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INDUSTRIAL APPLICATIONS OF
SOLAR ENERGY
FIRST QUARTERLY PROGRESS REPORT

MASTER

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Section 1

SUMMARY

The objective of this program is to define solar energy systems that are technically and economically feasible, can satisfy all or part of selected industry demands, and to determine the market potential for such systems. The primary emphasis will be placed on the application of total energy systems where industrial process heat, electrical needs, and space heating and cooling requirements are satisfied with a single solar collector field at maximum possible efficiency.

During this reporting period, industrial energy usage in the United States and the Southwest was surveyed to determine which industries were most energy intensive. This resulted in the selection of six major groups: (1) Chemicals and Allied Products - SIC 28, (2) Primary Metals - SIC 33, (3) Petroleum and Coal Products - SIC 29, (4) Paper and Allied Products - SIC 26, (5) Stone, Clay, and Glass Products - SIC 32, and (6) Food and Kindred Products - SIC 20. These groupings account for approximately 80% of the total industrial energy usage, both nationwide and within the Southwest. These major groups were then pursued through their subdivisions to determine more specifically the largest energy users and their locations within the Southwest, allowing the final industry selection.

Approximately 300 representatives of the selected industries were contacted to determine their specific energy requirements as well as architecturally related energy parameters. Climatic and seismic data is also being collected for the areas encompassing the selected regions.

Figures of Merit are being defined and their applicability to total energy systems tested. Subsystem definition work was initiated and is continuing.

Section 2
INDUSTRY SURVEY AND SELECTION

2.1 Nationwide Energy Usage

The national industrial sector was reviewed to determine those major groups which were the largest energy consumers. Extensive use was made of Department of Commerce data (reference 1) which classifies groups by Standard Industrial Classification (SIC's). Based on the SIC, a seven digit classification system operates so that the industrial coverage is progressively narrowed with the successive addition of digits. This is illustrated in the following (from reference 1.):

<u>SIC Code</u>	<u>Level</u>	<u>Description</u>
20	Major Group	Food and Kindred Products.
201	Group	Meat Products
2011	Industry	Meat Packing Plants
20111	Product Class	Beef, not canned or made into sausage
2011112	Product	Whole carcass beef, from animals slaughtered at the same plant.

The two digit SIC's were used to determine those major industrial groups which consume the most energy on a national basis. These results are presented in Figure 1. Note the top six groupings account for approximately 80% of the industrial energy consumption. This information was pursued further and the type of energy consumed by each industry and their relative rankings established. Figures 2, 3, and 4 illustrate the rankings of the major groups in consumption of natural gas, fuel oil, and electricity respectively. As indicated, the top six major groups account for 85% of the natural gas consumption and 77% of the fuel oil usage. The rankings of the largest electrical energy consumers shows Transportation Equipment (SIC 37) and Textile Mill Products (SIC 22) replacing

Stone, Clay, and Glass Products (SIC 32) and Petroleum and Coal Products (SIC 29) in the top six users. Growth patterns were then determined for all major industry groups, (figure 5) and the top six users of fuel oil and natural gas (figures 6 and 7) as well as total energy consumption (figure 8).

The six major groups were then pursued to the third digit SIC in order to determine more specifically the largest energy users. The results of this investigation are shown in figures 9 through 14. As illustrated, the major energy users within the six categories are as follows:

- SIC 28: 281 Industrial Chemicals
- SIC 33: 331 Blast Furnaces and Basic Steel Products
333 Primary Non-Ferrous Metals
- SIC 29: 291 Petroleum Refining
- SIC 32: 324 Hydraulic Cement
327 Concrete, Gypsum, and Plaster Products
322 Glass and Glassware, Pressed or Blown
325 Structural Clay Products
- SIC 26: 262 Papermills, except Building Paper
263 Paperboard Mills
- SIC 20: 204 Grain Mill Products
203 Canned Cured and Frozen Foods
201 Meat Products
206 Sugar

2.2 Southwestern United States Energy Usage

The energy usage in the Southwest - defined for this program as all of Arizona and New Mexico, central and western Texas and Oklahoma, and southern Colorado, Utah, Nevada, and California - was then reviewed to ensure that national trends were valid. This was done for each of the states and categorized for the eighteen industry groups shown in Table 1. The energy demand was established for five different categories, electric, fuel oil, natural gas, coal and coke, and others not specified. The raw data was given in several forms and was converted to a standard set utilizing the conversion factors given in Table 2.

Figures 15 through 22 show the energy consumption by State for each industry group in each of the fuel categories. Also shown are the all industry totals

for each fuel type in each State. The all fuel total for each industry is shown as an addition on top of the majority usage fuel. Because of the wide range of the data, a logarithmic scale over seven orders of magnitude was used to display the data. In the majority of industries across all states, natural gas consumption far exceeded other fuel usage. The total consumption by fuel type and industry group are shown for the entire Southwest in Figures 23 and 24. Totals for each fuel type in Southwest are as follows:

<u>Fuel</u>	<u>10⁶ Megawatt-Hours</u>
Electric	76.41
Fuel Oil	17.58
Coal & Coke	18.34
Natural Gas	684.51
Others and Not Specified	17.28
Total	<u>869.50</u>

The actuals in every case exceed the sum of the components as the total data includes some unclassified consumption.

