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A STUDY OF HANFORD CAPABILITY FOR SOLAR ENERGY RESEARCH AND DEVELOPMENT

K. Drumheller

Battelle
Pacific Northwest Laboratories
Richland, Washington 99352

NOVEMBER 1973

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RICHLAND, WASHINGTON 99352

EXECUTIVE SUMMARY

There is a rapidly growing interest in solar energy. Several studies indicate that solar energy can provide a substantial portion of U.S. energy requirements by 1990-2000.

The Hanford site provides unique capability for solar energy R&D work. The basic attributes of the Hanford site which could make it one of the world's leading solar energy sites are:

Site Attributes

- Large available land areas
- Consistent sunshine during much of the year (although not comparable to Arizona and the U.S. Southwest)
- Extreme temperatures for test purposes (-27° to 115°F)
- Cooling water availability
- Ecology approximating ecology in some other solar areas

Facilities Attributes

- R&D facilities applicable to most solar technology
- Equipment immediately useful for solar energy programs

Personnel Attributes

- Technical background in most areas of solar energy technology
- Experience with large energy systems
- Background in systems analysis

From the solar energy production standpoint, the energy which falls on the 600+ square miles fenced off within the Hanford site would produce approximately 100,000 megawatts if a 33-1/3% efficiency can be achieved. In terms of input to the nation's energy requirements, if a 90% efficient

process for the production of hydrogen from water can be achieved, the Hanford site could produce 8.2 quadrillion btu per year, or 7% of the nation's 1985 forecast energy requirements.

Preparation of a national solar energy R&D program outline and a comparison of Hanford capability with this outline show that Hanford can contribute in almost every area.

There are several programs which could be undertaken immediately to begin to take advantage of the Hanford site. These include:

1. Process development for photovoltaic device fabrication.
2. Process development for thin film heat trap fabrication.
3. Laboratories for collecting, analyzing and disseminating solar insolation data and for device testing and calibration.
4. Utilization of 100 Area emergency generators for power production.
5. Hydrogen production development.
6. Building heating and cooling system development.
7. Systems analysis and economics.
8. System design.
9. National program planning.

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1.0 INTRODUCTION

An investigation of the Hanford site as a possible location for solar energy research and development work was conducted. The conclusion was that a great contribution can be made to the nation's energy programs through utilization of Hanford land, facilities and people on solar energy R&D. The site also has great potential as a solar energy production site, particularly if solar energy hydrogen production systems are developed.

Areas discussed herein include the climate characteristics of the Hanford reservation, the facilities available, and the personnel available. Some immediate program possibilities are also discussed.

There is increasing U.S. and world interest in the development of new sources of energy. Solar energy is one of the most promising sources which is relatively untapped today.

In recent years the potential for the utilization of solar energy has increased greatly. An outline for a national solar energy R&D program was recently issued by a National Academy of Sciences panel.[1] The panel study was conducted by NASA and NSF. The recommendation was for a program of R&D estimated to cost $3.5 billion over the next 15 years. The program would include the application of solar energy to building heating and cooling, the production of renewable new clean fuel sources by photosynthesis of organic materials and hydrogen, and electrical power generation by solar thermal conversion. Also included are direct solar energy conversion, wind energy conversion and power from ocean thermal differences. The national outline dwells very briefly on hydrogen production. Recent developments have improved the potential for hydrogen production from solar energy.

The magnitude of solar energy is indicated in the following statements.

- The solar energy intercepted by the earth is 1.76×10^{11} megawatts.
- In the U.S., the average incidence of solar energy on the ground is 17 thermal watts/ft.^{2},[1] or $17 \times (5.3 \times 10^3)^2 = 474$ megawatts per square mile. This average considers day and night, cloudy and sunny days, and seasonal variation.
- On a sunny summer day at Hanford, the peak power approaches 3000 megawatts thermal per square mile.[2] The yearly average in the Richland area is about equal to the national average.[3]
- With a 10% conversion efficiency, 1970 U.S. electrical energy requirements could have been supplied by the solar energy incident on less than 0.2% of the U.S. land area.[1]
- The energy which falls on the roof area of the average house is enough to supply all of its electrical needs and all of its heating and cooling.
- From U.S. land area alone, it is not unreasonable to consider all U.S. power needs being supplied by solar power in the next century or two. Use of ocean space and orbiting solar power collectors could increase the available power immensely.

For those not familiar with solar energy systems, a brief discussion of several systems being considered today will be found in Appendix A.

2.0 HANFORD CAPABILITY

2.1 General

From the experience of Hanford contractors (and other organizations), a background in nuclear energy is applicable in many ways to the development of other energy sources. Hanford facilities and personnel have in recent years been active, and in several cases highly successful, in the development of geothermal and fossil energy systems in addition to nuclear.

A comparison of the technological developments required for a wider utilization of solar energy with Hanford capability illustrates a unique correlation. Hanford can contribute in almost all of the technological areas.

2.2 Site Attributes

The basic attributes of the Hanford site which could make it one of the world's leading solar energy sites are:

- Large available land areas
- Consistent sunshine during much of the year (although not comparable to Arizona and the US southwest)
- Extreme temperatures for test purposes (-27°F to 115°F)
- Cooling water availability
- Ecology approximating ecology in some other solar areas

From the solar energy production standpoint, the energy which falls on the 600+ square miles fenced off within the Hanford site would produce approximately 100,000 megawatts if a 33-1/3% efficiency can be achieved. In terms of input to the nation's energy requirements, if a 90% efficient process for the production of hydrogen from water can be achieved, the Hanford site could produce 8.2 quadrillion btu per year, or 7% of the nation's 1985 forecast energy requirements.

Specific Hanford site information is discussed in Section 3.0 below.

2.3 Personnel and Facilities Attributes

Personnel attributes include:

- Technical background in most areas of solar energy technology
- Experience with large energy systems
- Background in systems analysis

Facilities attributes include:

- R&D facilities applicable to most solar technology
- Equipment immediately useful for solar energy programs

Table 1 is an outline of a national solar energy program. This outline is based on the NASA-NSF study[1] with some additions. The areas in which Hanford could readily make a significant contribution in terms of facilities or personnel are indicated in Table 1. It is significant to note that Hanford could contribute in almost every area. The degree of expertise varies. However, in many areas, such as thin film work, materials compatibility, photometric calibration, equipment development, and economics, Hanford personnel and facilities are among the world leaders. Specific examples of immediate program possibilities are discussed in Section 4.0, page 17. A more detailed discussion of possible programs will be found in Appendix B.

Table 1

SOLAR ENERGY PROGRAM OUTLINE

	Areas in Which Hanford Can Contribute	
	Personnel	Facilities
1.0 GENERAL		
1.1 Solar Energy Availability	X	X
1.2 Albedo	X	X
1.3 Solar Energy Characteristics	X	X
1.4 Photon--Matter Interactions	X	X
1.5 Environmental Effects	X	X
1.6 Economics	X	X
1.6.1 Overall Energy System	X	X
1.6.2 Individual Systems	X	X
1.6.3 Technical Assistance	X	X
1.7 Systems Analysis	X	X
2.0 THERMAL CONVERSION		
2.1 Collectors		
2.1.1 Reflector Materials & Fab	X	X
2.1.2 Corrosion Resistant Materials	X	X
2.1.3 Compatibility	X	X
2.1.4 Fresnel Lenses	X	X
2.1.5 Thin Film Heat Traps	X	X
2.1.6 Mass Production Techniques	X	X
2.2 Storage		
2.2.1 Eutectic Salts	X	X
2.2.2 Geothermal Caverns	X	X
2.2.3 Other		
2.3 Heat Transfer	X	X
2.4 Systems	X	X
2.5 Pilot Plant	X	X
2.6 Demonstration Plant	X	X
3.0 DIRECT CONVERSION		
3.1 Solid State Studies		
3.1.1 General	X	X
3.1.2 Silicon Systems	X	X
3.1.3 CdS Systems	X	X
3.1.4 Other Inorganic	X	X
3.1.5 Organic	-	-
3.2 Solar Cell Fabrication		
3.2.1 Single Crystal	X	X
3.2.2 Polycrystalline	X	X
3.2.3 Amorphous	X	X
3.2.4 Organics	-	-

Table 1 (Cont'd)

	Areas in Which Hanford Can Contribute	
	Personnel	Facilities
3.0 DIRECT CONVERSION (Cont'd)		
3.3 Power Collection	X	X
3.4 Controls	X	X
3.5 Pilot Plant	X	X
3.6 Demonstration Plant	X	X
4.0 CHEMICAL CONVERSION		
4.1 Thermal Dissociation of H_2O	X	X
4.2 Hi Temperature Electrolysis	X	X
4.3 Combined Thermal-Electrolysis	X	X
4.4 Other Chemical Conversion Systems	X	X
4.5 Chemical Energy Storage	X	X
4.6 Support	X	X
5.0 PHOTOSYNTHESIS		
5.1 Growing Forests	X	X
5.2 Other Photosynthesis	X	X
5.3 Conversion of Organic Materials to Fuels or Heat	X	X
6.0 BIO-CONVERSION		
6.1 Photosynthesis Bio-conversion	-	-
6.2 Thermal Bio-conversion		
6.2.1 Algae	X	X
6.2.2 Organics	X	X
7.0 OCEAN TEMPERATURE DIFFERENCES	X	X
8.0 BUILDING HEATING AND COOLING		
8.1 Heating	X	X
8.2 Cooling	X	X
8.3 Hot Water	X	X
8.4 Solar Powered Demonstration	X	X
8.5 Energy Conservation	X	X
9.0 INDUSTRIAL PROCESSING	X	X

3.0 HANFORD SITE INFORMATION

3.1 General

The Hanford reservation is located in southeastern Washington at approximately 46-1/2° north latitude. It covers an area of approximately 600 square miles.

The general public has been partially excluded from this area for thirty years. The utilization of vast portions of the area for solar energy collection is thus likely to be met with a minimum of public concern.

The average solar energy falling on the Hanford reservation is approximately 474 MW per square mile.[2] This considers the low energy periods of night time, winter time, and cloudy days. In the summer time when the sun is shining, the energy on a tilted collector is in the 3000 MW per square mile range. Thus at a 33% efficiency, there is energy in a square mile comparable to the energy produced by McNary Dam. While the average energy in the Hanford area is about the same as the average solar energy throughout the U.S., Hanford has an advantage in the form of amny continuously clear days in the summer time and peak energies similar to those found in areas such as Arizona and New Mexico.

As a solar energy development site, Hanford can be competitive with a majority of the organizations currently deeply involved with solar energy research and development. In fact, the leading solar energy R&D organizations include northern latitude locations such as the University of Minnesota, University of Wisconsin, University of Pennsylvania, University of Massachusetts, M.I.T., Boston College, University of Delaware, Case Western Research University in Cleveland, and Rutgers of New Jersey. One of the largest programs in the U.S. today for the development of central station solar energy plants is at the University of Minnesota.

The availability of water from the Columbia River is likely to be a plus for any energy production system.

Hanford has an excellent capability for the growing of forest and other plant life which might be applicable to solar energy utilization.

Hanford has the large power system engineering capability and electrical facilities to provide immediate research and development work in central station development.

An application of solar energy which is being studied on a modest scale in the U.S. today is the utilization of ocean temperature differences. There are large basins in the Hanford 100 Areas which conceivably could be used for stationary test beds for systems utilizing water temperature differences. Whether this would provide advantages over actual ocean testing is not known at present.

In summary, it can be said in general that the Hanford site has:

1. An excellent test site for solar energy systems.
2. The physical plant to do development work in almost any area of solar energy.
3. The technical and administrative talent to man solar energy R&D programs on a small or enormous scale.

