Apr 1st, 8:00 AM

Current Solar Applications and Economics

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ABSTRACT

Until relatively recently, man has been almost totally dependent on the sun to directly, or more often indirectly, provide energy for his well-being. High quality stored solar energy in the form of oil, natural gas and, to a lesser extent, coal have been in such great demand during this century that they are being depleted at an intolerably high rate. Consequently, more "renewable" forms of energy are being considered—or more accurately, reconsidered. It was proven feasible to harness the wind, to collect sunlight and store it as heat, and to convert thermal energy stored in the oceans to do useful work decades ago. However, as adequate distribution networks for the fossil fuels and electricity were developed, these convenient sources of energy led to the abandonment of windmills, solar water heaters and the few experimental ocean thermal conversion plants which the French worked on during the second quarter of the century. As supplies of our convenience fuels dwindle, "convenience" will become increasingly expensive and availability will become an important factor influencing future sources of energy. The main body of the paper contains an overview of important considerations essential to the evaluation of energy alternatives. Those considerations include a review of the status of simple solar harvesting techniques, direct economic comparisons and socio-economic ramifications of several of the most promising solar alternatives.

**

The tools which make use of the sun's rays go back to and before the birth of Christ. In 212 B.C., Archimedes is said to have ordered the defending soldiers of his city-nation of Syracuse, or what we now call Sicily, to reflect sunlight from their polished bronze shields onto the main sails of each ship of an invading Roman fleet as it came through the narrow entrance of the harbor. This concentrated sunlight was alleged to have set the fleet on fire and to have saved the city. Although this story may have enjoyed some embellishment with the telling through the years (at least two other versions of it are circulating), it does indicate that man's interest in the practical harnessing of the sun's energy is not new. The rapid rise in the cost of petroleum which has occurred since 1973 has triggered investigation of alternate sources of energy, and attention is being redirected toward the sun as one of those sources.

Sunshine has some unique characteristics. For one thing, it is a replenishable form of energy—we won't run out of it in the foreseeable future. For another, it is found everywhere—everywhere in two senses of the word. One, it falls with equal intensity on our yards, homes, factories, lakes, beaches and forests. Two, it falls on the equatorial regions and on the poles of the earth. While the total annual amounts and monthly distribution of radiation impinging on Nome, Alaska, and the island of Trinidad differ markedly, the differences are less than you would expect between Bangor, Maine, and Key West, Florida. Table 1 (21) shows mean daily radiation in Langley. (To convert this information to Btu's per square foot, multiply by 3.69.) The table reports total incident radiation measured on a horizontal surface. Since the sun swings in a low arc across northern skies much of the year, a south-facing, tilted surface will intercept more sunshine than will a horizontal one. This is true to a lesser extent in the South.

Figure 1 (22) shows the angles of elevation from the horizontal appropriate for various latitudes and for different seasonal heat collecting requirements—maximum summer, spring and fall, and winter collection.

Devices to harvest solar energy run the gamut from dark clothing to oil wells. We may warm our bodies with dark clothing on a sunny winter day, or may drill for oil which nature has produced from solar energy stored as vegetation tens of millions of years ago. Table 2 (9) lists sources of energy currently available to mankind. From this table it is apparent that most of the energy we have been using during man's tenure on earth has had as its source the sun.

Until about 200 years ago, we lived pretty much in energy balance with our environment. Then came the industrial revolution, and since that period we've developed an ever-increasing greed for energy. Additional pressures have developed during the last 50 years on the earth's oil and natural gas reserves because we have found those materials to be excellent feed stocks from which to make fertilizer, textiles, medicine, synthetic rubber and plastics. It may be that, as the finite reserves of oil and natural gas shrink, we will want to use them exclusively as raw materials and stop using them as fuel. Those two energy sources directly or indirectly provide us with 76% of the energy we used in America during 1977. The production of oil from oil shale is, unfortunately, fraught with economic and environmental problems. Consequently, oil shale is not an energy genius which will give us low cost energy.

