SOLAR ENERGY UTILIZATION: A BIBLIOGRAPHIC GUIDE

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By Robert C. Liu [1/]

INTRODUCTION

Solar energy can be used as a major source to conserve fossil fuel now, but this is only a limited immediate goal (10, 13, 18, 25, 29).[2/] Of global significance, solar energy has and will continue to be important to further cultural development of mankind (1, 4, 5, 6, 8, 24, 28). The current energy crisis and the ever increasing demand for clean energy production emphasize importance of solar energy (7, 16). Solar and solar-related energy sources can contribute to meeting the prospective needs of the world and preserve the earth from depletion of unrenewable energy resources (11, 12, 14, 18, 19).

Solar energy offers the following advantages:

- It is a virtually inexhaustible and widely distributed source of energy.
- For some applications, the cost of converting solar energy to useful forms of energy will become competitive.
- With substantial development program, solar energy could, by the year 2020, economically provide up to (a) 35 percent of the total building heating and cooling load; (b) 30 percent of the Nation's gaseous fuel; (c) 10 percent of the liquid fuel; and (d) 20 percent of the electric energy requirements (47, 48, 62).
- Solar energy is one alternative to nuclear power as a long range energy source (17, 27, 38, 41, 46).

1/ Agricultural engineer, Light and Plant Growth Laboratory, Plant Physiology Institute, Northeastern Region, ARS, USDA, Beltsville, Md. 20705.

2/ Underlined figures in parentheses refer to references at end of publication.

The sun is the primary source of energy powering the earth, therefore, wise utilization of solar energy is required to power mankind's enterprise in the future. The author believes that man can meet his problems through the rational application of his intelligence, and that by these means he may develop practical means of harnessing solar energy to reach his technological and social goals (55, 56, 60, 63, 64, 67).

This bibliographic guide is intended to serve as a source of information to those who are interested in solar energy utilization.

The bibliography is based on many sources of information. Those sources found most helpful were The Congressional Research Service, Federal Energy Administration, National Aeronautics and Space Administration, National Science Foundation, National Academy of Sciences, the newly established U.S. Energy Research and Development Administration, and the Proceedings of the United Nations Energy Conferences. No attempt has been made to list all publications on the subject; however, those listed should be useful to the reader in obtaining background information on a particular area of interest.

SOLAR ENERGY AND AGRICULTURE

Solar energy effects all biological matter through the process of photosynthesis. Thus the potential of biomass energy (1) should not be overlooked. Solar energy has been utilized in agricultural process since the dawn of civilization (10, 12, 18, 53, 54, 65). For years farming has become more energy intensive. In North American agriculture, 5 Btu's of fossil fuel energy is needed to produce 1 Btu of food energy, as compared with the 1 Btu of human energy required to produce 53.5 Btu of rice in China (34). If we are to tackle the major problems facing our nation today -- energy and food -- then we must start with a reassessment of the scene in agriculture. The use of renewable natural energy sources could contribute to the farmer being independent in his power requirements. Improved efficiency of this utilization and the development of new methods in agricultural processes could result from the following:

- Investigating methods for warming the soil with solar or wind energy in the early spring to permit earlier planting of crops.

- Investigating the mechanics, efficiency, and operation of such practices as cold frames, hotbeds, and greenhouses to extend the industry.

- Studying the mechanics of solar crop drying to relieve the demand for fossil fuels, principally propane. Solar crop dryers with storage systems might be combined with solar house heating systems on the farm.

- Investigating the anaerobic decomposition of animal and vegetable waste products for production of methane.

- Investigating the pyrolysis of organic surplus material for the production of fuels.

- Investigating the feasibility of energy plantation concept. Can new faster growing plants be developed which would be ecologically compatible?

- Investigating the role of windpower in meeting the farmer's power needs for pumping water, generating electricity, or other purposes.

- Investigating feasibility of using the methane to operate tractors and other farm equipment.