3.2 Climatology

In July, the mean daily solar radiation on a horizontal surface is greater at Prosser, Wash. (707 Langleys)[3] than at Phoenix (658 Langleys). See Figure 1. Prosser is one of the U.S. weather stations close to the Hanford reservation. The mean daily solar radiation on an annual basis is 520 Langleys

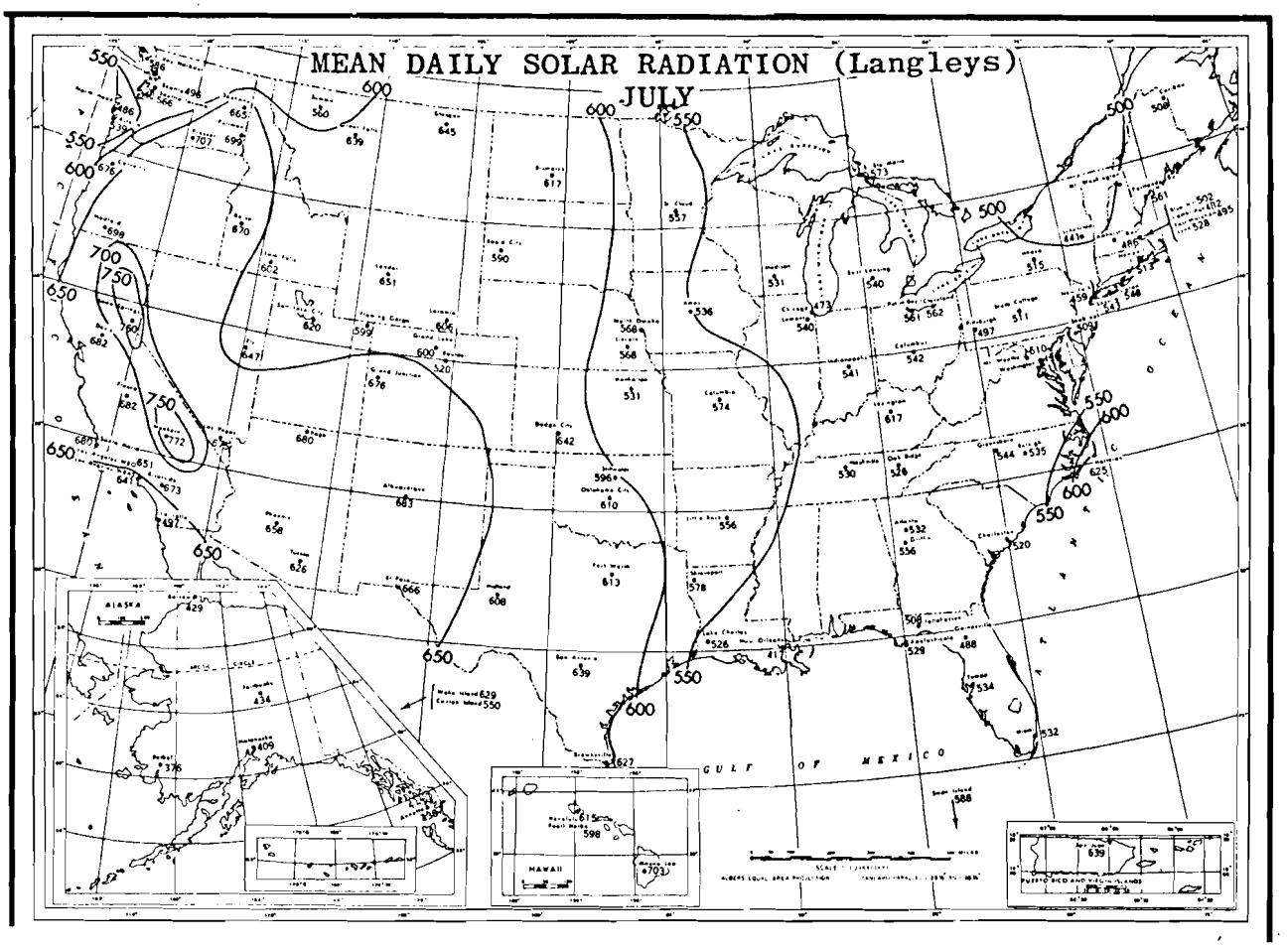


Figure 1 (3)

Mean Daily Solar Radiation (Langleys), July*

* Based on all usuable solar radiation data, direct and diffuse, measured on a horizontal surface and published in the Monthly Weather Review and Climatological Data National Summary through 1962. All data were measured in, or were reduced to, the International Scale of Pyrheliometry, 1956. Langley is the unit used to denote one gram calorie per square centimeter (1 langley = 1 gm. cal. cm^{-2}.

at Phoenix and 399 at Prosser, a difference of only 23%.

The average daily total at the Hanford Meteorology Station[2] is 663 Langleys and the yearly average is 372 Langleys. This is slightly lower than at Prosser. It is possible that there is a slight difference in measuring systems.

From Figures 1 & 2, Table 2, and References 2 and 3, the mean daily solar radiation on an annual basis and in July at several locations is shown below.

	Annual	July
Hanford Met. Station	372	663
Prosser	399	707
Los Angeles	436	651
Washington, D.C. (C.O.)	356	536
Twin Falls, Idaho	378	602
Chicago, Ill	273	473
Lemont, Ill	352	540
Alberqueque	512	683
Phoenix	520	658
Oak Ridge	364	526
New York	298	459

As seen in Figure 3 and Table 3, the Hanford reservation is in an area with many total hours of sunshine compared to the rest of the Northwest. The hours of sunshine are comparable to those in Florida, but not comparable to those in the Southwest.

In the Hanford area the four cloudiest months are November through February.[2] The remainder of the year, particularly July (see Figure 4) has a high percentage of sunny days.

It should be noted that the energy collected on a given area of properly tilted flat plate or parabolic collector will be only slightly less at 45°N latitude than at 20°N latitude given comparable atmospheric conditions. This effect is illustrated in Figure 5. The significant fact in this is that while a greater land area may be required in northern latitudes, the collector area is not much greater to collect comparable solar energy while the sun is shining.

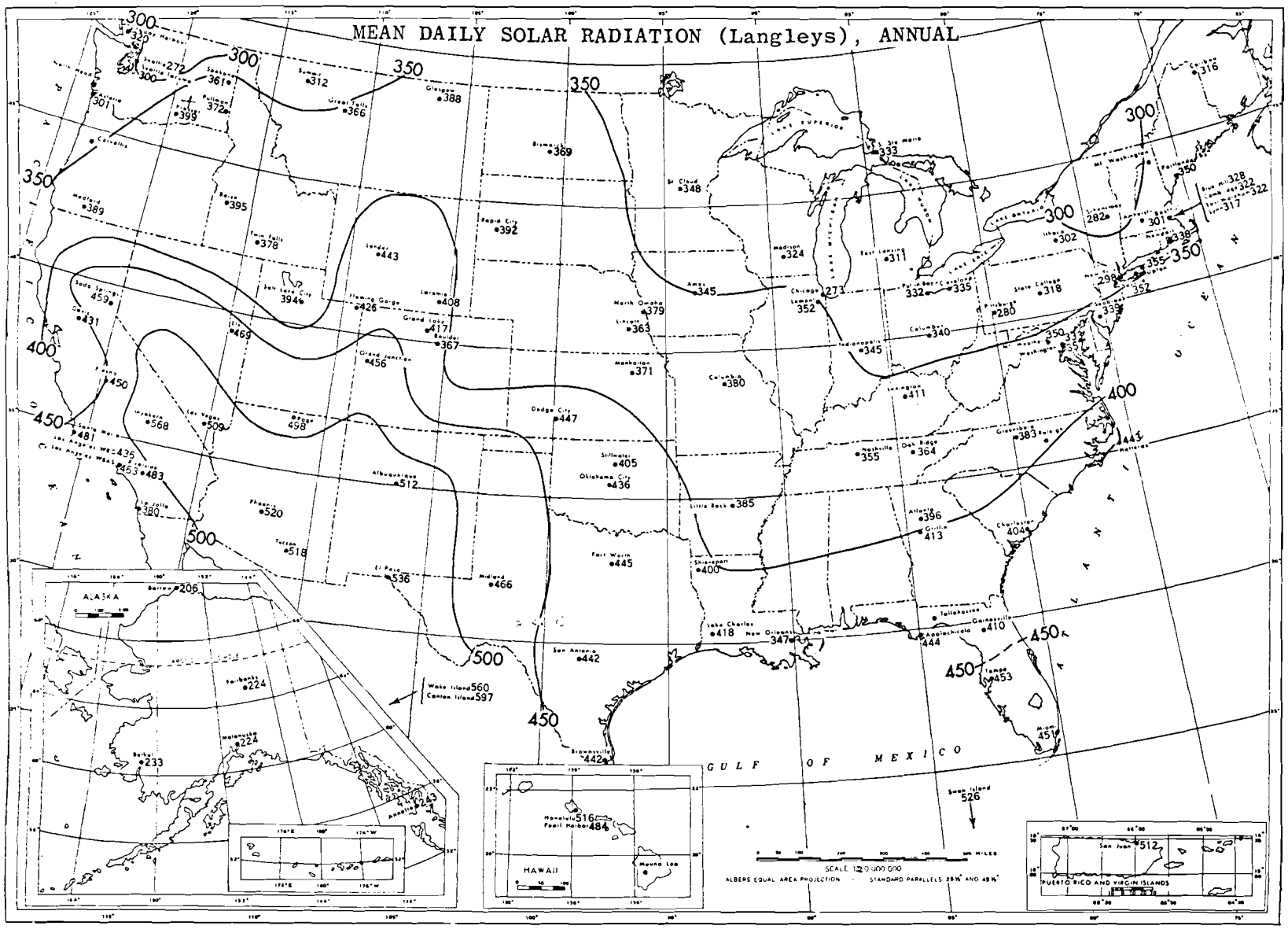


Figure 2.(3) Mean Daily Solar Radiation (Langleys), Annual*

*Based on all usuable solar radiation data, direct and diffuse, measured on a horizontal surface and published in the Monthly Westher Review and Climatological Data National Summary through 1962. All data were measured in, or were reduced to, the International Scale of Pyrheliometry, 1956. Langley is the unit used to denote one gram calorie per square centimeter (1 langley = 1 gm. cal. cm^{-2}).

Table 2 (3)