In terms of alternative energy sources, coal is a major possibility and the pollution problems asso-
associated with its use are being studied (4). Fluidized bed coal-fired boilers will be expensive to operate, but they will not produce as much air pollution as old fashioned coal boilers. We have plenty of coal for the next few hundred years right here in the United States, however the environmentalists are less than enthusiastic about renewed strip mining.

Rotational tree farming of 400 square miles is being considered by a New England utility company to provide wood chips as fuel for an electric generating plant large enough to serve 500,000 people (10). Like oil, gas and coal, wood represents stored solar energy, but the storage cycle is 20 to 50 years, not millions. Trees and fast growing crops are being studied as a source of alcohol and methane fuel for transportation needs, space conditioning and power generation (4), (10). It’s estimated that two-thirds of our annual petroleum consumption could be eliminated if one-third of the farmland under cultivation were devoted to the raising of such crops (10). Whether farmers will give up lucrative crops like wheat and corn to experiment with an “energy crop” is not certain. Even if they do, the cost of the final product will be high.

Moisture evaporated from the surface of low-level bodies of water and returned to higher regions as rain has for years been turning water wheels and providing power for mills or for electric generators. Unfortunately, most of the natural hydroelectric sites in the United States are being used to their maximum productive potential at the present time. The creation of new sites with any productive capacity of consequence would require the flooding of scenic valleys and farmlands—an unpopular side effect which the environmentalists are resisting vehemently. While only 38% of the available hydroelectric sites in the United States are being used, they are the best of those available.

Work is being done in wind energy for irrigation and on-site power generation. A 100 KW NASA wind generator is in use near Sandusky, Ohio, and another is planned for use in 1978-1979 with a 1,500 KW capacity (5), (11). About 1.5% of the solar energy which falls on the earth is converted to wind energy (10) and there are several places in the United States where it’s thought that harvesting it is practical (11). But the harvesting equipment is expensive as is the maintenance required. (Neiman-Marcus’ 1977 Christmas catalog featured “his and hers” windmills at about $15,000 each.)

Wave and tidal energy are not being seriously considered for use except in areas where tidal resonance creates very large high-to-low tide differentials. Few of those areas exist in the United States, but one tidal electric plant is in operation in France.

Nuclear energy is now producing about 8%-10% of the electrical power we consume in America (22). The scientific community is not unanimous in praising the light water reactor, however. The pros and cons have been extensively discussed in the press (20). While experts’ opinions differ, this much is clear: strict operating procedures and inspections are making the expansion of nuclear power production much slower than had been expected. Many utility companies have dropped their plans to build more nuclear reactor-powered electric plants.

Geothermal power has been used in California to generate electricity for some time. Some severe problems have been encountered because of the highly corrosive nature of the steam (6). The problems are academic to Florida, however. The hottest spot found within 2,000 meters of ground level is only 76°C. (It’s in Charlotte County.) Brine with a temperature of 100°C is thought to be more than 4,000 meters below the surface of Florida (33). It isn’t within the realm of economic feasibility to drill that deep for an unknown quantity of steam. The Department of Energy (DOE) is funding experimental work in this field—tentative evaluation, costly energy.

That leaves us direct harvesting of the sunshine as thermal energy, as electrical energy, or the more indirect harvesting of solar energy stored as atmospheric heat or as oceanic heat. The technology for harvesting in any of these ways has long been at hand.

Flat-plate and concentrating collectors have been in use since Lavoisier melted iron with a pair of glass lenses in 1774 (35). In fact, from 1900 through about 1960, the use of flat-plate solar heat collectors was so widespread in Florida that it supported a fair-sized solar industry. Inexpensive electric water heaters and “live better electrically” merchandising coupled with very low per KWH electric charges caused the public to turn away from solar water heaters during the 1960’s, and by 1970 the manufacturing capability had died out nearly completely (27).

Heat pumps have been in widespread use for a quarter of a century to transfer heat from the atmosphere at, say, 40°F to a building at 70°F. They use expensive electricity to power their compressors, but with propane, natural gas and oil prices continuously rising, those with high coefficients of performance may soon be cheaper to operate than conventional furnaces. Solar-assisted heat pumps show considerable potential.

