts on the environment during its extraction. An example might be coal production by strip-mining, as currently practiced. Even if coal-burning processes could be developed to mitigate waste-stream problems, the extraction process of coal produces enough unacceptable impacts on the environment to eliminate considering it as a renewable resource.

One final criterion used in determining whether an energy source is renewable or not is the alternative usage of consumed resources “for a better good”. Asking the question of whether it is better to produce energy or another consumable with a given resource is important in an overall evaluation of the concept of renewable energy sources. An important example relates to biomass energy sources. Biomass farming (as an alternative to using biomass wastes) as a source of energy comes in direct conflict with using the same arable land (and water) to grow food. The question must then be asked: if arable land with water is available, is it better to grow trees or other biomass for energy production, or to grow food for the world’s hungry population? Before large-scale implementation of any renewable energy scheme, considerations of “alternate use” of the required resources must be made.

Therefore, in this article we will attempt to consider only energy sources that are large relative to demand, require benign and minimal extraction and conversion processes, and do not consume resources that could be better used elsewhere in society.

2. Renewable Energy Sources

The examples of “renewable energy sources” selected here satisfy most of the criteria discussed above. They include the direct conversion of solar energy into thermal energy and electricity, the indirect (or natural) conversion of solar energy into thermal or electrical energy, and the conversion of other long-term natural processes such as ocean tides, waves, and geothermal energy.

The goal of all of our energy conversion processes is to supply energy either for heating or for doing work. Heat energy (or thermal energy) is a basic requirement for life in terms of space heating, and to drive many industrial and chemical processes such as steel-making and the production of fertilizers. Work energy (causing motion) is used to replace the efforts of humans and beasts of burden. Engines, motors, and pumps are the basic devices that today make our lives easier, and extend our capabilities. We can use renewable energy sources to supply both heat and work.
Electricity is an intermediate form of energy (except for a small percentage used directly for electronic devices). Since there is no (utilizable) natural source of electricity, we use an energy resource such as coal, oil, or natural gas to generate

electricity. Electricity is easily transported by wires, inexpensively and with little loss, over long distances and into homes and factories, where it is reconverted into the usable forms of energy, work or heat. Some of the solar energy conversion processes discussed below provide heat energy directly and some provide electricity. This ease of transport and conversion is important for development of renewable energy sources, as will be seen in the discussions that follow.

Our current technologies for collecting solar energy can be divided into either (a) those collecting solar energy directly as it reaches the earth, or (b) those that collect after the solar energy has performed some natural function such as causing winds to blow or plants to grow. This division is described here only as an aid to understanding the various alternatives for solar energy capture. It is the authors' opinion that no one of these techniques is "best", and that most if not all of these will find their place in an appropriate mix of energy conversion technologies for different locations and times.

2.1 Direct Solar Energy Conversion

The sun, our most important source of renewable energy, sits at the center of the solar system and emits energy as electromagnetic radiation at an extremely large and relatively constant rate, 24 hours a day, 365 days of the year.

The rate at which this energy is emitted from the sun's surface is equivalent to the energy coming from a furnace at a temperature of about 6000 K (5730 °C). If we could harvest the energy coming from just 10 hectares of the sun's surface, we would have enough to supply the current world demand for energy.

However, not all of the energy leaving the sun's surface is available to us, for three reasons. First, the radiant energy spreads out from a point source, becoming less dense the further away the receiver is. Since the earth is nominally 150 million km from the sun, much less energy is incident on a hectare on earth, than leaves a hectare on the sun. Second, the earth rotates about its polar axis every 24 hours, leaving half of the earth with no solar energy for half of the time. The third and least predictable factor is the condition of the thin shell of atmosphere that surrounds the earth's surface. On the clearest days, the earth's atmosphere accounts for another 30% reduction of the sun's energy, and at worst, most of the sun's energy can be shielded for days at a time.