MEAN DAILY SOLAR RADIATION (Langleys) AND YEARS OF RECORD USED

STATES AND STATIONS	JAN	YRS	FEB	YRS	MAR	YRS	APR	YRS	MAY	YRS	JUNE	YRS	JULY	YRS	AUG	YRS	SEPT	YRS	OCT	YRS	NOV	YRS	DEC	YRS	ANNUAL
ALASKA, Annette	63	6	115	6	236	7	364	7	437	6	438	6	438	6	341	6	258	7	122	7	59	7	41	7	243
Barrow	*		38	8	180	8	380	8	513	8	528	8	429	9	255	10	115	10	41	10	#		#		206
Bethel	38	9	108	10	292	9	444	10	457	10	454	10	376	10	252	10	202	10	115	10	44	9	22	9	233
Fairbanks	16	25	71	27	213	25	376	28	461	28	504	29	434	28	317	29	180	29	82	30	26	26	6	26	224
Matanuska	32	6	92	6	242	4	356	7	436	7	462	6	409	6	314	6	198	6	100	6	38	6	15	7	224
ARIZ., Page	300	2	382	3	526	3	618	2	695	2	707	2	680	3	596	3	516	3	402	3	310	3	243	3	498
Phoenix	301	11	409	11	526	11	638	11	724	11	739	11	658	11	613	11	566	11	449	11	344	11	281	11	520
Tucson	315	5	391	5	540	4	655	5	729	5	699	5	626	6	588	6	570	6	442	6	356	6	305	6	518
ARK., Little Rock	188	9	260	9	353	10	446	9	523	9	559	9	556	8	518	9	439	7	343	8	244	10	187	10	385
CALIFORNIA, Davis	174	18	257	17	390	18	528	18	625	18	694	18	682	18	612	18	493	18	347	19	222	19	148	19	431
Fresno	184	31	289	31	427	31	552	31	647	31	702	32	682	32	621	31	510	31	376	32	250	31	161	32	450
Inyokern (China Lake)	306	11	412	11	562	11	683	11	772	11	819	11	772	11	729	10	635	8	467	9	363	11	300	12	568
LaJolla	244	19	302	18	397	19	457	20	506	19	487	21	497	22	464	22	389	22	320	21	277	20	221	20	380
Los Angeles WBAS	248	10	331	10	470	10	515	10	572	9	596	9	641	9	581	10	503	10	373	10	289	10	241	10	463
Los Angeles WBO	243	9	327	9	436	9	483	9	555	9	584	9	651	9	581	10	500	10	362	10	281	10	234	10	436
Riverside ‡	275	8	367	8	478	9	541	9	623	9	680	9	673	9	618	9	535	9	407	9	319	9	270	9	483
Santa Maria	263	11	346	11	482	11	552	10	635	11	694	11	680	11	613	11	524	11	419	11	313	11	252	11	481
Soda Springs	223	4	316	3	374	4	551	4	615	3	691	4	760	3	681	3	510	3	357	4	248	4	182	3	439
COLO., Boulder	201	5	268	4	401	4	460	4	460	4	525	5	520	5	439	5	412	4	310	4	222	4	182	4	367
Grand Junction	227	9	324	9	434	8	546	8	615	9	708	8	676	8	595	8	514	8	373	10	260	10	212	10	456
Grand Lake (Granby)	212	6	313	7	423	7	512	8	552	8	632	8	600	8	505	7	476	6	361	7	234	6	184	7	417
D. C., Washington (C.O.)	174	3	266	3	344	2	411	2	551	2	494	2	536	2	446	3	375	3	299	3	211	3	166	3	356
American University	158	39	231	39	322	39	398	39	467	39	510	39	496	39	440	38	364	38	278	38	192	39	141	39	333
Silver Hill	177	7	247	6	342	7	438	7	513	7	555	7	511	7	457	7	391	8	293	8	202	7	156	6	357
FLA., Apalachicola	298	10	367	10	441	10	535	10	603	9	578	9	529	9	511	9	456	9	413	10	332	10	262	10	444
Belle Isle	297	10	330	10	412	10	463	10	483	10	464	10	488	11	461	10	400	10	366	11	313	11	291	10	397
Gainesville	267	11	343	10	427	12	517	12	579	12	521	10	488	10	483	8	418	9	347	8	300	10	233	10	410
Miami Airport	349	10	415	9	489	9	540	10	553	10	532	10	532	10	505	10	440	10	384	10	353	10	316	10	451
Tallahassee	274	2	311	2	423	3	499	3	547	3	521	3	508	3	542	2	*		*		292	2	230	2	---
Tampa	327	8	391	8	474	8	539	8	596	8	574	9	534	9	494	9	452	9	400	9	356	9	300	9	453
GA., Atlanta	218	11	290	11	380	11	488	11	533	11	562	11	532	10	508	10	416	10	344	11	268	11	211	11	396
Griffin	234	9	295	9	385	10	522	11	570	11	577	11	556	11	522	11	435	11	368	11	283	11	201	11	413
HAWAII, Honolulu	363	4	422	4	516	4	559	5	617	5	615	5	615	5	612	5	573	5	507	5	426	5	371	5	516
Mauna Loa Obs.	522	2	576	2	680	2	689	3	727	3	*		703	3	642	2	602	2	560	2	504	2	481	3	---
Pearl Harbor	359	5	400	4	487	4	529	5	573	5	566	5	598	5	567	5	539	5	466	5	386	5	343	5	484
IDAHO, Boise	138	10	236	9	342	9	485	9	585	10	636	9	670	10	576	10	460	10	301	11	182	11	124	11	395
Twin Falls	163	20	240	20	355	20	462	21	552	20	592	18	602	20	540	20	432	19	286	20	176	20	131	19	378
ILL., Chicago	96	19	147	19	227	19	331	19	424	19	458	18	473	19	403	18	313	19	207	20	120	20	76	20	273
Lemont	170	6	242	6	340	6	402	6	506	6	553	6	540	6	498	6	398	5	275	5	165	5	138	5	352
IND., Indianapolis	144	10	213	10	316	10	396	10	488	9	543	11	541	10	490	11	405	11	293	11	177	11	132	11	345
IOWA, Ames	174	5	253	5	326	5	403	5	480	5	541	5	436	6	460	6	367	6	274	7	187	7	143	7	345
KANS., Dodge City	255	7	316	7	418	7	528	7	568	7	650	7	642	8	592	9	493	9	380	9	285	10	234	10	447
Manhattan	192	3	264	3	345	3	433	3	527	4	551	4	531	4	526	4	410	4	292	4	227	4	156	4	371
KY., Lexington	172	9	263	9	357	10	480	10	581	10	628	9	617	10	563	10	494	10	357	9	245	9	174	11	411
LA., Lake Charles	245	11	306	11	397	11	481	11	555	11	591	11	526	11	511	11	449	11	402	11	300	10	250	10	418
New Orleans	214	14	259	14	335	15	412	16	449	14	443	13	417	15	416	15	383	15	357	13	278	13	198	14	347
Shreveport	232	3	292	3	384	3	446	4	558	4	557	4	578	4	528	4	414	4	354	4	254	4	205	4	400
MAINE, Caribou	133	8	231	9	364	8	400	10	476	10	470	10	508	11	448	11	336	11	212	11	111	11	107	9	316
Portland	152	7	235	8	352	7	409	8	514	9	539	9	561	9	488	8	383	7	278	9	157	8	137	9	350
MASS., Amherst	116	2	*		300	2	*		431	2	514	2	*		---		---		---		152	2	124	2	---
Blue Hill	153	27	228	27	319	26	389	26	469	27	510	27	502	26	449	27	354	28	266	28	162	28	135	28	328
Boston	129	16	194	17	290	17	350	17	445	16	483	16	486	16	411	16	334	17	235	16	136	16	115	15	301
Cambridge	153	4	235	3	323	3	400	3	420	3	476	3	482	4	464	4	367	4	253	4	164	4	124	4	322
East Wareham	140	13	218	13	305	12	385	14	452	14	508	14	495	14	436	14	365	13	258	14	163	14	140	13	322
Lynn	118	2	209	2	300	2	394	2	454	2	549	4	528	4	432	3	341	2	241	3	135	3	107	3	317
MICH., East Lansing	121	10	210	11	309	11	359	11	483	10	547	11	540	11	466	11	373	11	255	11	136	11	108	11	311
Sault Ste. Marie	130	10	225	9	356	10	416	10	523	10	557	11	573	11	472	10	322	10	216	9	105	9	96	9	333
MINN., St. Cloud	168	8	260	8	368	8	426	8	496	8	535	8	557	9	486	8	366	8	237	7	146	8	124	8	348
MO., Columbia (C. O.)	173	10	251	10	340	11	434	11	530	11	574	11	574	10	522	10	453	10	322	10	225	10	158	9	380
University of Missouri	166	5	248	6	324	6	429	6	501	6	560	6	583	6	509	6	417	6	324	5	177	5	146	5	365
MONT., Glasgow	154	6	258	8	385	7	466	8	568	8	605	8	645	9	531	10	410	10	267	8	154	8	116	7	388
Great Falls	140	8	232	9	366	9	434	8	528	8	583	8	639	9	532	9	407	10	264	10	154	10	112	10	366
Summit	122	3	162	2	268	3	414	3	462	3	493	3	560	2	510	2	354	2	216	2	102	2	76	2	312
NEBR., Lincoln	188	39	259	39	350	39	416	39	494	40	544	38	568	38	484	38	396	38	296	36	199	40	159	39	363
North Omaha	193	3	299	3	365	3	463	3	516	3	546	4	568	4	519	4	410	4	298	4	204	4	170	4	379
NEV., Ely	236	7	339	9	468	9	563	9	625	10	712	10	647	11	618	11	518	11	394	10	289	10	218	10	469
Las Vegas	277	11	384	11	519	11	621	11	702	11	748	10	675	11	627	11	551	11	429	11	318	11	258	11	509
N. J., Seabrook	157	8	227	8	318	8	403	8	482	9	527	8	509	8	455	9	385	9	278	7	192	8	140	8	339
N. H., Mt. Washington	117	2	218	2	238	2	*		*		*		---		---		*		*		*		96	2	---
N. Mex., Albuquerque	302	13	386	13	511	13	618	13	686	13	726	13	683	12	626	13	554	14	438	15	334	15	276	14	512
N. Y., Ithaca	116	22	194	21	272	23	334	23	440	24	501	23	515	23	453	23	346	21	231	22	120	23	96	23	302
N. Y. Central Park	130	34	199	34	290	33	369	35	432	35	470	34	459	35	389	35	331	36	242	36	147	36	115	35	298
Sayville	160	11	249	11	335	10	415	10	494	10	565	10	543	10	462	10	385	10	289	10	186	10	142	11	352
Schenectady	130	8	200	9	273	9	338	9	413	9	448	8	441	8	397	8	299	8	218	8	128	8	104	8	282
Upton	155	8	232	8	339	8	428	8	502	8	573	8	543	7	475	7	391	7	293	6	182	7	146	7	355
N. C., Greensboro	200	7	276	9	354	9	469	9	531	10	564	10	544	10	485	10	406	10	322	10	243	10	197	8	383
Hatteras	238	10	317	9	426	8	569	9	635	10	652	10	625	10	562	11	471	11	358	11	282	11	214	11	443
Raleigh	235	3	302	2	*		466	3	494	2	564	2	535	3	476	3	379	3	307	3	235	3	199	3	---
N. D., Bismarck	157	7	250	8	356	6	447	8	550	8	590	9	617	10	516	11	390	11	272	11	161	10	124	10	369
OHIO., Cleveland	125	6	183	6	303	7	286	8	502	8	562	8	562	8	494	8	278	8	289	9	141	9	115	7	335
Columbus	128	7	200	7	297	7	391	7	471	6	562	4	542	5	477	4	422	4	286	4	176	4	129	5	340
Put-in-Bay	126	10	204	9	302	10	386	11	468	11	544	11	561	10	487	10	382	11	275	11	144	11	109	11	332
OKLA., Oklahoma City	251	10	319	10	409	9	494	10	536	10	615	7	610	8	593	8	487	9	377	10	291	9	240	9	436
Stillwater	205	8	289	8	390	9	454	9	504	9	600	10	596	10	545	10	455	11	354	10	269	9	209	8	405
OREG., Astoria	90	7	162	8	270	8	375	8	492	8	469	8	539	8	461	7	354	7	209	8	111	8	79	8	301
Corvallis	89	2	*		287	3	406	3	517	3	570	3	676	4	558	4	397	4	235	4	144	4	80	4	---
Medford	116	11	215	11	336	11	482	11	592	11	652	11	698	10	605	11	447	11	279	11	149	11	93	11	389
PA., Pittsburgh	94	6	169	5	216	6	317	6	429	6	491	6	497	7	409	6	339	6	207	5	118	6	77	5	280
State College	133	19	201	19	295	20	380	20	456	20	518	20	511	20	444	20	358	20	256	20	149	20	118	20	318
R. I., Newport	155	23	232	22	334	23	405	23	477	23	527	24	513	24	455	24	377	24	271	24	176	24	139	24	338

Table 2 (Cont'd)

MEAN DAILY SOLAR RADIATION (Langleys) AND YEARS OF RECORD USED

STATES AND STATIONS	JAN	YRS	FEB	YRS	MAR	YRS	APR	YRS	MAY	YRS	JUNE	YRS	JULY	YRS	AUG	YRS	SEPT	YRS	OCT	YRS	NOV	YRS	DEC	YRS	ANNUAL
S. C., Charleston	252	11	314	11	388	11	512	11	551	11	564	11	520	11	501	11	404	11	338	11	286	11	225	11	404
S. D., Rapid City	183	11	277	11	400	11	482	11	532	11	585	11	590	11	541	11	435	11	315	10	204	10	158	10	392
TENN., Nashville	149	18	228	19	322	19	432	19	503	18	551	18	530	17	473	17	403	17	308	19	208	18	150	19	355
Oak Ridge	161	11	239	11	331	11	450	11	518	11	551	11	526	11	478	11	416	11	318	11	213	10	163	11	364
TEXAS, Brownsville	297	16	341	10	402	10	456	11	564	10	610	9	627	8	568	11	475	11	411	11	296	11	263	10	442
El Paso	303	11	430	11	547	10	654	11	714	11	729	11	666	11	640	10	576	11	460	11	372	11	313	11	536
Ft. Worth	259	11	320	11	427	11	488	11	562	11	651	11	613	11	593	11	503	11	403	11	306	11	245	9	445
Midland	283	7	358	8	476	9	550	8	611	8	617	8	608	7	574	8	522	9	396	9	325	8	275	8	466
San Antonio	279	9	347	9	417	9	445	9	541	9	612	9	639	9	585	9	493	10	398	10	295	10	256	8	442
UTAH, Flaming Gorge	258	2	298	2	443	2	522	2	565	2	650	2	599	3	538	3	425	3	352	3	262	3	215	3	426
Salt Lake City	195	8	256	8	354	8	479	8	570	7	621	7	620	6	551	7	446	8	316	8	204	8	146	9	394
VA., Mt. Weather	172	2	274	2	338	2	414	2	508	2	525	3	510	3	430	3	375	3	281	2	202	2	168	2	350
WASH., North Head	*		167	2	257	3	432	2	509	3	487	3	486	3	436	3	321	3	205	3	122	3	77	3	---
Friday Harbor	67	8	157	7	274	8	418	8	514	9	578	10	585	10	507	11	351	8	194	10	102	10	75	8	320
Prosser	117	4	222	4	351	4	521	5	616	4	680	4	707	4	604	4	458	4	274	4	136	4	100	4	399
Pullman	121	4	205	2	304	2	462	2	558	4	653	5	699	5	562	4	410	4	245	5	146	5	96	5	372
University of Washington	67	9	128	9	245	10	364	9	445	10	461	10	495	11	435	10	299	8	170	9	93	9	59	9	272
Seattle-Tacoma	73	9	139	9	265	9	403	9	503	9	511	9	566	9	452	10	324	10	188	10	104	9	64	10	300
Spokane	115	8	204	8	321	8	474	9	563	9	596	9	665	9	556	9	404	10	225	9	131	9	75	7	361
WIS., Madison †	148	46	220	46	313	45	394	47	466	47	514	47	531	47	452	47	348	47	241	47	145	44	115	46	324
WYO., Lander	225	8	324	9	452	9	548	11	587	11	678	11	651	11	586	10	472	8	354	9	239	9	196	9	443
Laramie	215	3	295	3	424	3	508	3	554	3	643	3	606	3	536	3	438	3	324	3	229	3	186	4	408
ISLAND STATIONS																									
Canton Island	588	9	626	7	634	7	604	9	561	9	549	8	550	9	597	9	640	9	651	9	600	8	572	8	597
San Juan, P. R.	401	5	481	4	580	4	622	4	519	5	536	6	639	5	549	6	531	6	460	6	411	6	411	6	512
Swan Island	442	5	465	7	615	6	646	6	625	6	544	8	588	8	591	7	535	8	457	7	394	8	382	8	526
Wake Island	438	7	515	7	577	7	627	7	642	8	656	6	629	7	623	7	587	6	525	7	482	7	421	7	560

NOTES:

* Denotes only one year of data for the month -- no means computed

--- No data for the month (or incomplete data for the year).

\# Barrow is in darkness during the winter months.

† Madison data after 1957 not used due to exposure influences.

‡ Riverside data prior to March 1952 not used-instrumental discrepancies.

Langley is the unit used to denote one gram calorie per square centimeter.