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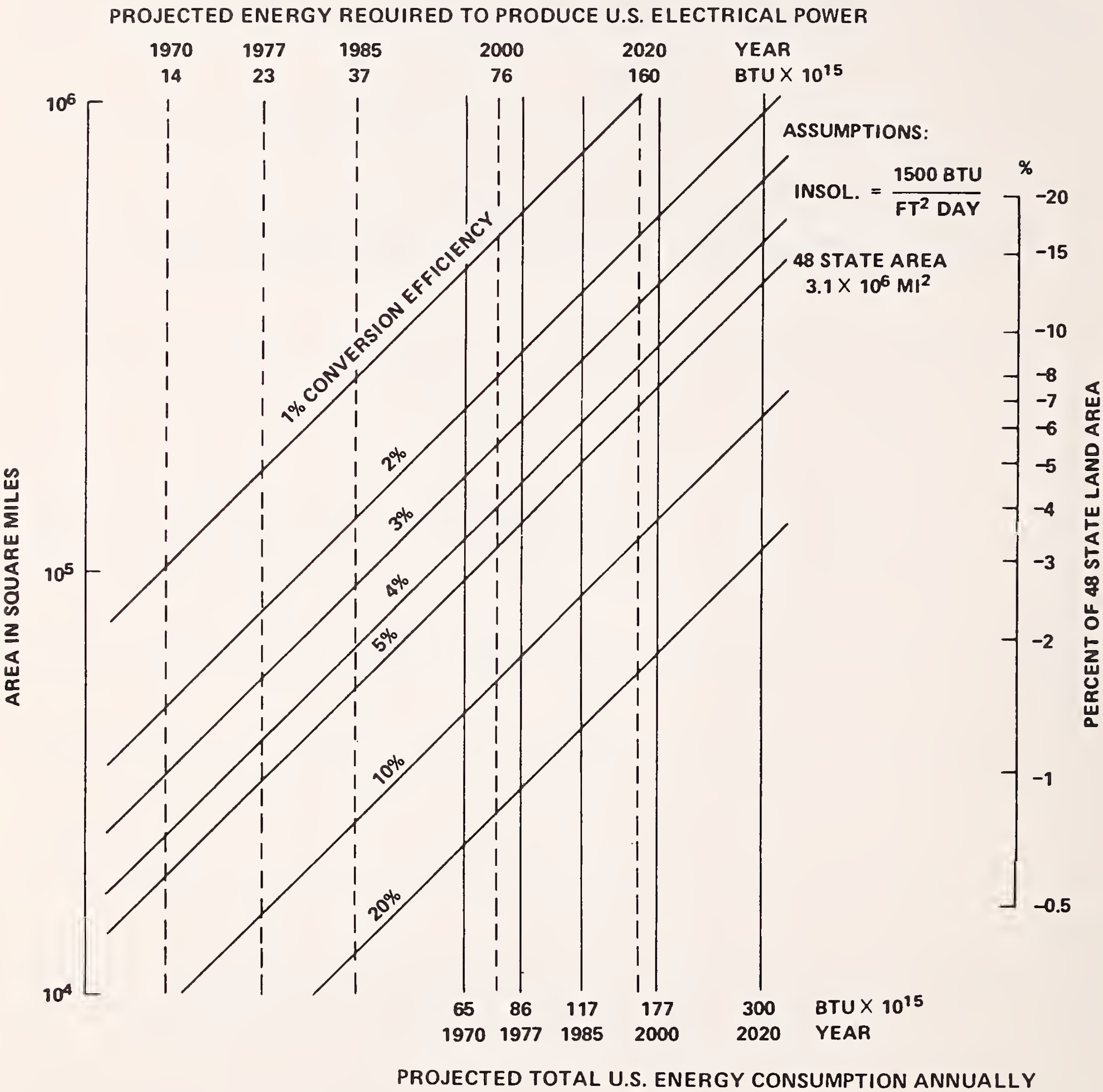
SELECTED GRAPHS AND TABULAR MATTER

The following presents a selected graph and tabular matter from publications by the National Science Foundation/NASA Solar Energy Panel (48) and the U.S. Federal Energy Administration (62):

- Availability of solar energy vs. land area (48).
- Summary of potential impacts of solar energy technologies (62).
- Comparative costs of space heating (48).
- Average solar insolation and degree days by census region (62).

AVAILABILITY OF SOLAR ENERGY VS. LAND AREA



Source: National Science Foundation/NASA Solar Energy Panel (48, p. 24).