Still, enough solar energy falls on an area of approximately 50 000 km^2 to satisfy the world's current demand for energy. This is about 10% of the land area of Spain, 20% of the land area of the US state of Arizona, or about 0.036% of the earth's land area. Granted, we cannot collect all of the solar energy falling on a given area of land. However, if every country would collect the solar energy falling on, say, 0.5% of their land area, there would be plenty of energy, both electrical and thermal, for us all for many years to come.

2.1.1Conversion to Heat

Solar collectors harvest solar energy falling on the earth. A solar collector is a device designed to collect the incident solar energy (short-wavelength electromagnetic radiation), and convert it into one of the two basic forms of energy useful to humans: heat or electricity.

The method of this collection and conversion varies greatly depending on the application, location, and the desired output. However, the design of any solar energy conversion system is determined by the fact that solar energy is dispersed over a wide area. Consequently, solar collectors must cover large areas to collect large amounts of solar energy. This means that the materials used to collect solar energy must be carefully chosen since the cost of covering large surface areas can be prohibitive.

As an example, on the clearest days, the maximum rate of solar energy falling on one square meter (1 m^2) is about 1 kW. Over a full day, more than 8 kWh fall on a "good" solar energy site in the summer in the United States. Averaged over a year, the full-day solar energy falling on 1 m^2 of land area varies from about 2 to 6 kWh, depending on the location. For a location averaging 6 kWh per day, the amount of solar energy falling on just one square meter of land is enough energy to do the following:

- Provide heat for three 5-minute showers per day.
- Heat one room of a modern house for 7 hours per day.
- Operate one 60 W light bulb for 100 hours.
- Operate 100 60 W light bulbs for one hour.
- Replace 60 gallons of gasoline per year.

To complicate the direct collection of solar energy further, some of the sun's energy is dispersed by the earth's atmosphere as it comes to the surface. This results in a 'beam' component coming from the disk of the sun, and a 'diffuse' component coming from the rest of the sky. It is the beam component that causes shadows and the diffuse component that permits you to read in the shade of a tree. On a clear day, almost 90% of solar energy is beam with 10% being diffuse. On cloudy days when the sun cannot be "seen", there is no beam solar energy (and also no shadows). This is important for understanding the various methods of collecting solar energy because some schemes collect both beam and diffuse, and others only collect beam. Specifically, any collection scheme that requires concentration of the sun's energy will only concentrate direct solar energy. The diffuse component is lost to this type of collector. Since some regions have a greater fraction of their solar energy as diffuse energy, the ability to collect this form of energy may be important in selecting the appropriate type of system.

One further consideration affecting the design of different solar energy collection schemes is the direction in which the collecting surface is pointing. For a surface to receive the maximum amount of beam solar energy, it should be aimed toward the sun. Although it is usually easiest to design horizontal solar energy collector surfaces, an easy alternative is to permanently tilt the collector surface toward the south so that when the sun is highest in the sky, the collector will receive more energy. An alternative to permanent mounting is to make the collector movable so that it can be continuously aimed at the sun. This "tracking" of the collector permits the maximum amount of energy to be collected all day long. Tracking is required for collectors that concentrate the sun's energy.

In the following sections, we will briefly introduce different concepts for collecting and converting solar energy into the forms useful to humans: heat and electricity.

Passive Solar Building Design An important use of solar energy is for heating the inside environment in which people live and work. The underlying idea of passive solar building design is to configure the building as a solar collector and energy storage device such that people live and work inside a solar collector. This concept generally employs large, south-facing vertical areas of glass windows to let solar energy come into the building. It incorporates heavy floors and walls, well insulated to the outside environment, to store the energy during the day and make it available at night when there is no sunshine. Another important aspect of passive solar design is the natural control of the incoming heat with angular placement and shading that reduces the solar input during the summer months.

Using the building envelope as a solar energy collector is site specific, and designs vary depending on the solar cycles and the living-space constraints. However, this can be one of the least expensive means of collecting and using solar energy for heating the interior spaces of a building.