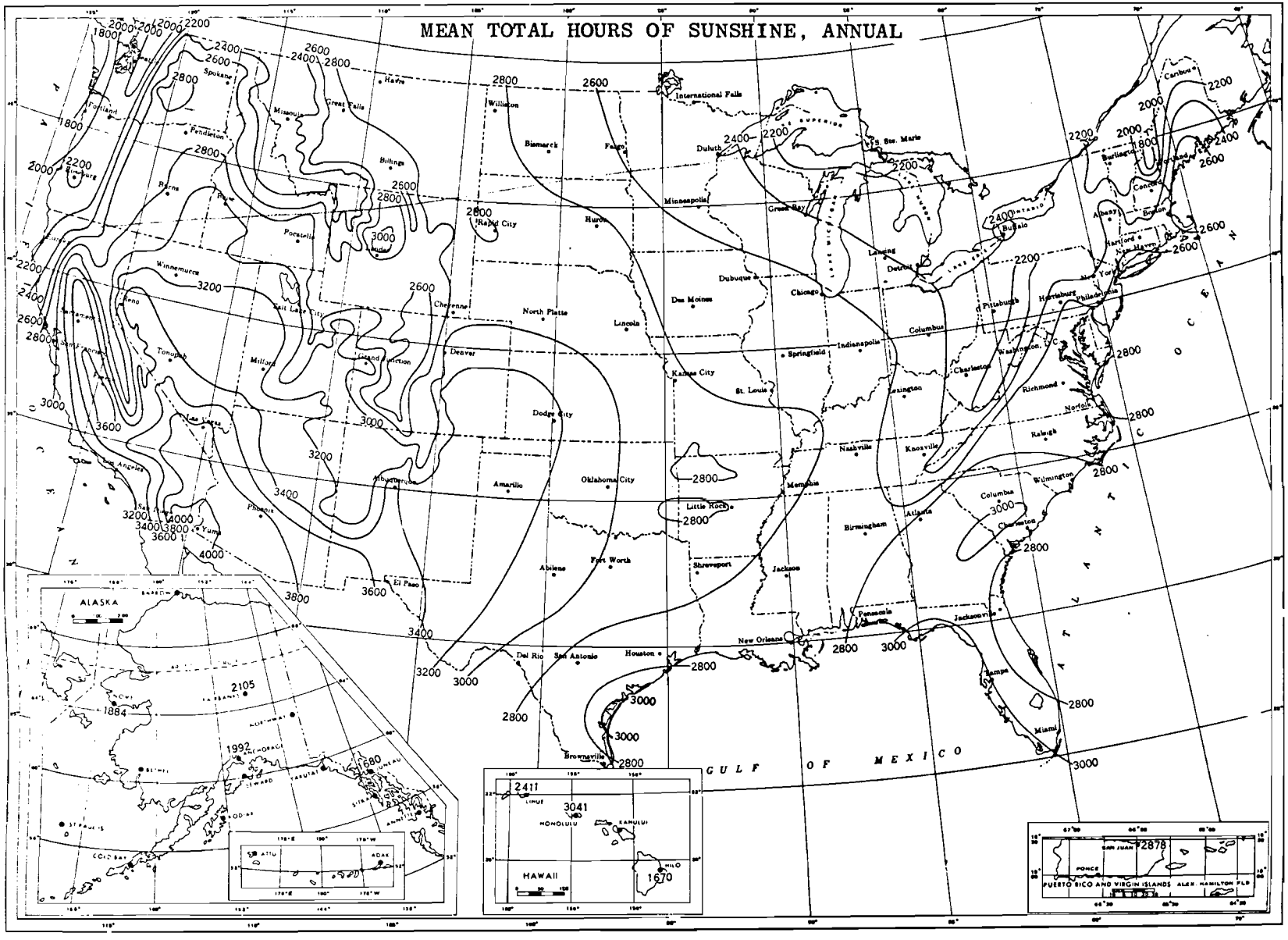


Figure 3.[3] Mean Total Hours of Sunshine, Annual

Table 3 (3)

MEAN NUMBER OF HOURS OF SUNSHINE

STATE AND STATION	YEARS	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL
ALA. BIRMINGHAM	30	138	152	207	248	293	294	269	265	244	234	182	136	2682
MOBILE	22	157	158	212	253	301	299	249	259	235	254	195	146	2708
MONTGOMERY	30	160	168	227	267	317	311	288	296	260	250	200	156	2894
ALASKA ANCHORAGE	19	78	111	210	231	258	288	235	184	128	96	68	49	1992
FAIRBANKS	20	54	120	224	302	319	334	274	164	122	83	71	36	2103
JUNEAU	29	71	102	171	200	230	251	193	161	123	67	60	51	1680
NOME	27	72	109	193	226	285	297	204	146	142	101	67	42	1884
ARIZ. PHOENIX	30	248	244	314	346	404	404	377	351	334	307	267	236	3832
PRESCOTT	11	232	239	293	323	376	392	393	303	315	286	254	228	3349
TUCSON	13	255	266	317	350	399	394	329	329	335	317	280	258	3829
YUMA	30	258	266	337	365	419	420	404	380	351	330	283	262	4077
ARK. FT. SMITH	30	146	156	202	234	268	303	321	305	261	230	174	147	2747
LITTLE ROCK	30	143	158	213	243	291	316	321	316	265	251	181	142	2840
CALIF. EUREKA	30	120	138	180	209	247	261	214	205	195	164	127	108	2198
FRESNO	29	153	192	283	310	344	418	435	406	355	306	221	144	3632
LOS ANGELES	30	221	217	273	264	292	300	352	336	295	263	249	220	3284
RED BLUFF	15	156	186	215	302	366	375	438	407	341	277	199	154	3466
SACRAMENTO	30	134	169	255	306	367	405	437	406	347	293	197	122	3422
SAN DIEGO	30	216	212	262	242	261	253	293	277	255	234	236	217	2958
SAN FRANCISCO	30	165	182	251	281	314	330	300	272	267	243	198	156	2959
COLO. DENVER	30	207	205	247	252	281	311	321	297	274	246	200	192	3033
GRAND JUNCTION	30	169	182	243	265	314	350	349	311	291	255	198	168	3095
PUEBLO	30	221	217	261	271	299	340	349	318	290	265	225	211	3270
CONN. HARTFORD	30	141	166	206	223	267	285	299	268	220	193	137	136	2541
NEW HAVEN	30	155	172	215	234	274	291	309	281	238	215	157	154	2704
D. C. WASHINGTON	30	138	160	205	226	267	288	291	264	233	207	162	135	2576
FLA. APALACHICOLA	26	193	195	233	274	328	296	273	259	236	263	216	175	2941
JACKSONVILLE	30	192	159	241	267	296	260	255	248	199	205	191	170	2713
KEY WEST	20	229	238	285	296	307	273	277	259	236	237	226	225	3098
LAKELAND	7	204	186	222	251	285	268	252	242	203	209	212	198	2732
MIAMI	30	222	227	266	275	280	251	267	263	216	215	212	209	2903
PENSACOLA	30	175	180	232	270	311	302	278	284	249	265	206	166	2918
TAMPA	30	223	220	260	283	320	275	257	252	232	243	227	209	3001
GA. ATLANTA	25	154	165	218	266	309	301	284	285	247	241	188	160	2821
MACON	30	177	178	235	279	321	314	292	295	253	236	202	168	2950
SAVANNAH	30	175	173	229	274	307	279	267	256	212	216	197	167	2752
HAWAII HILO	7	153	135	161	112	106	158	184	134	137	153	106	131	1670
HONOLULU	30	227	202	250	255	276	230	293	290	279	257	221	211	3041
LIHUE	10	171	162	176	176	211	246	246	236	246	210	170	161	2411
IDAHO BOISE	30	116	144	218	274	322	352	412	378	311	232	143	104	3006
POCATELLO	30	111	143	211	255	300	338	380	347	296	230	145	108	2864
ILL. CAIRO	15	124	160	218	254	298	324	345	336	279	254	181	145	2918
CHICAGO	30	126	142	199	221	274	300	333	299	247	216	136	118	2611
MOLINE	18	132	139	189	214	255	279	337	300	231	214	130	123	2563
PEORIA	30	134	149	198	229	273	303	335	299	259	222	149	122	2673
SPRINGFIELD	30	127	149	193	224	282	304	346	312	266	225	152	122	2702
IND. EVANSVILLE	30	123	145	199	237	294	322	342	318	274	236	156	120	2766
FT. WAYNE	30	113	136	191	217	281	310	342	306	242	210	120	102	2570
INDIANAPOLIS	30	118	140	193	227	278	313	342	313	265	222	139	118	2868
TERRE HAUTE	24	125	148	189	231	274	302	341	305	253	235	150	122	2675
IOWA BURLINGTON	19	148	165	217	241	284	315	353	327	270	243	175	147	2885
CHARLES CITY	22	137	157	190	226	258	285	336	290	241	207	130	115	2572
DES MOINES	30	155	170	203	236	276	303	346	299	263	237	156	136	2770
SIOUX CITY	30	164	177	216	254	300	320	363	320	270	236	160	146	2926
KAN. CONCORDIA	30	180	172	214	243	281	315	348	308	249	245	189	172	2916
DODGE CITY	30	205	191	249	268	305	335	359	333	290	266	218	198	3219
TOPEKA	18	159	160	193	215	260	287	310	304	263	229	173	149	2702
WICHITA	30	187	186	233	254	291	321	350	325	277	245	206	182	3057
KY. LOUISVILLE	30	115	135	188	221	283	303	324	295	256	219	148	114	2601
LA. NEW ORLEANS	30	160	158	213	247	292	287	260	269	241	260	200	157	2744
SHREVEPORT	19	151	172	214	240	298	332	339	322	289	273	208	177	3015
MAINE EASTPORT	22	133	151	196	201	245	248	273	260	205	175	105	115	2309
PORTLAND	30	155	174	213	226	268	288	312	294	229	202	146	148	2653
MD. BALTIMORE	30	148	170	211	229	270	295	299	272	238	212	164	145	2653
MASS. BLUE HILL OBS.	10	125	136	165	182	233	248	266	241	211	181	134	135	2257
BOSTON	30	148	168	212	222	263	283	300	280	232	207	152	148	2615
NANTUCKET	22	128	156	214	227	278	284	291	279	242	208	149	129	2585
MICH. ALPENA	21	86	124	198	228	261	303	339	285	204	159	70	67	2324
DETROIT	30	90	128	180	212	263	293	321	284	226	189	98	89	2375
LANSING	30	84	119	175	215	272	305	344	294	228	182	87	73	2378
ESCANABA	30	112	148	204	226	266	283	316	267	198	162	90	94	2366
GRAND RAPIDS	30	74	117	178	218	277	308	349	304	231	188	92	70	2406
MARQUETTE	30	78	113	172	207	248	268	305	251	186	142	68	66	2104
SAULT STE. MARIE	30	83	123	187	217	252	269	309	256	165	133	61	62	2117
MINN. DULUTH	30	125	163	221	235	268	282	328	277	203	166	100	107	2475
MINNEAPOLIS	30	140	166	200	231	272	302	343	296	237	193	115	112	2607
MISS. JACKSON	12	130	147	199	244	280	287	279	287	235	223	185	150	2646
VICKSBURG	30	136	141	199	232	284	304	291	297	254	244	183	140	2705
MO. COLUMBIA	30	147	154	207	232	281	296	341	298	262	225	166	138	2757
KANSAS CITY	30	154	170	211	235	278	313	347	308	266	235	178	151	2846
ST. JOSEPH	23	154	165	211	231	274	301	347	287	260	224	168	144	2766
ST. LOUIS	30	137	152	202	235	283	301	325	289	256	223	166	125	2694
SPRINGFIELD	30	145	164	213	238	278	305	342	310	269	233	183	140	2820
MONT. BILLINGS	21	140	154	208	236	283	301	372	332	258	213	136	129	2762
GREAT FALLS	19	154	176	245	261	299	299	381	342	256	206	132	133	2884
HAVRE	30	138	174	234	268	311	312	384	339	260	202	132	122	2874
HELENA	30	138	168	215	241	292	292	342	336	258	202	137	121	2742
MISSOULA	25	85	109	167	209	261	260	378	328	246	178	90	66	2377
NEBR. LINCOLN	30	173	172	213	244	287	316	356	309	266	237	174	160	2907
NORTH PLATTE	30	181	179	221	246	282	310	343	304	264	242	184	169	2923
OMAHA	30	172	188	222	259	305	332	379	311	270	248	166	145	2997
VALENTINE	30	185	194	229	252	296	323	369	326	275	242	174	172	3037
NEV. ELY	22	186	197	262	250	300	354	359	344	303	255	204	187	3211
LAS VEGAS	8	239	251	314	336	386	411	383	364	345	301	258	250	3838
RENO	30	185	199	267	306	354	376	414	391	336	273	212	170	3483
WINNEMUCCA	30	142	155	207	255	312	345	393	375	316	242	177	139	3061
N. H. CONCORD	23	136	153	192	196	229	261	286	260	214	179	122	126	2354
MT. WASHINGTON OBS.	18	94	98	133	141	162	145	150	143	139	139	89	87	1540
N. J. ATLANTIC CITY	30	151	173	210	233	273	287	294	271	239	218	177	153	2683
TRENTON	30	145	168	203	235	277	294	309	273	239	208	160	142	2653
N. MEX. ALBUQUERQUE	30	222	218	273	299	343	355	340	317	293	279	245	219	3418
ROSWELL	21	216	223	286	306	330	333	341	313	266	266	242	216	3340
N. Y. ALBANY	30	125	151	194	213	266	301	317	286	224	192	115	112	2496
BINGHAMTON	30	94	119	151	170	226	256	266	230	184	158	92	79	2025
BUFFALO	30	110	125	180	212	274	319	333	297	239	183	97	84	2458
NEW YORK	30	154	171	213	237	268	289	302	271	235	213	169	155	2677
ROCHESTER	30	93	123	172	209	274	314	333	294	224	173	97	86	2392
SYRACUSE	30	87	115	165	197	261	295	316	276	211	163	81	74	2241
N. C. ASHEVILLE	30	146	161	211	247	289	292	268	250	235	222	179	146	2646
CAPE HATTERAS	9	152	168	206	259	293	301	286	265	214	202	169	154	2669
CHARLOTTE	30	165	177	230	267	313	316	291	277	247	243	198	167	2891
GREENSBORO	30	157	171	217	231	299	302	287	272	243	236	190	163	2767
RALEIGH	29	154	168	220	255	290	284	277	253	221	215	184	156	2680
WILMINGTON	30	179	180	237	279	314	312	286	273	237	238	206	178	2919
N. DAK. BISMARCK	30	141	170	205	236	279	294	358	307	243	198	130	125	2686
DEVILS LAKE	30	150	177	220	250	291	297	352	302	230	198	123	124	2714
FARGO	30	132	170	210	232	283	288	343	293	222	187	112	114	2586
WILLISTON	29	141	168	215	260	305	312	377	329	247	208	131	129	2819
OHIO CINCINNATI (ABBE)	30	115	137	188	222	273	309	323	295	253	205	138	118	2574
CLEVELAND	30	79	111	167	209	274	301	325	289	235	187	99	77	2352
COLUMBUS	30	112	132	177	215	270	296	323	291	250	210	131	101	2508
DAYTON	10	114	136	195	222	281	313	323	307	268	229	152	124	2664
SANDUSKY	30	100	128	193	229	285	312	343	302	248	201	111	91	2533
TOLEDO	30	93	120	170	203	263	296	331	298	241	196	106	92	2409
OKLA. OKLAHOMA CITY	29	175	182	235	253	290	329	352	331	292	243	201	175	3048
TULSA	18	152	164	200	213	244	287	314	308	261	241	207	172	2783
OREG. BAKER	22	119	143	198	251	302	313	406	368	299	215	132	100	2835
PORTLAND	30	77	97	142	203	246	249	329	275	218	134	87	65	2122
ROSEBURG	30	69	96	148	205	257	278	369	329	255	146	81	50	2283
PA. HARRISBURG	30	132	160	203	230	277	297	319	283	233	200	140	131	2604
PHILADELPHIA	30	142	166	203	231	270	281	288	253	225	205	158	142	2564
PITTSBURGH	25	89	114	163	200	239	260	283	250	234	180	114	76	2202
READING	30	133	151	195	220	259	275	293	259	219	198	144	127	2473
SCRANTON	30	108	138	178	199	251	269	290	249	213	183	120	105	2303
R. I. PROVIDENCE	30	145	168	211	221	271	285	292	267	226	207	153	143	2589
S. C. CHARLESTON	30	188	189	243	284	323	308	297	281	244	239	210	187	2993
COLUMBIA	30	173	183	233	274	312	312	291	283	243	242	202	166	2914
GREENVILLE	26	166	176	227	274	307	300	278	274	239	232	192	157	2822
S. DAK. HURON	30	153	177	213	250	295	321	367	320	260	212	142	134	2844
RAPID CITY	30	164	182	222	245	278	300	348	317	266	228	164	144	2858
TENN. CHATTANOOGA	30	126	146	187	239	290	295	278	266	217	220	169	128	2591
KNOXVILLE	30	124	144	189	237	281	288	277	248	237	213	157	120	2515
MEMPHIS	30	135	152	204	244	296	321	319	314	261	243	180	139	2808
NASHVILLE	30	123	142	196	241	285	308	292	279	250	224	168	126	2534
TEX. ABILENE	13	190	199	250	259	290	347	335	322	276	245	223	201	3137
AMARILLO	30	207	199	258	276	305	338	350	328	298	260	229	205	3243
AUSTIN	30	148	152	207	221	266	302	331	320	261	242	180	160	2790
BROWNSVILLE	30	147	152	187	210	272	297	326	311	246	252	165	151	2716
CORPUS CHRISTI	21	160	165	212	237	295	329	366	341	276	264	194	164	3003
DALLAS	30	155	159	220	238	279	326	341	325	274	240	191	163	2911
DEL RIO	27	173	173	230	237	259	279	331	319	252	240	195	178	2866
EL PASO	30	231	236	299	329	373	369	336	327	300	287	257	236	3583
GALVESTON	30	151	140	203	230	288	322	305	292	257	264	199	151	2811
HOUSTON	30	144	141	193	212	256	293	294	281	238	239	181	146	2633
PORT ARTHUR	30	153	149	209	235	292	317	295	281	252	256	191	144	2764
SAN ANTONIO	30	148	153	213	224	258	292	325	307	261	241	183	160	2765
UTAH SALT LAKE CITY	30	137	155	227	269	329	353	377	346	306	249	171	135	3059
VT. BURLINGTON	30	103	127	184	195	244	270	291	266	199	152	77	80	2178
VA. LYNCHBURG	26	153	169	216	243	288	297	288	264	235	217	177	158	2705
NORFOLK	30	156	174	223	257	304	311	296	232	237	220	182	161	2903
RICHMOND	30	144	165	211	248	280	295	245	263	230	211	176	152	2663
WASH. NORTH HEAD	22	76	97	135	182	221	214	226	186	170	123	87	66	1783
SEATTLE	30	74	99	154	201	247	234	304	248	197	122	77	62	2019
SPOKANE	30	78	120	197	262	308	309	397	350	264	177	86	57	2605
TATOOSH ISLAND	30	70	100	135	182	229	217	235	190	175	129	71	59	1792
WALLA WALLA	30	72	106	194	252	317	335	411	367	240	198	92	51	2685
W. VA. ELKINS	24	110	119	158	198	227	256	225	236	211	186	131	103	2160
PARKERSBURG	30	91	111	155	200	252	277	286	264	239	189	117	93	2285
WIS. GREEN BAY	30	121	148	194	210	251	279	314	266	213	176	110	106	2388
MADISON	30	126	147	195	214	258	285	336	288	230	198	115	109	2502
MILWAUKEE	30	116	134	191	213	267	293	340	292	235	193	125	106	2510
WYO. CHEYENNE	30	191	197	213	237	259	304	318	286	265	242	189	170	2900
LANDER	30	200	208	260	254	301	340	361	326	280	233	186	185	3144
SHERIDAN	30	160	179	226	245	286	303	367	313	266	221	153	145	2884
P. R. SAN JUAN	30	231	229	273	252	240	245	264	257	219	229	217	222	2878