SUMMARY OF POTENTIAL IMPACTS OF SOLAR ENERGY TECHNOLOGIES [1/]

[Units of 10^{15} Btu/year of output energy provided by solar energy systems]

	1980	1985	1990	1995	2000
Heating and cooling	0.3 (0.01)	0.6 (0.3)	1.5 (0.6)	2.4 (1.3)	3.5 (2.3)
Solar thermal	.0 (.0)	0.002 (0.002)	0.02 (0.02)	0.2 (0.1)	1.3 (0.6)
Wind conversion	0.01 (0.008)	0.5 (0.4)	2.0 (1.6)	3.4 (2.7)	5 (4.0)
Bioconversion	0.06 (0.06)	0.3 (0.1)	0.9 (0.2)	3.3 (0.4)	15 (0.7)
Ocean thermal	0 (0)	0.03 (0.03)	0.2 (0.1)	1.0 (0.4)	7 (1.7)
Photovoltaic conversion	Neg. (Neg.)	0.01 (0.003)	0.3 (0.07)	2.4 (0.3)	7 (1.5)
Total U.S. demand [2/]	93	120	144	165	180

[1/] Assumptions include: (1) The successful completion of the recommended Research and Development program plan for solar energy technologies and (2) conventional fuel prices equivalent to $11 per barrel of oil. (One barrel = 5.8×10^6 Btu.)

Numbers shown without parentheses are for the accelerated implementation plan; those in parentheses are for the business-as-usual implementation plan.

[2/] Estimates based on pre-embargo analyses. See "The Nation's Energy Future," Atomic Energy Commission, December 1, 1973.

Source: U.S. Federal Energy Administration (62, Table I-1, p. I-7).

COMPARATIVE COSTS OF SPACE HEATING

Energy Source	$\$/10^6$ Btu
Electric	2.30 - 5.30
Gas	0.80 - 3.00
Oil	1.50 - 2.40
Solar	1.50 - 4.50

Source: From NSF/NASA Solar Energy Panel (48, p. 17, graph).

AVERAGE SOLAR INSOLATION AND DEGREE DAYS BY CENSUS REGION

	Solar Insolation, $WH/ft^2/day$ 1/			
Region	Annual	Maximum	Minimum	Average degree days
New England	346	540	130	6,500
Middle Atlantic	346	551	140	6,000
East North Central	356	572	151	7,000
West North Central	389	659	194	6,000
South Atlantic	442	572	248	4,000
East South Central	421	572	205	4,200
West South Central	464	659	281	1,800
Mountain	464	702	238	6,000
Pacific	421	702	162	2,400

1/ 1 WH = 3.413 Btu.

Source: U.S. Federal Energy Administration (62, p. A-I-9).

DEFINITIONS

[Definitions taken from U.S. Federal Energy Administration publication (62, p. A-I-1-2).]

Solar energy is the power obtained from solar radiation through the use of collectors, solar cell, and bioconvertors.

Solar radiation is the total electromagnetic radiation emitted by the sun.

Peak power is the power output of a solar energy system on a clear day due to direct peak solar radiation at normal incidence. Peak solar radiation is normally assumed to be 1,000 watts per square meter, or 93 watts per square foot.

Rated solar power for direct solar systems is the power output integrated over time (for the direct radiation) divided by the time (i.e. area under the curve divided by the normal time of operation during a day).

Average power is the power integrated over time divided by 24 hours, that is, 1 complete day).

Ratio of peak power to average power overall is estimated to be about 5 to 1. For the Southwest this ratio is approximately 4 to 1.

Degree-day equals daily mean temperature - 65° F.

Daily mean temperature = $\frac{t_{max} + t_{min}}{2}$.

Btu required is the heat rate of building (Btu/hourdegree) x 24 hrs/day x degree days, or the heat supplied by the heating system to maintain the desired inside temperature.

Heat rate of building is the hourly building heat loss divided by the difference between inside and outside design temperatures.

Wind energy is a secondary form of solar energy in that wind results from the heating of the earth's surface by the sun. Exploitable wind energy averaging more than 12 mph is available in such areas as the Great Plains and the Northeastern coast.

Rated wind power is the constant output power obtained any time the wind velocity is at or above a defined design rated wind velocity and below a storm emergency shutdown velocity.

Output power varies between zero at the cut-in wind velocity to rated power at rated wind velocity.