Flat-Plate Solar Collectors To obtain the higher temperatures that are needed to provide hot water for domestic purposes (washing, bathing, etc.), the most common solar energy collector for this purpose is the "flat-plate collector". Flat-plate collectors absorb both beam and diffuse solar energy coming from any direction above the collector. Since no concentration of the solar energy is involved, it is unnecessary to track the daily movements of the sun.

In its simplest configuration for water heating, a flat-plate collector is simply a flat sheet of blackened metal with tubes attached to it to remove heat. Solar energy (both beam and diffuse) is absorbed on the metal sheet, heating it, and water passing through the tubes absorbs this heat and transports it to the point of use. For temperatures above approximately 45–50 °C, a cover sheet of glass or plastic is placed above the blackened flat plate to reduce heat loss to the surrounding air. For even higher temperature applications, or where the ambient air is very cold, two or sometimes three transparent cover sheets are used.

Flat-plate collectors are used to provide heat energy for many different applications, such as domestic hot-water heating, swimming pool heating, space heating, and industrial applications requiring temperatures up to (80–85 °C). As an alternative to heating water, air can be used to extract heat from the metal plate by blowing it past the heated surface (either front or back). Other designs use plastic with water passages extruded into a flat sheet.

Flat-plate solar collectors and the flow systems to utilize them for hot-water heating are simple and inexpensive. In addition, they are efficient, capturing 70–90% of the sun's energy including the diffuse energy scattered throughout the sky. It is not necessary to track the changing position of the sun, making their fixed installation simple and inexpensive. These collectors are usually tilted toward the south at an angle approximating the local latitude angle in order to increase the amount of solar energy that is collected.

Because of their low-temperature operation, and their use for water heating, a major disadvantage of flat-plate collectors is that in most climates, water remaining in the passageways of the collectors can freeze, causing them to burst. This can happen at night when the outside air temperature drops below 5 °C. Another disadvantage is that the basic construction of flat-plate collectors requires large amounts of materials. Materials such as sheet copper and glass are typically used with copper pipe brazed onto the absorber. Since large areas are typically involved, this can be a major expense.

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Biographical Sketch

William B. Stine is a professor emeritus of mechanical engineering at California State Polytechnic University in Pomona, California, and a Fellow of the American Society of Mechanical Engineering. His areas of expertise include renewable energy, solar energy, and Stirling engines. After receiving his bachelor's degree in mechanical engineering from West Virginia University, he received a doctor of philosophy degree from the University of Southern California, where his thesis dealt with heat transfer processes in flames. Dr. Stine also received the degree of Master of Business Administration from the University of Southern California. His initial employment in 1958 was with North American Aviation, where he worked as a design engineer on the propulsion systems of a number of aircraft. His initial academic employment was at California Polytechnic State University in San Luis Obispo, California, in 1973. Here he taught thermal sciences courses and developed a high-temperature solar energy course and laboratory, and developed a student research project using the gas from local sewage processing as an automobile fuel. It was during this time that he initiated career-long research and consulting relationship with Sandia National Laboratories of Albuquerque, New Mexico, and the National Renewable Energy Laboratories, Golden, Colorado, and the California Energy Commission.

In 1983, Professor Stine moved to California State Polytechnic University in Pomona, California where he continued his research, teaching courses in the thermal sciences and developing courses in renewable energy, solar energy and Stirling engines. In addition he joined an interdisciplinary faculty group to found the J. T. Lyle Center for Regenerative Studies. He has been active with the International Energy Agency's SolarPACES solar power development program, being an invited researcher at the Plataforma Solar de Almeria (Spain) in 1993 and where he continues his research and writing projects to date. He has been an invited speaker and organizer for technical conferences in the U.S.A., Mexico, Spain, France and Japan, and in 1983 published a textbook on solar energy system design. Other works include numerous reports, book chapters, and technical papers in the areas of concentrating solar power, Stirling engines, and regenerative studies.