The smoothed isolines on these charts and the data in this tabulation are based on Weather Bureau records from black-bulb type sunshine recorders. These values are those made during the 1931-60 period.

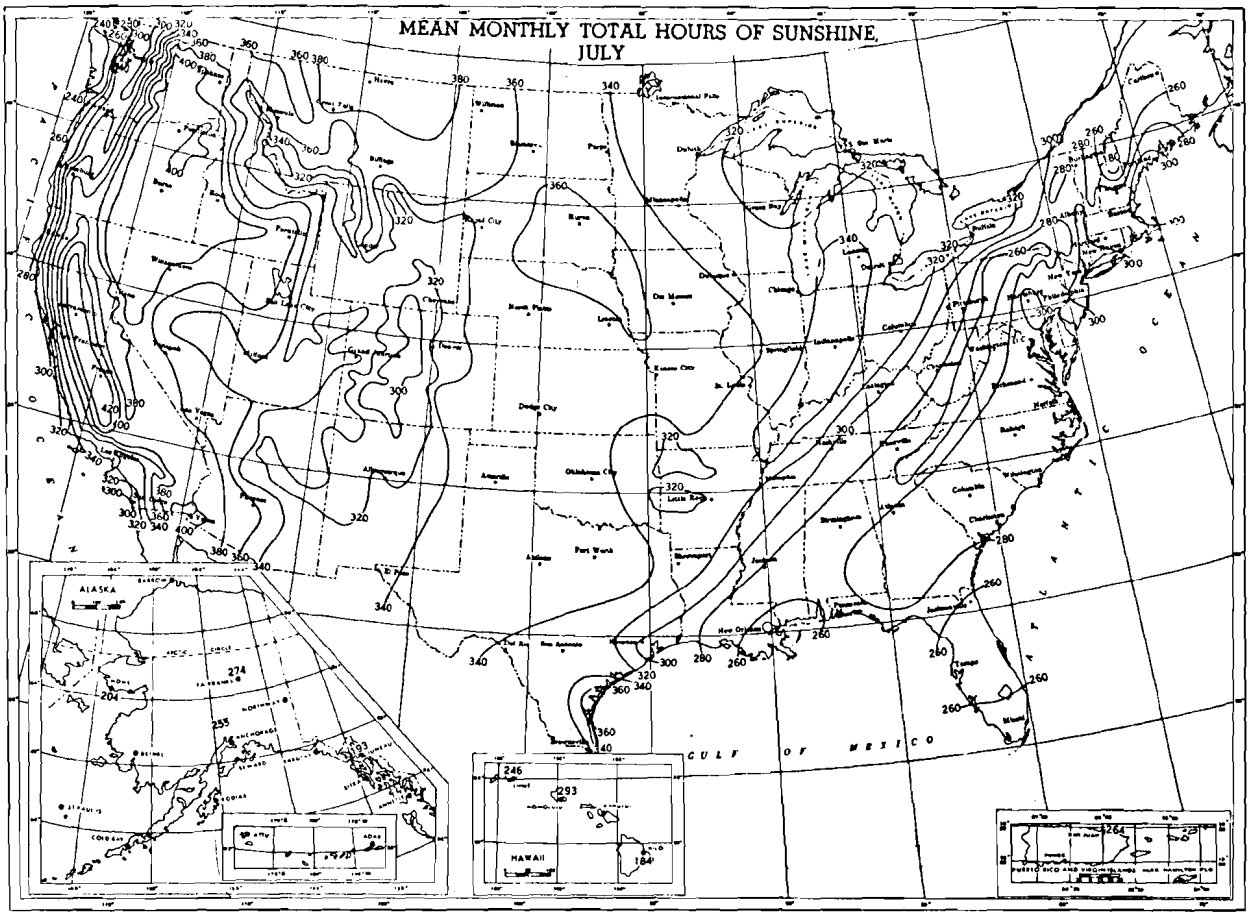
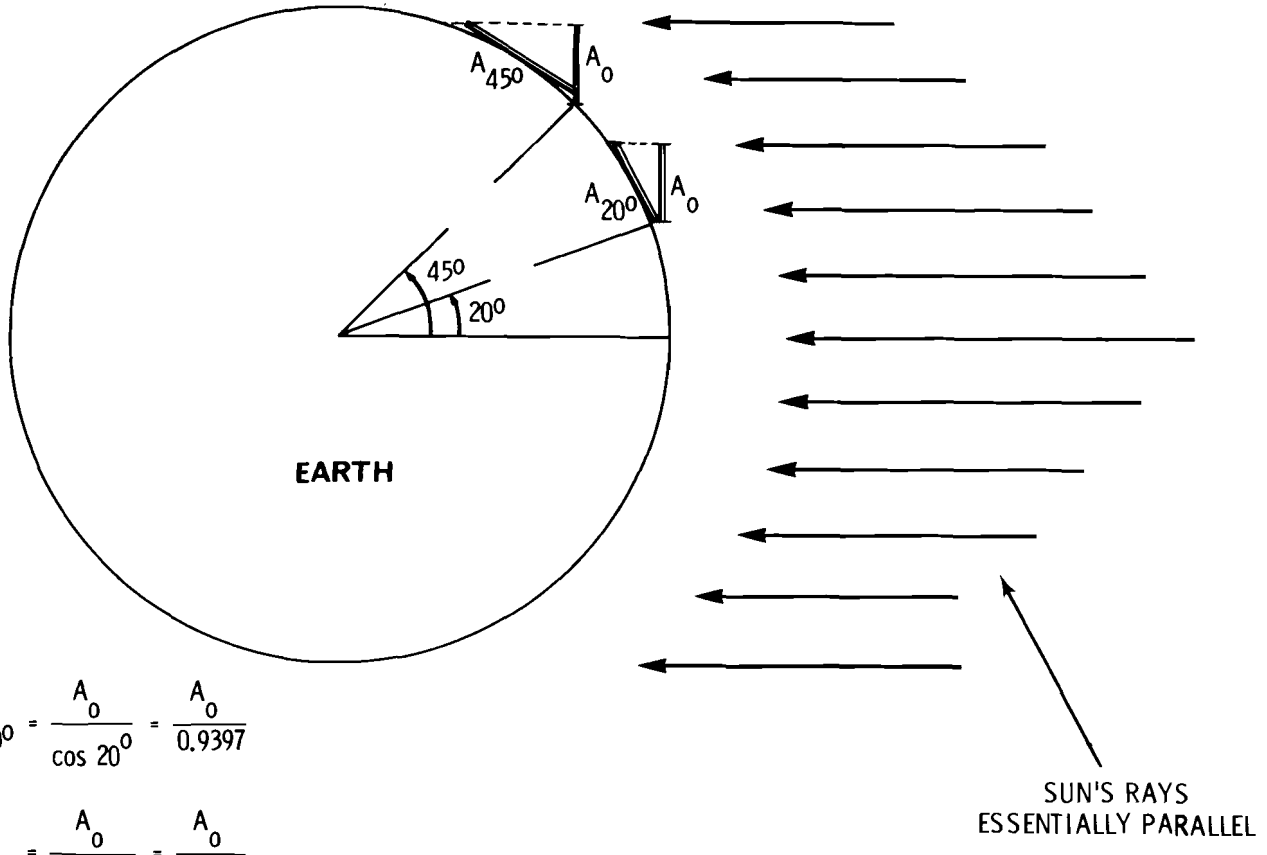


Figure 4 (3)

Mean Monthly Total Hours of Sunshine, July



$$A_{20^0} = \frac{A_0}{\cos 20^0} = \frac{A_0}{0.9397}$$

$$A_{45^0} = \frac{A_0}{\cos 45^0} = \frac{A_0}{0.7071}$$

A_{45^0} = AREA REQUIRED AT 45^0 NORTH LATITUDE = 1.42 A_0

A_{20^0} = AREA REQUIRED AT 20^0 NORTH LATITUDE = 1.07 A_0

THUS, LAND AREA REQUIRED AT 45^0N IS ABOUT 33% GREATER THAN THAT REQUIRED AT 20^0N (WILL VARY WITH TIME OF YEAR)

Figure 5. Illustration of the Difference in Solar Energy on Horizontal and Tilted Collectors

4.0 IMMEDIATE PROGRAM POSSIBILITIES

There are several programs which could be undertaken immediately to begin to take advantage of the Hanford site. These include:

1. Process development for photovoltaic device fabrication.
2. Process development for thin film heat trap fabrication.
3. Laboratories for collecting, analyzing and disseminating solar insolation data, and for device testing and calibration.
4. Utilization of 100 Area emergency generators for power production.
5. Hydrogen production development.
6. Building heating and cooling system development.
7. Systems analysis and economics.
8. System design.
9. National program planning.