That both the collectors and heat pumps utilize on-site solar energy to meet on-site energy needs is to their advantage. It eliminates the costly transportation of raw fuel. Of course, the heat pump uses some off-site produced energy, but (in the heating mode) only about 1/3 of that which would be used by resistance heating. (Solar-powered absorption air conditioners will be considered in a subsequent paragraph.)

Ocean thermal gradients of 30°F exist within a few miles of sections of Florida’s Atlantic coastline. Serious thought is being given to evaporating ammonia or propane with 80°F water from the Gulf Stream, driving turbines with the hot vapor and condensing it with 50°F water from the ocean bottom (36). Several methods have been suggested for getting electricity produced by such an Ocean Thermal Energy Conversion system to shore. One suggestion involves electrolyzing sea water and piping the hydrogen produced...
to the point of use. All this requires that we think big. Huge generators, pipes, turbines, crew quarters and the like are involved. Huge outlays of money and long periods of time will be required to build such systems. The idea is not a new one. One such device was built off the shore of Cuba between 1925 and 1934 by Georges Claude (26), (30). In addition to their enormity, the ocean thermal gradient harvesters have at least one other shortcoming. They do not make use of on-site resources to meet on-site energy needs. Thus, they do not allow us to capitalize on one of solar energy's greatest assets, free delivery. However, the main problem is that the energy they will supply will be expensive.

Photovoltaic cells use on-site energy. They convert light energy into electrical energy with about 12% efficiency. About one kilowatt of solar energy falls on each square meter of Florida roofs for about eight hours each day (3). Since most household appliances use electricity, albeit AC rather than DC, it seems logical to view photo cells as our salvation. There is, however, a problem. Durable monolithic silicon photo cells cost about $12,000 per kilowatt capacity. This places the cost of an array plus storage batteries with enough capacity to power the average 1,600-square-foot house at some $200,000. Mobil-Tyco solar energy laboratories near Boston are working on a machine with which their scientists hope to grow a "ribbon" crystal which will be much cheaper than the single crystals now in use. Thin film cell systems are showing promise, but no one knows as yet how soon cheaper photovoltaic converters will be available.

In the meantime, it is well to remember that the University of Florida solar research laboratory reports that 85% of the energy Florida homes consume is used for water heating, space heating and cooling (7). These are all low-temperature thermal processes, and sunlight can be converted to low-temperature thermal energy with either a flat-plate heat collector, Figure 2 (25) or a concentrating lens or reflector type collector, Figure 3 (27).

Because of the fact that solar energy density is about 1/500 of that impinging on the tubes of a fossil-fueled boiler (13), solar collectors must be quite large if they are to meet a substantial portion of a given energy demand. The sizing requirement holds true whether the collector is a non-concentrating flat-plate collector or a concentrating collector. While the concentrators collect energy at a higher temperature than do the flat-plate collectors, the same quantity of solar energy strikes either shape of surface. Their per-square-foot output in Btu's is about the same, so long as they are operated within their respective temperature ranges.

The flat-plate collector is shown in cross section in Figure 2. Because the glass cover or covers are transparent to the entire solar spectrum, they admit solar energy. Because glass is opaque to long wavelength heat radiation, the reradiation from the blackened heat deck is trapped within the heat collector and the thermal energy may be taken elsewhere for use or storage by liquid or gaseous heat transport fluids.
3 tons (36,000 Btu/hr) up. A number of manufacturers produce the same type of system in the 20-to 100-ton range. These units are designed to operate in the waste steam temperature range—say, 220°F. Arkla has in limited production some units which are designed to operate as low as 180°F-190°F.

Now, herein lies the problem. Flat-plate heat collectors, which can be produced for a reasonable cost, function very inefficiently at 180°F-200°F. Their top limit for operation at 40%-60% efficiency is 140°F-170°F. On the other hand, concentrating mirrors and lenses, which will operate efficiently at 180°F-220°F (or 600°F-1,200°F, for that matter) are expensive. Additionally, concentrating collectors are able to utilize only direct or beam radiation from the sun, Figure 3. That means they must be aimed to keep their energy focused on their heat-collecting pipe. Most often they track the sun across the sky from morning until night. Gimbaled mounting and drive mechanisms are very expensive if they are constructed to withstand hurricane force winds.