A percentage breakdown for each fuel type by industry is shown in Figures 25 through 29. The percentage of each fuel is of the total industry wide demand shown by the first bar on the left; e.g., as shown on Figure 25, electricity represents 8.8 percent of the total Southwestern demand for manufacturing. For each industry group, the percentage use of a particular fuel is shown along with the percent of total energy usage for that particular fuel. For example, the amount of natural gas (Figure 28) used in the Chemical Industry (SIC 28) is 27.1 percent of all the natural gas used industry wide in the Southwest and represents 21.3 percent of the total energy used for manufacturing. As can be seen, in only five industry groups (20, 28, 29, 32, and 33) does the natural gas usage represent more than one percent of total Southwestern energy demand. Figure 30 shows a breakdown by industry group of energy use in descending order of their percent of total usage. Note that the same six industry groups again show up as the significant users and in fact represent approximately 88 percent of all Southwestern demands. These major groups were selected for further investigation.

Since this program is limited to the Southwestern United States defined as all of Arizona and New Mexico, Central and Western Texas and Oklahoma, and the

southern portions of California, Utah, Nevada, and Colorado, the geographic locations of the energy intensive industries are shown in Table 3. Applying the requirement that "the industrial sites selected will have requirements common to at least two other selected sites while having unique solar insolation and environmental conditions" (reference 2), SIC groups 26 and 33 (Paper and Allied Products and Primary Metals) are eliminated. The final industry selections and their distributions by state are presented in Table 4.

Approximately 300 industries representing the final selections have been contacted to determine energy demand schedules (hourly, daily, weekly, seasonal), process parameters (state variables, flow rates), energy required for each process step (electrical, fossil fuels), square feet of office and plant area, number of employees (office plant), building characteristics, and land availability. Appendix 1 is a sample of the questionnaire and Appendix 2 is a sample of an exceptionally complete response.

Section 3
INDUSTRIAL SITE SURVEY AND RELATED DATA

3.1 Industrial Site Survey

Industrial sites selected for study purposes include a variety of applications with dissimilar solar insolation characteristics. To aid in the site selection, maps of various solar and climatic parameters were obtained from an United States Environmental Data Service publication (Reference 3). The maps shown in this report are for March, June, September, and December, representing conditions for the months of equinoxes and solstices. In addition to the selected monthly maps, annual charts of the solar and climatic parameters are also presented. Specific parameters examined include the following:

Mean percentage of possible sunshine, Figures 31 through 33

Mean total hours of sunshine, Figures 34 through 36

Mean sky cover, sunrise to sunset, Figures 37 through 39

Mean daily total solar radiation, Figures 40 through 42

Some comments on the solar radiation maps are in order. It is obvious that the highest concentration of solar energy occurs in the Southwestern United States. During June, the highest insolation occurs in the arid to semi-arid interior valleys and plateaus of the Southwestern United States, where the lack of heavy cloud cover is the primary cause of values above 700 Langley (1 Langley = 1 gm cal/cm²) over most of the region. Even higher values are indicated for the sections of California and Nevada immediately east of the Sierra Nevada Mountains. Near the California coast, the fog and stratus clouds are responsible for one of the steepest gradients of solar radiation found anywhere on earth.

The December map indicates that during winter the geographical distribution of solar radiation is dominated by a strong south to north gradient. The steep east-west gradient on the California coast that occurs in the June map is almost non-existent in December, principally because the interior valleys experience winter cloud cover almost as heavy as locations along the coast.

The previously defined study region is defined by a boundary which corresponds to a daily total solar insolation value (annual average) of 425 Langleys or 4942 watt-hrs/m²/day as shown in Figure 43 (obtained by interpolation of curves and data of Figure 42).

3.2 Site Related Data

The objective of this task is to determine total daily and seasonal solar insolation along with direct and diffuse components for each industrial site either from existing solar data or based on published correlations of solar insolation data. The probability of continuous sunshine will also be determined from existing cloud cover data. Supplemental environmental data that impact solar energy systems for each site are to be determined; typical such data are ambient temperature ranges, rainfall, snowfall, wind speed, air quality, and restrictions on heat rejection systems.

Solar radiation data is available from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service for twenty-eight stations (Table 5) that are located within the Southwest United States. The solar radiation data consists of hourly or daily total radiation (normal incidence plus diffused, scattered radiation) received on a horizontal surface. Only at two stations (Albuquerque, New Mexico and Tucson, Arizona) in the Southwest United States have measurements of direct normal radiation been made. The period of record varies from station to station. In most locations records of more than twenty years duration are available.

Solar radiation data can be obtained in tabular form (WB Form 610-8) or on tape from the National Climatic Center in Asheville, North Carolina. Two solar radiation data tapes are available: (1) Tape No. 480 contains long term records of total daily insolation and (2) Tape No. 280 contains hourly insolation data.