4.1 Process Development for Photovoltaic Device Fabrication

Hanford is a leader in thin film fabrication by several different methods. The fabrication of solar cells is likely to utilize thin film processes.

The cost of the basic material in solar cells presently utilized is less than $.05/sq.ft. The cost of solar cells to be economically competitive with other means of central station power generation is in the $1/sq.ft. range. The basic requirement for direct solar energy conversion is thus the development of economical fabrication processes.

Pacific Northwest Laboratory is a leader in the field of sputtered material and has utilized the process for several advanced materials development programs.

The vacuum vapor deposition process developed for periscope mirrors is also potentially applicable to photovoltaic device fabrication. Chemical vapor deposition and thermal decomposition processes developed for isotopic heat source fabrication are also potentially applicable to solar cell fabrication.

Hanford personnel have a background in the fabrication of advanced ceramic and composite materials. This background would be useful in fabrication process development for single crystal solar cells such as the conventional silicon cells.

A broad background in advanced materials fabrication development and volume production processes can bring to bear an unexcelled capability in photovoltaic device fabrication process development.

4.2 Process Development for Thin Film Heat Trap Fabrication

The thin film process development capability described above is also directly applicable to the fabrication of interference films which will allow sunlight in through a cover plate but will not allow infrared rays back out. Such films are desirable for solar energy systems which utilize thermal energy. Thermal energy will be used for building heating and cooling, industrial processing, hydrogen production and central station power generation.

This technology is also applicable to the fabrication of reflector surfaces which will retain their reflectivity after long exposure to atmospheric conditions.

The extensive Hanford work in compatibility of materials under long term and elevated temperature conditions will also be directly applicable to heat trap development work.

4.3 Laboratories for Collecting, Analyzing and Disseminating Solar Insolation Data, and for Device Testing and Calibration(4)

Solar insolation data is incomplete, not standardized, lacks spectral information, suffers from lack of a systematic distribution method, and, in general, is inadequate for the country's present needs. For example, there has not been enough statistical analysis of temporal variation of insolation to permit reasonable evaluation of particular sites. Improvement is needed in intercalibration of devices, and satellite data often suffers from lack of absolute intensity calibration.

National laboratories for collecting, analyzing and disseminating data, and for device testing, calibration, and development are necessary to the orderly development of solar energy systems.

This work is very close to the kind of photometric calibration problems dealt with at Hanford. In fact, a Pacific Northwest Laboratory staff member prepared the standard documentation on photometric calibration for the Bureau of Standards for use during the International Geophysical Year.

4.4 Utilization of 100 Area Emergency Generators for Power Production

Several emergency generators are currently installed in the 100 Areas. These emergency generators are designed for operation on steam and are connected to the Bonneville grid.

In the K Areas there are six turbine-generators of 3500 Kw capacity each. They operate on 400 psi-750°F steam. In B and D Areas there are smaller turbine-generators (750 Kw) which operate at 200 psi with 62° superheat.

Each of the generator systems has a large (several million gallon capacity) clear well system nearby. The clear wells could quite possibly be utilized as salt tanks for energy storage. With the exception of collectors, basic components are thus in place for electrical generation utilizing solar energy

steam. These generators are also close to large open areas in which solar collectors could be installed. Solar energy input to the nation's power system could thus be provided with a minimum of engineering and construction work.

For an eight hour day, the average solar energy at Hanford during June, July, and August is about 60 Langleys (calories/ cm^2) per hour.[2]

Sixty Langleys per hour is equal to 1820 megawatts per square mile. The instantaneous area requirement for 1 megawatt at 60 Langleys/hour is thus

$$\frac{5280 \times 5280}{1820} = 15{,}200 \text{ sq.ft.},$$

or an area 123 feet on a side. With a 50% collection efficiency and 25% thermal efficiency, this would be increased to $\frac{15{,}200}{0.5 \times .25} = 121{,}000$ sq.ft., or an area 347 feet on a side.

At a collector cost of $10.00 per square foot, cost of collectors for a one megawatt system would be $1,210,000. Low temperature collectors currently sell for $6.25 per square foot or less. A collection cost of $2.00 a square foot is considered to be within reason. The $10.00 per square foot allowance would provide some extra for concentration and headers. It would not provide much for development. However, it is of interest to note that the cost scale for a solar energy demonstration with existing units could be in the $1,000,000 per megawatt or $1,000 per kilowatt range.

Whether one of the emergency generators for solar energy would be practical is an economics question which can be answered only through detailed analysis. It is technically possible to produce solar electricity in the megawatt range in the immediate future utilizing Hanford emergency generators.

4.5 Hydrogen Production Development

The Hanford area has many of the requisites for the development of a hydrogen economy. The production and utilization of hydrogen as an energy source is increasingly being recognized

as having great potential. Hanford is in an excellent position to participate in hydrogen economy activity.

Hydrogen can be produced with electrical energy, thermal energy, light energy, and biological conversion. The only two systems of significance today are electrolysis utilizing electrical energy and the utilization of hydrocarbons and thermal energy.

Development work is underway on a modest scale at several sites in the world to develop means of producing hydrogen directly from water with thermal energy without using a hydrocarbon.

If the thermal energy systems are successful, then hydrogen can be produced from water through the utilization of thermal energy from reactors, solar energy or geothermal energy as well as fossil energy.

Hydrogen, if it were economical and abundantly available, could be used to meet nearly all of the energy needs of the U.S. It can be used with relatively minor modification to burners or as hydrogen bearing compounds in most systems which use fossil fuels today. For long distance transmission, it can be less expensive to transport energy in the form of hydrogen than in the form of electricity. Existing natural gas pipe lines and systems can be utilized with hydrogen. Hydrogen has the potential for providing economical storage of peak electrical capacity and solar energy.

Hydrogen can also be utilized to increase the effectiveness of fossil fuels in processes such as coal gasification and shale oil extraction.

Hanford facilities and talent can be utilized in the development of hydrogen systems. Hanford personnel have capability in chemical processing, nuclear heat production, geothermal energy utilization and solar energy utilization.

4.6 Building Heating and Cooling System Development

The extremes of temperature in the Hanford areas (-27°F to +115°F) provide a unique test bed for building heating and cooling systems. Building heating and cooling is planned as one of the first approaches to the utilization of solar power in the U.S. The capability in equipment development, materials development, fabrication process development and construction techniques which exists at the Hanford site could be utilized to provide one of the earliest major programs in building heating and cooling development.

4.7 Systems Analysis and Economics

Hanford personnel have for years led in establishing the economic position of various energy producing systems. This expertise is directly applicable to optimizing the utilization of solar energy in the U.S.

In addition to establishing the position of solar energy systems in the overall energy picture, Hanford expertise can be utilized in the economic development of solar energy systems. The choice of economical alternate paths for development is essential to sound engineering.

4.8 System Design

Hanford expertise in the development and design of large reactor systems is directly applicable to the design of central station solar power systems.

4.9 National Program Planning

Hanford personnel have participated in the development of national program plans on a large scale for several energy systems.

One of the fundamental needs for an expanded national solar energy program is the definition of a research and development program in terms of problems to be solved, dollars necessary to solve the problems, and time. Hanford personnel have

a unique capability in defining large scale R&D programs.

4.10 Other

It is almost a certainty that as a more aggressive national solar program develops, additional possibilities for immediate programs will be recognized.

5.0 SOLAR ENERGY SPONSORS

5.1 Government

The principal government sponsor of solar energy work is the National Science Foundation. Work sponsored by them in FY 1973 is summarized in Appendix A. Their present FY 1974 budget is $12-14 M. However, a program plan has been prepared which calls for substantially greater expenditures.[1]

The recently announced reorganization of the AEC may have a significant effect on the AEC position with respect to solar energy.

The Department of Commerce has an interest in solar power and has funded some work in the past. They may fund small projects directed towards Department of Commerce goals.

The Department of Housing and Urban Development has an interest in solar power and could possibly sponsor significant projects relating to building heating and cooling.

The Post Office Department reportedly has funded a $1 million program at the University of Pennsylvania on the solar heating and cooling of post office buildings.

The Department of the Interior has general energy money in FY 1974. Some of this could be applied to solar power work, particularly in the area of coal gasification or shale oil production.

NASA has funded some solar energy work in the past, generally directed at space projects. The utilization of solar power for terrestrial purposes has become a primary NASA goal. NASA laboratories, faced with cutbacks in the space programs, have developed sizable solar power programs (as yet largely unfunded). However, because of the cutbacks, they will probably support in-house work to the maximum possible extent.

It is expected that the responsibilities discussed above will become more orderly in the near future and that more specifically defined responsibilities will be established.

The NSF-NASA panel recommended in their report to the OST that the National Solar Power program be increased to $3.5 billion over the next 15 years or over $200 million per year. There are thus growing indications that solar power funding will increase significantly in the very near future.

5.2 Industrial Sponsors

Utilities have provided group sponsorship for solar power programs in the past. A group of southwest utilities sponsored the Meinels at the University of Arizona in 1972. Utilities, along with the State of Delaware, have funded a substantial program at the University of Delaware.

The EPRI goals document indicates $168 million for solar power over the next 29 years. It is expected that their interest may increase since the estimate was prepared before solar power became popular.

Particularly in the area of coal gasification or shale oil extraction, energy companies could be potential sponsors. However, it should be recognized that they generally have in-house capability.

There are small hot water heater companies in Florida. None of these have grown to significant size as yet. However, any manufacturer of equipment, such as air conditioners or furnaces, can be considered as a potential sponsor.

REFERENCES

1. *An Assessment of Solar Energy as a National Resource*, by NSF-NASA Solar Energy Panel, Dr. Paul Donovan, et. al, December, 1972.

2. *Climatography of the Hanford Area*, BNWL-1605, W. A. Stone, et. al, June 1972.

3. *Climatic Atlas of the United States*, U. S. Department of Commerce, Environmental Science Services Administration, Environmental Data Service, Woodrow C. Jacobs, Director, June, 1968, U. S. Government Printing Office, 1968, 0-311-220.

4. Letter, R. J. Hock, BNW, November 13, 1973.

A P P E N D I X A

SOLAR ENERGY BACKGROUND

APPENDIX A

SOLAR ENERGY BACKGROUND

1.0 Basic Systems

There are several basically different systems for the utilization of solar energy. These include thermal conversion which may utilize concentrated sunlight to make steam, direct conversion such as photovoltaics, chemical conversion, photosynthesis, biological conversion, and industrial processing. Thermal systems also include the utilization of ocean temperature differences.

One of the keys to the effective utilization of thermal systems is the development of cheap interference films which will allow the sun's energy to pass through but will not let infrared rays back out. These heat traps are available to a degree. However, there is much room for improvement and cost reduction.

There are two schools of thought on the best geographical method of utilizing solar energy. One favors central station systems and the other localized systems. An example of the latter is the utilization of the roof area of a building for heating, cooling and power.

Industrial processing is an area of potential in which little has been done to date.