There is another problem encountered with concentrating collectors. As much as 30% of the total radiation which a heat collector receives in the course of a summer day is not direct—it is diffuse. It is reflected from the cumulus clouds which dot summer skies. Flat-plate collectors utilize diffuse as well as beam radiation; concentrating collectors do not. This presents a dilemma: flat-plate collectors are inefficient at high temperatures; concentrating collectors fail to collect diffuse radiation. At present, solar air conditioning systems, regardless of which types of collector is used, are not economically competitive with conventional systems.

Several solutions are being pursued (8), (17), (24). Redesign of the refrigerant generator section of lithium bromide-water systems may allow solar energy to raise the brine solution from absorber temperature ca. 85°F to ca. 160°F and oil or gas energy of the brine from 160°F to 200° - 220°F. While the quantity of refrigerant (H20) which can be driven off the brine solution is not linearly related to the temperature, this solution exhibits promise. Dr. Ronald Evans, chairman of the Department of Mechanical Engineering and Aerospace Sciences at F.T.U., has explored this possible solution. Work at the University of Florida pursues a different solution (6). Ammonia-water absorption systems (in which ammonia is the refrigerant) will operate at 160°F. For some years the solar demonstration house at the University of Florida has been air conditioned with such a unit. One deterrent to the commercial adoption of such systems may be the fact that the ammonia is confined under about 10 atmospheres of pressure. Ammonia is highly toxic.

Regardless of how the problems end up being solved, solar air conditioning will be of more use in Florida than anywhere else in the United States, with the exception of the southwestern desert region, Figure 10 (22).

There are three other areas of solar utilization which may become increasingly important.

Solar-operated irrigation pumps were in use throughout the world during the late 1800’s and early 1900’s (15). They have been studied more recently for use in India and other food-poor nations (14). Solar-operated irrigation pumps could be useful for remote pumping stations on large ranches and farms as conventionally-powered pumps become more expensive to operate.

Another area of solar application of importance relates to agriculture. The largest independent ornamental plant nursery in Florida (John’s Nurseries, Apopka) spent 10.4¢ per square foot of greenhouse for heating during the winter of 1975-1976 ($140,000 total) (28). New concepts in greenhouse design may allow a reduction in the quantity of expensive oil and gas required for freeze protection (16), (29).

Like fossil fuels, fresh water is becoming scarce in some localities. Rivers are polluted. Salt intrusion is already a problem for some cities which draw their water from well fields near the coasts. Pollution of the aquifer is a problem in several locations scattered throughout the country. As the population grows, these problems are bound to intensify. In this area, too, we may wish to use solar energy. Solar stills provide all the water for the Chilean nitrate mines near Las Salinas from 1872 to 1910 (34). Extensive experimentation with solar stills was carried out at Ponce de Leon Inlet, Florida during the 1950’s by Battelle Memorial Institute (31), (32). A recent development in Germany incorporates heat pipes in solar stills. The output of those stills has been increased from three liters per day to five liters per day for each square meter of deck area when they are used in warm climates (19).

In terms of near-term assistance in reducing energy costs, our greatest allies are probably conservation measures. For nearly 25 years following World War II, energy costs went down. Electricity was not even an item in the family budget. Gas price wars were the rule rather than the exception. It was natural that we develop some very wasteful habits. However, the oil-producing nations have realized that they are the custodians of an exhaustible asset. It’s a pretty good bet that petroleum cannot ever again be looked to for the production of cheap energy. Unfortunately, the alternative energy sources will not bring back cheap energy either. Becoming more conservation-conscious in our approach to energy usage offers us an opportunity to effect savings immediately with a minimum expenditure for new equipment (18).

The next step may well be the use of simple on-site solar harvesters such as flat-plate or concentrating solar heat collectors. Dependent upon technical and manufacturing progress, solar cells may become inexpensive enough for widespread use before nuclear breeder reactors produce a significant portion of our electric power.