Equivalent duration in hours is the total yearly energy output divided by the rated power. When divided by 8,760 hours per year, it reflects the equivalent of a load factor.

BASIC SOLAR ENERGY INFORMATION

Total solar flux incident outside the atmosphere of the earth is 178×10^{12} kW, continuous for the whole globe, or 1.5×10^{18} kWh/year (i.e. 5.12×10^{21} Btu/year).

The average solar energy available at the bottom of the atmosphere on the land areas of the earth is 2.16×10^{17} kWh/year (i.e. 7.37×10^{20} Btu/year).

Source: U.S. Federal Energy Administration (62, p. A-I-6).

ENERGY EQUIVALENTS

[bbl = 42 gal. barrel; (U-235 fission with 192 MeV per fission).]

Crude oil	5.8×10^{6} Btu/bbl
Natural gas (dry)	1,035 Btu/scf [standard cubic feet]
Natural gas (liquid)	4.1×10^{6} Btu/bbl
Coal (average)	25×10^{6} Btu/ton
Fissionable material	74×10^{6} Btu/g
One 42-gal barrel of oil	5.8×10^{6} Btu
	5.6×10^{3} scf (methane)
	1.70 MWh
	0.232 ton coal
	6.119×10^{9} joules
1 million bbl/day	2.1×10^{15} Btu/year
	0.365 billion bbl/year

Source: U.S. Federal Energy Administration (62, p. A-1-19).

CONVERSION FACTORS

To Convert--	Into--	Multiply By--
acres	square feet	43,560
acres	square meter	4,047
angstroms	meters	1×10^{-10}
British thermal unit (Btu)	calories	252
Btu	joules	1,055
Btu	kWh	2.93×10^{-4}
Btu	megawatt-years	3.34×10^{-11}
Btu/sq ft	Langleys (cal/cm^2)	0.271
calories	foot-pounds	3.09
calories	joules	4.18
calories/minute (cal/min)	watts	0.0698
centimeters (cm)	inches	0.394
feet (ft)	meters	0.305
foot-pounds	joules	1.36
foot-pounds	kilogram-meters	0.138
foot-pounds	kWh	3.77×10^{-7}
gallons (gal)	liters	3.79
grams	pounds	0.00220
GGj	Btu	0.95×10^{15}
Gigawatts (GW)	watts	1×10^{9}
horsepower (hp)	kilowatts	0.745
joules	Watt-hours	2.78×10^{-4}
Kcal/minute	kilowatts	0.0698

To Convert--	Into--	Multiply by--
kilowatts (kW)	horsepower	1.34
Langleys/min	watts/sq cm	0.0698
Megawatt-hours (MWh)	Btu	3.41×10^{6}
Microns	meters	1×10^{-6}
miles	meters	1,609
square centimeters (sq cm)	sq ft	0.00108
sq cm	sq in	0.155
square feet (sq ft)	sq in	144
sq ft	sq m	0.0929
sq m	sq mi	3.86×10^{-7}
square miles (sq mi)	acres	640
sq mi	sq ft	2.79×10^{7}
tons (short)	Kg	907
tons (short)	lb	2,000
tons (metric)	tons (short)	1.1025
watt-hour (Wh)	joules	3,600
°Fahrenheit	°Centigrade	Subtract 32 and multiply by 0.555
°Centigrade	°Fahrenheit	Multiply by 1.8 and add 32.
cal per sq cm-sec-°C	Btu per sq ft-hr-°F	7,380
Btu per sq ft-hr-°F	cal per sq cm-sec-°C	1.35×10^{-4}

GLOSSARY OF TERMS

kW_e	kilowatt electric
kW_t, kW_{th}	kilowatt thermal
MBtu	Million Btu
Mill	0.1 cents or 10^{-3} dollars
diffuse radiation	solar radiation which is scattered by the atmosphere
insolation	solar radiation received over a given area
GGj	giga giga joule, 10^{18} joule, 10^{25} erg
spandrel	a secondary structural member that fills the space between windows on different floor levels
desiccant	a substance which absorbs moisture
BCF	bioconversion to fuels
OTEC	ocean thermal energy conversion
PEPS	photovoltaic electric power system
POCE	proof of concept experiment
STC	solar thermal conversion
WECS	wind energy conversion system

Source: U.S. Federal Energy Administration (62, p. A-I-20-22).

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