2.0 Thermal Conversion

Thermal conversion systems generally utilize mirrors or Fresnel lenses to concentrate sun on a boiler or primary coolant fluid. A solar collector for a thermal system is illustrated in Figure 1.[1]

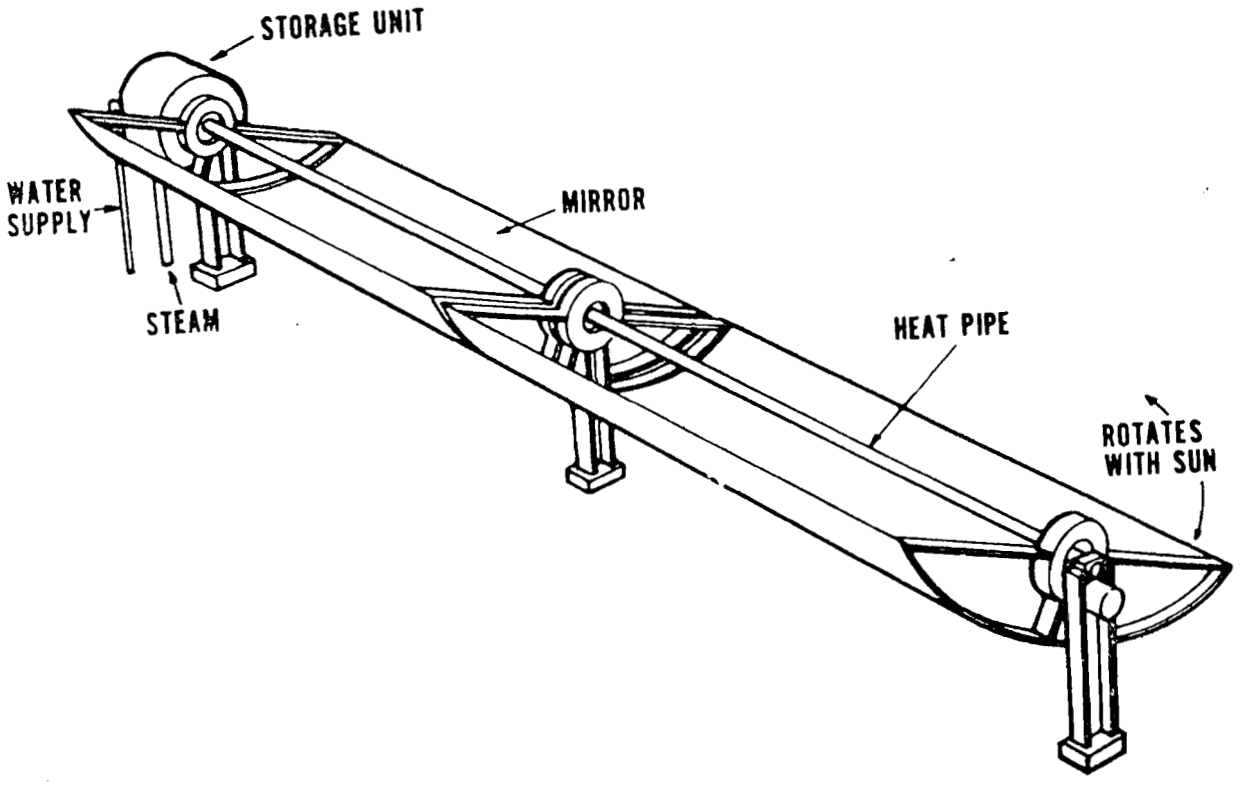


Figure 1. Solar Collector Concept[1]

Francia in Italy built small plants beginning in the early 1960s.[2] These plants operate at temperatures up to 600°C and achieve insolation-to-heat-input efficiencies of 70%.

Meinel of the University of Arizona contributed greatly to the present increase in solar power interest by publicizing thermal concepts.[3] He was one of the first to demonstrate through calculations that the economics for large scale thermal plants were promising.

Another study of thermal plants is currently underway by the University of Minnesota and Honeywell.[1] This is the most complete thermal program in progress. The University of Minnesota expects to start a pilot plant within the next two years. They are working with Babcock and Wilcox as well as Honeywell.[4]

Generally speaking, thermal plants are felt to be a factor of 5 or so too expensive to build right now. Improvements in materials, tracking systems and engineering are required for them to be competitive.

Storage methods considered for thermal systems include heat storage in rocks or salt, pumped storage of water or air, chemical storage, storage in geological formations such as salt flats, geothermal caverns, etc.

3.0 Direct Conversion

The most commonly considered systems for direct conversion are photovoltaic devices such as silicon or cadmium sulfide cells.

Silicon cells are considered expensive and there are those who feel they can never be economically practical. They are currently made by growing single crystals of silicon, cutting up the single crystal (with a material loss of up to 80%) and doping with trace elements. There is some potential for the

achievement of columnar grain structures with thin film deposition processes. This could greatly reduce the cost. There are some concepts in silicon cell technology which, if successful, could make them economically competitive.[5]

Silicon cells are relatively efficient photovoltaic devices with a conversion efficiency of 10 to 20%. Ten percent efficiency is considered good with 20% being at the top of the theoretical range.[6]

Cadmium sulfide cells have the potential for much less expensive fabrication. They can be made by simply coating a substrate with a few microns thick layer of cadmium sulfide. The principal problem in producing cadmium sulfide cells is reproducibility. The efficiency of present day cells is in the 5% range.

There is some possibility that solar cells can be used with a concentration factor of 10 or so which would reduce the number of solar cells required accordingly.

Organic solar cells are not available at this time, and there is little literature on them. There are some who feel that organic semiconductors can some day be made cheaply with overall efficiencies of 80%.[7] The high efficiency would be achieved by using several layers of semiconductors with each layer taking out a part of the spectrum and allowing the rest to be transmitted to the next layer. Conceivably, these materials can be made almost as cheaply as polyethylene plastic.

Thermionic and thermoelectric devices are also considered. However, they are not generally felt to have great potential for solar power because of low efficiencies.

Storage systems considered for direct conversion systems include electrolysis, batteries, and pumped storage of water or air.

4.0 Chemical Conversion

One of the most promising systems for the utilization of solar energy is the thermal dissociation of water. If systems can be developed for this, a virtually inexhaustible supply of clean fuel and a practical storage and transportation system for solar energy will be in hand.

There is also the possibility of applying solar energy to coal gasification, thus achieving the gasification of most of the coal rather than the 50% that is gasified with most present day processes.

The production of oil from oil shale requires temperatures of only about 700°F. This is another potential application for solar energy.

There are other potential reactions for thermal energy storage.

5.0 Photosynthesis

The photosynthesis of solar energy in plant-life is considered by the National Science Foundation as one of the promising potential systems. It is stated that efficiencies up to 3% can be achieved in terms of thermal energy.[8]

The conversion of organic matter to fuel is another potential system.

There is a minor amount of work being done on bacteria systems.[8]

6.0 Industrial Processing

With improvements in solar concentration systems, solar industrial processing may become practical. Approximately 25% of our energy today is used for industry. This is an open market for solar power.

7.0 Ocean Temperature Differences

A system which uses the thermal gradients from ocean areas such as the Gulf Stream has some promise.[9] This type of system is illustrated in Figure 2. The temperature difference is used to operate a low vapor pressure turbine. Systems utilizing ocean temperature differences have actually been built and operated. They are not economically practical at present but may be in the future. Three independent engineering analyses indicate the system may be economically feasible today. Some experimental work must be done before it is known whether the potential is really there. For example, heat exchangers which can be economically built and which will stand up in the ocean without scaling or corroding away must be demonstrated.

8.0 Building Heating and Cooling

There are many areas of the country in which solar heating would be economical today. This is illustrated in Table 1. However, solar heating systems currently require more attention than conventional systems and generally are more effective when the building is designed for solar heating.

Solar refrigeration systems have been built. To date, these systems have operated on low grade heat and have been relatively inefficient. Commercial solar cooling systems are not yet available.

Commercial solar hot water heaters are available and have been used to some extent in California and Florida. They generally lose popularity as other energy distribution systems become effective. However, because of the high cost of fuel and electricity today, they may once again become popular.

9.0 Environmental Effects

Some people are fond of saying that the utilization of solar power would not have any environmental impact because we receive solar power anyway. This is not true. Significant environmental impact can be expected from solar energy utilization, and it is essential that environmental considerations be handled from the beginning.

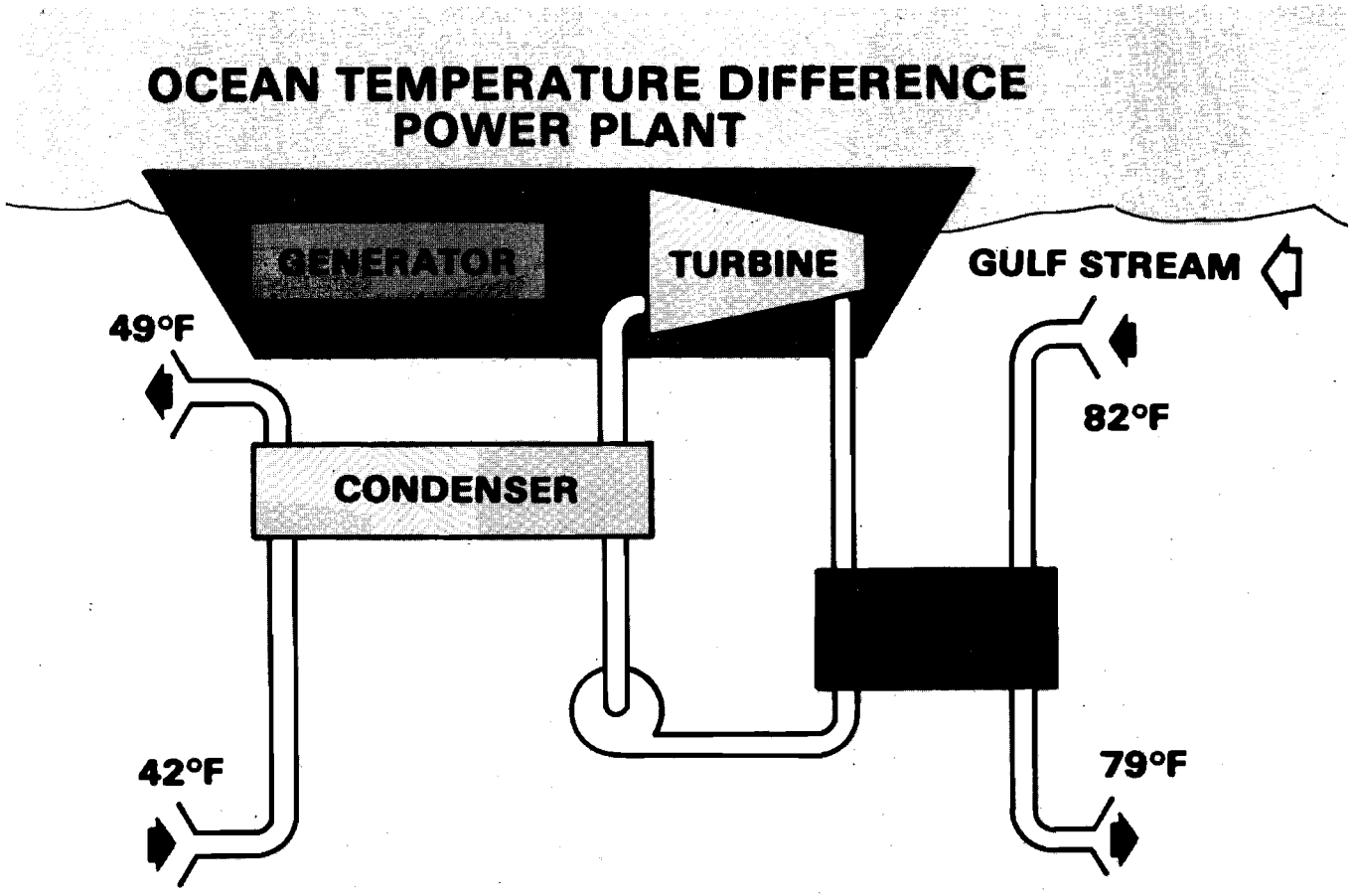

OCEAN TEMPERATURE DIFFERENCE
POWER PLANT
GENERATOR
TURBINE
GULF STREAM
49°F
82°F
CONDENSER
42°F
79°F

FIGURE 2

Table 1

COSTS OF SPACE HEATING (1970 Prices) IN DOLLARS PER MILLION BTU USEFUL DELIVERY

(From "An Assessment of Solar Energy as a National Resource," by NSF-NASA Solar Energy Panel, Dr. Paul Donovan, et. al, Dec. 1972.)

Location	Optimized solar heating cost in 25,000 BTU/degree-day house, capital charges @ 6%, 20 years		Electric heating, usage 30,000 kwh/year	Fuel heating, fuel cost only	
	Collector @ $2/ft.^{2}	Collector @ $4/ft.^{2}		Gas	Oil
Santa Maria	1.10	1.59	4.28[1]	1.52	1.91
Albuquerque	1.60	2.32	4.63	0.95	2.44
Phoenix	2.05	3.09	5.07	0.85	1.89
Omaha	2.45	2.98	3.25[3]	1.12	1.56
Boston	2.50	3.02	5.25	1.85	2.08
Charleston	2.55	3.56	4.22	1.03	1.83
Seattle-Tacoma	2.60	3.82	2.29[2,3]	1.96	2.36
Miami	4.05	4.64	4.87	3.01	2.04

Notes: [1]Electric power costs are for Santa Barbara, Electric power data for Santa Maria were not available.
[2]Electric power costs are for Seattle.
[3]Publicly owned utility.

Solar heat costs are from optimal design systems yielding least cost heat.

Electric power heat costs are from U.S. Federal Power Commission, All Electric Homes, Table 2 (1970). Conventional heat fuel costs are derived from prices per million BTU reported in P. Balestra, The Demand for Natural Gas in the United States, Tables 1.2 and 1.3 (North Holland Publishing Co., 1967). The 1962 costs were updated to 1970 by use of national price indexes on gas (121.1 in 1970 versus 112.8 in 1962) and on fuel oil (119.22 in 1970 versus 101.2 in 1962) as adjustment factors on each fuel price in each state. Bureau of Labor Statistics fuel prices indexes obtained from Gas Facts. Fuel prices were converted to fuel costs by dividing by the following national average heat (combustion) efficiencies: gas, 75%; oil, 75%. Heat efficiencies are from American Society of Heating, Refrigerating and Air Conditioning Engineers, Guide and Data Book 692-694 (1963 ed.).

All solar heat costs based on amortizing entire solar system capital costs in 20 years at 6 percent interest. Capital investment based on current prices of solar water heaters at $4 per sq. ft. plus current costs of other components, and on anticipated near-term solar collector price of $2 per sq. ft.