Huge ocean thermal gradient harvesters and massive desert solar-electric plants seem less likely to prove cost effective in the near future, but as time passes they, too, will be required to meet our energy needs.
LITERATURE CITED


(6) Evans, Ronald, D. Chairman, Department of Mechanical Engineering and Aerospace Sciences, Florida Technological University, Orlando, Florida, Interview. 1976.


(22) Nimmo, Bruce G. Professor of Engineering Science, Florida Technological University, Orlando, Florida, Interview, 1975.


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**Notes:**
- **Climate Data:**
  - MEAN DAILY SOLAR RADIATION (Langley's)
  - YEARS OF RECORD USED

**Tables:**
- Table 1: CLIMATIC ATLAS OF THE UNITED STATES JUNE 1968
- Table 2: CLIMATIC ATLAS OF THE UNITED STATES DECEMBER 1968

**References:**
- J. Climate Atlases
- U.S. Weather Bureau

**Additional Information:**
- Table 1:
  - MEAN DAILY SOLAR RADIATION (Langley's)
  - YEARS OF RECORD USED
- Table 2:
  - CLIMATIC ATLAS OF THE UNITED STATES DECEMBER 1968

**Figures:**
- No figures provided

**Choropleth Maps:**
- No choropleth maps provided

**Graphs:**
- No graphs provided

**Tables and Figures:**
- Table 1: CLIMATIC ATLAS OF THE UNITED STATES JUNE 1968
- Table 2: CLIMATIC ATLAS OF THE UNITED STATES DECEMBER 1968

**Additional Data:**
- Monthly Weather Review
- J. Climate Atlases
- U.S. Weather Bureau

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**Conclusion:**
- The data provided is comprehensive and covers various regions and dates.
- The tables and figures are essential for understanding the climatic data and its usage.
- The notes at the bottom provide additional context and references.

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**3-28**
TABLE 2. ENERGY SOURCES

FIGURE 1. OPTIMUM COLLECTOR ANGLES
Not less than 3/8" if two covers used.

4" to 8" between soldered tubes.

1 1/2" to 2" between deck and cover.

No smaller than 1/4" I.D. tube except on closed loop systems. Boiler scale can be a problem with small diameter tubing.

Minimum deck thickness:
- Copper .006"
- Aluminum .010"
- Galv. iron .020"

Minimum bottom insulation thickness:
- 1" foam
- 2 1/2" fiberglass

Edge insulation: 1/4" to 1" foam. While increasing the thickness of edge insulation reduces edge losses, it also reduces heat collection area and thus heat gains. 1/4" of good quality foam is a rule of thumb compromise for most climates when insulating metal housing boxes.

FIGURE 2. CROSS SECTION OF A FLAT PLATE HEAT COLLECTOR.
Safety devices such as Pressure & Temperature Relief Valves must be installed in all systems and meet applicable codes.

FIGURE 3. CONCENTRATING COLLECTORS.

FIGURE 4. CONCEPTUAL DRAWING OF THERMOSYPHON SOLAR WATER HEATING SYSTEM
FIGURE 5 CONCEPTUAL DRAWING OF PUMPED SOLAR WATER HEATING SYSTEM

FIGURE 6. SOLAR STORAGE TANK.
PROJECTED UTILITY COSTS FOR WATER HEATING BY THE YEAR FROM 1976 - 1985 FOR LAKELAND, FLORIDA

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(BASED ON 95 KWH/PERSON/MONTH)

WATER HEATING COST SAVINGS FOR LAKELAND, FLA.

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(COURTESY: SOLAR INNOVATIONS 412 LONGFELLOW BLVD. LAKELAND, FL 33801)

TABLE 3
FIGURE 7. CROSS SECTION, SOLAR AIR HEATER.

FIGURE 8. SOLAR BUILDING HEATING SYSTEM (HOT AIR).
FIGURE 9. SOLAR AIR CONDITIONING.

FIGURE 10. MEAN DAILY SOLAR RADIATION.