There is a basic energy balance difference in the utilization of solar power. If solar power is collected, there will be less heat radiating from the point of collection than under normal circumstances. For electrical power generation, this heat would be transferred to another location and probably be reirradiated at a lower temperature and thus at a slower rate. It is unlikely that this would have significant effects on the overall heat balance of the earth. However, it could have localized effects and certainly the earth's heat balance must be considered in the long term. Incidentally, it should be noted that geothermal power probably has an opposite effect in that heat which is normally diffused out of the earth's surface is brought up to the surface where it will radiate at a higher temperature. Conceivably the utilization of geothermal and solar power could be used to balance the earth's heat inventory.

Localized solar power plants will have potential visual impact and local shading effects. For some types of plants there may be a problem in the elimination of waste heat.

For the utilization of ocean temperature differences, the ocean might ultimately be reduced in temperature. This could have the greatest effects in areas such as the Cape Cod area which currently benefit from the Gulf Stream.

If futuristic concepts such as the space collection of solar energy ever become feasible, the power transmission and collection system could have significant environmental impact.

The forest growing aspects of solar power could prove to have beneficial impact. In this concept, it should be noted that the burning of fuel grown with solar power will increase the CO_2 in the atmosphere. However, the forest would deplete CO_2.

Probably a minimum environmental effect would result from the local use of building roof areas for solar heating and cooling and for energy production for this application. Visual impact will undoubtedly be considered initially.

REFERENCES

1. *Research Applied to Solar-Thermal Power Systems*, NSF/RANN/SE/GI-34871/PR/72/4, by U. of Minn. and Honeywell, January 1973.

2. G. Francia, *Pilot Plants of Solar Steam Generating Stations*, Solar Energy, Vol. 12, pp. 51-64, 1968.

3. Meinel, Aden & Majorie, *Is it Time for a New Look at Solar Energy*, Bulletin of the Atomic Scientists, October, 1971.

4. Personal communication, Dr. R. C. Jordan, U. of Minn., April 19,1973.

5. C. G. Currin, et. al, *Feasibility of Low Cost Silicon Solar Cells*, Dow Corning Corporation, Hemlock, Michigan.

6. *Solar Cells, Outlook for Improved Efficiency*, National Academy of Sciences, 1972.

7. *The Future of Power from the Sun*, by P. E. Glaser, Power, August 1968.

8. *An Assessment of Solar Energy as a National Resource*, by NSF-NASA Solar Energy Panel, Dr. Paul Donovan, et. al, December, 1972.

9. J. Hilbert Anderson and James H. Anderson, Jr., *Large Scale Sea Thermal Power*, paper presented to the American Society of Mechanical Engineers, November, 1965.

A P P E N D I X B

PROGRAM POSSIBILITIES

APPENDIX B

PROGRAM POSSIBILITIES

1.0 National Program Outline

The recent NSF-NASA report outlines a prospective national program. The outline of Table 1 (from page 5 of the main report) includes some additional items. This outline is presented here as a summary of the type of work involved in a reasonably complete solar energy R&D program. A comparison of Hanford capability with this outline indicates that contributions can be made in almost every area.

2.0 Comments on Specific Problems Relating to Hanford Capabilities

Specific problems are indicated below. Comments on specific problems are by no means complete. They are intended only to illustrate the existence of a plentiful R&D field. It should also be noted that thoughts below may be impractical. However, several will warrant a preliminary analysis. The numbers below relate to the outline of Table 1 of the main report.

1.1 Solar Energy Availability

The information on solar energy availability in the Hanford area is probably as complete as that for any place in the country. Using this as a starting point, a study of the availability of solar energy in the Northwest as a part of an overall national program to more closely define solar energy availability.

1.2 Albedo

A preliminary analysis of the effects of large scale utilization of solar power on the earth's heat balance and area heat balance.

1.4 Photon Matter Interactions

Optimal glass for Fresnel lenses and heat traps. Glasses which will transmit a maximum of desirable parts of the spectrum.

Table 1

SOLAR ENERGY PROGRAM OUTLINE

1.0 GENERAL

- 1.1 Solar Energy Availability
- 1.2 Albedo
- 1.3 Solar Energy Characteristics
- 1.4 Photon - Matter Interactions
- 1.5 Environmental Effects
- 1.6 Economics
  - 1.6.1 Overall Energy System
  - 1.6.2 Individual Systems
  - 1.6.3 Technical Assistance
- 1.7 Systems Analysis

2.0 THERMAL CONVERSION

- 2.1 Collectors
  - 2.1.1 Reflector Materials & Fab
  - 2.1.2 Corrosion Resistant Materials
  - 2.1.3 Compatibility
  - 2.1.4 Fresnel Lenses
  - 2.1.5 Thin Film Heat Traps
  - 2.1.6 Mass Production Techniques
- 2.2 Storage
  - 2.2.1 Eutectic Salts
  - 2.2.2 Geothermal Caverns
  - 2.2.3 Other
- 2.3 Heat Transfer
- 2.4 Systems
- 2.5 Pilot Plant
- 2.6 Demonstration Plant

3.0 DIRECT CONVERSION

- 3.1 Solid State Studies
  - 3.1.1 General
  - 3.1.2 Silicon Systems
  - 3.1.3 CdS Systems
  - 3.1.4 Other Inorganic
  - 3.1.5 Organic

Table 1 (Cont'd)

3.0 DIRECT CONVERSION (Cont'd)

- 3.2 Solar Cell Fabrication
  - 3.2.1 Single Crystal
  - 3.2.2 Polycrystalline
  - 3.2.3 Amorphous
  - 3.2.4 Organics
- 3.3 Power Collection
- 3.4 Controls
- 3.5 Pilot Plant
- 3.6 Demonstration Plant

4.0 CHEMICAL CONVERSION

- 4.1 Thermal Dissociation of H_2O
- 4.2 Hi Temperature Electrolysis
- 4.3 Combined Thermal-Electrolysis
- 4.4 Other Chemical Conversion Systems
- 4.5 Chemical Energy Storage
- 4.6 Support

5.0 PHOTOSYNTHESIS

- 5.1 Growing Forests
- 5.2 Other Photosynthesis
- 5.3 Conversion of Organic Materials to Fuels or Heat

6.0 BIO-CONVERSION

- 6.1 Photosynthesis Bio-conversion
- 6.2 Thermal Bio-conversion
  - 6.2.1 Algae
  - 6.2.2 Organics

7.0 OCEAN TEMPERATURE DIFFERENCES

8.0 BUILDING HEATING AND COOLING

- 8.1 Heating
- 8.2 Cooling
- 8.3 Hot Water
- 8.4 Solar Powered Demonstration
- 8.5 Energy Conservation

9.0 INDUSTRIAL PROCESSING

1.5 Environmental Effects

The ecological evaluation of the effect of shading large areas.

1.6 Economics

1.6.1 Overall Energy System

As a reference work for future analyses relating to solar power and other energy systems, it is desirable to establish the areas taken by hydro plants, fossil plants, nuclear reactors - including the total operating cycle from mine to waste storage, etc. This should help to put the area required for solar plants in perspective and could also be useful in other analyses.

The development of standard codes for solar energy economic comparisons.

A study of the requirements in our society for the acceptance of solar heating and cooling in homes.

A study of the financial requirements, such as including solar heating in home mortgages, to achieve utilization of solar power.

An analysis of the potential application of solar power to a variety of home utensils.

Some assistance could be given indirectly in the development of a national plan for solar energy development.

2.1.1 Reflector Materials and Fab

The development of a cheap process for reflector fabrication.

2.1.2 Corrosion Resistant Materials

The development of reflective materials which have the potential to last for 20 years.

2.1.4 Fresnel Lenses

The development of cheap processes for the fabrication of glass Fresnel lenses, such as extruding or pressing long panels.

2.1.5 Thin Film Heat Traps

The development of cheap processes for the fabrication of interference films.

2.2.2 Geothermal Caverns

The utilization of geothermal-solar systems to provide 6 month-type energy storage.

2.3 Heat Transfer

The development of heat pipes for solar energy systems.

2.5 Pilot Plant

The design and construction of a pilot plant utilizing existing 100 Area emergency generators. This could provide the first solar power in-put to US power grids.

3.1 Solid State Studies

3.1.2 Silicon Systems

The photovoltaic properties of silicon structures with columnar grains.

3.1.3 Cadmium Sulfide Systems

Basic properties necessary for cheap production techniques for cadmium sulfide systems.

3.1.5 Organic

Determination of the properties of organic semiconductors.

3.2.1 Single Crystal

The growth of shaped and segmented silicon single crystals.

Some years ago there was very preliminary work done on the growth of aluminum oxide single crystals in the shape of a dog bone. By jolting the molten Al_2O_3 ultrasonically as the crystal was pulled from the melt, an impurity buildup was achieved intermittently along the crystals. The single crystal was shaped magnetically to a dog-bone cross-section. Theoretically, the crystals could be tapped with a hammer and shattered to numerous individual sapphires with a built-in dog bone shape. This was done as a part of the composite materials program. Conceivably, it would provide a very inexpensive way of making silicon semiconductors.

3.2.2 Polycrystalline

Work for NASA in tungsten coating some years ago developed a technology for producing columnar grains of tungsten in thin films. Similar techniques conceivably could produce single crystal columnar grains of silicon to achieve photovoltaic effects.

3.2.3 Amorphous

Development of cheap processes for the fabrication of photovoltaics such as cadmium sulfide.

3.3 & 3.4 Power Collection and Control

The development of energy collection and control systems for large scale photovoltaic systems. The output of a solar cell is in the one volt range. The utilization of solar energy in a photovoltaic system in a central station power will require the attachment of thousands of solar cells and the collection of the energy from these cells in a manner which will minimize energy losses and permit inexpensive maintenance operations. There seems to have been little conceptual design in methods which would actually function. Preliminary design work at this point can point out some of the future problems of the photovoltaic systems.

4.1 Thermal Dissociation of H_2O

The development of systems for the thermal conversion of water to hydrogen and oxygen.

4.3 Combined Thermal-Electrolysis

A dissociation system which combines the thermal combination of primary chemicals with regeneration by electrolysis.

4.4 Other Chemical Conversion Systems

The dissociation of chemicals other than H_2O for recombination to achieve energy extraction. A study of alternates to hydrogen and oxygen for chemical energy storage systems.

The development of processes for shale oil extraction.

The development of processes for the utilization of solar energy for coal gasification.

4.5 Chemical Energy Storage

The development of systems for hydrogen storage.

4.6 Support

Evaluation of materials which might be utilized in chemical storage systems such as hydrogen production.

7.0 Ocean Temperature Differences

Utilization of the large basin in the 100 Areas to test ocean temperature differences systems. One basin could be filled with water at 42° and the adjoining basin with water heated by solar power to 80° to provide a controlled test bed for ocean temperature differences systems.

8.1 Heating

The development of cheap, reliable and easily operable systems for building heating.

8.2 Cooling

Cheap reliable and easily operable systems for building cooling.

8.3 Hot Water

Cheap reliable and easily operable systems for building hot water.

8.4 Solar Powered Demonstration

It was suggested some time ago that a building powered completely by solar power would be a good demonstration and test bed. This subject has been mentioned many times since and almost invariably the reaction is that it really sounds good.

9.0 Industrial Processing

A survey of processes which might effectively utilize solar heat (temperature - heat - capital cost).

The design and construction of a solar heating system for general chemical processing uses.

The application of solar power to the production of cement from limestone.

The application of solar power to agricultural processing.

A P P E N D I X C

FY 1973 SOLAR ENERGY PROGRAMS

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APPENDIX C
FY 1973 SOLAR ENERGY PROGRAMS SPONSORED BY NSF

Studies of Thermal Conversion of Solar Energy for Electrical Power Production, Aden B. Meinel, University of Arizona, Tucson, Arizona 85721, $107,000.

Low-Cost Silicon Photovoltaic Cells for Large Solar Power Systems, P. H. Fang, Boston College, Chestnut Hill, Massachusetts, $52,200.

Direct Solar Energy Conversion for Large Scale Terrestrial Use, Karl W. Boer, University of Delaware, Newark, Delaware 19711, $291,200.

Hydrogen Production by Photosynthesis and Hydrogenase Activity--and Energy Source, L. O. Krampitz, Case Western Reserve University, Cleveland, Ohio 44106, $150,000.

Solar Energy Panel, Frederick H. Morse, University of Maryland, College Park, Maryland 20742, $57,800.

Ocean Sited Power Plants, William E. Heronemus, University of Massachusetts, Amherst, Massachusetts 01002, $145,100.

Research Applied to Solar-Thermal Power Systems, R. C. Jordan, University of Minnesota, Minneapolis, Minnesota, $446,600

Technology for the Conversion of Solar Energy to Fuel Gas, Iraj Zandi, University of Pennsylvania, Philadelphia, Pennsylvania, $195,000.

An Improved Schottky Barrier Photovoltaic Diode for Solar Energy Conversion, Wayne A. Anderson, Rutgers, The State University, New Brunswick, New Jersey, 08903, $16,000.

Computer Modeling and Simulation of Solar Heating and Cooling Systems, W. A. Beckman, University of Wisconsin, Madison, Wisconsin, 53706, $75,000.

A Proposal in Response to NSF RFP 72-121, A. B. Greenberg, Aerospace Corporation, El Segundo, California, $125,000.

Thermal Conversion of Solar Energy for Electrical Power Production, Aden B. Meinel, University of Arizona, Tucson, Arizona, $64,400.

Conservation and Better Utilization of Electric Power, Manfred Altman, University of Pennsylvania, Philadelphia, Pa. 19104, $530,000; Synthetic-Solar Fuel Cycle, $600,000.