Climatological data is available for a larger number of stations in the Southwest United States. Included in these stations are the 56 sky cover stations listed in Table 5. The climatological data generally covers temperature, precipitation, wind, and sky cover. Data is available on a daily basis, in monthly summaries, and in annual summaries. Hourly climatological data can

also be obtained from the Environmental Data Service on magnetic tape (Deck No. 144). Table 6 presents some environmental data that influence the performance of solar energy systems for various Southwest United States locations. The data includes the following: (1) mean and extreme ambient temperatures, (2) wind, (3) rain, and (4) snowfall.

An insolation data base consisting of hourly values of direct and total insolation for the 1962 - 1963 time period has been prepared by the Aerospace Corporation (Reference 4) for 18 stations located within the Southwest United States. The data base includes, in addition to the insolation data, solar position and weather information. The stations represented in the data base, as shown in Figure 44, includes 8 sites representing Southern California. The large number of Southern California stations are necessary because of the steep east-west solar radiation gradients which exist in the Southern California region during the peak intensity season. The data for the eight stations in the region provide representation for most of the different Southern California weather regions defined by the Weather Bureau as shown in Figure 45. The coast region is represented by Los Angeles Airport and San Diego, the coastal valleys by Los Angeles and Santa Maria, the intermediate valleys by Riverside and Edwards AFB, and the interior and desert regions by Inyokern and Yuma. The monthly variations of the total insolation and the direct normal insolation for the various Southern California weather regions are shown in Figures 46 and 47, respectively.

3.3 Solar Insolation Correlations

Although the number of insolation stations have grown over the years, an adequate distribution of stations from which to analyze, in detail, the insolation climate of any large area is lacking. Furthermore, station records generally have numerous periods with missing data. The usual procedure in filling missing data is to estimate values by means of empirical relations between insolation and a number of controlling variable, such as cloud cover and sunshine. Figure 48 shows the location of the twenty-eight solar radiation stations in the Southwest United States. Although the number (33) of stations reporting sunshine data is greater than insolation stations, sunshine generally

is measured at too few stations to provide good geographic coverage (Figure 49). In contrast, there are 56 sky cover stations in the Southwest United States and their distribution is considerably better (Figure 50).

For Western United States, and very likely in the remainder of the country, the percentage of possible sunshine almost always provides the best correlation for total insolation. A poor statistical relationship exists between total sky cover and insolation. However, opaque sky cover is almost as good as percentage of possible sunshine in estimating daily values of total insolation (Reference 5). This is fortunate because of the relatively large number of stations in the United States which measure opaque sky cover.

Correlating equations usually take the form

$$y = \frac{Q}{Q_0} = a + bx$$

where Q is the daily total solar radiation on a horizontal surface at the earth's surface, Q₀ is the daily extraterrestrial solar radiation on a horizontal surface, and x is the correlating variable. The regression coefficients a and b are determined from comparisons between measured solar insolation and the correlating variable, plotting one against the other, and making a least squares linear regression fit to the points. Mathmatically, the constants a and b are given by

$$b = \frac{\frac{\sum xy}{n} - \frac{\sum x \sum y}{n^2}}{\frac{\sum x^2}{n} - \frac{(\sum x)^2}{n^2}}$$

$$a = \bar{y} - b\bar{x}$$

where $\bar{y} = \frac{\sum y}{n}$

$$\bar{x} = \frac{\sum x}{n}$$

Table 7 presents published a and b constants for various stations in the Southwest United States using percentage of possible sunshine as the correlating variable. Large differences in the coefficients from station to station are evident. Part of the discrepancy can be attributed to different averaging periods (monthly vs daily) and/or different number of years of data.

The insolation-sunshine relationship could be improved if an equation was developed that includes geographic variables suspected of influencing the areal variation of the regression coefficients. Bennett (Reference 6) obtained this relationship by using the regression coefficients a and b from the simple linear relationship as dependent variables to establish regression relations with the variables station elevation in feet (H) and cosine of station latitude ($\cos \phi$) as independent variables. The resulting equation, which proved successful for the Western United States, took the form:

$$\frac{Q}{Q_0} = (.20 + 0.00037H) + (.276 - 0.00031H + .32 \cos \phi) \frac{S}{S_0}$$

where S/S_0 is the fraction of possible hours of sunshine. Using this method, monthly maps of average daily total insolation were prepared for New Mexico, (Reference 10). Since only one insolation measurement station is located in New Mexico, it was necessary to use some data from adjacent states. Actual insolation data were used where possible (Albuquerque, Tucson, El Paso, and Midland). Estimated values of insolation were calculated using the sunshine relationship for stations for which it was available (Roswell and Amarillo). A cloud cover relationship had to be used for Winslow, Alamosa, Raton, Clayton, Silver City and Lubbock. Station elevation was added to either the sunshine or cloud cover regressions in the estimation process for all stations. Table 8 summarizes the monthly values of average daily insolation for the New Mexico and surrounding stations.

A relation between opaque sky cover and total insolation was obtained by the Aérospacé Corporation (Reference 4). There was a great deal of scatter in the data but with the inclusion of a atmospheric path length term (air mass ratio) the scatter was reduced. A polynomial in the two variables, opaque sky cover and air mass ratio was obtained:

$$P = \frac{Q}{Q_0} \times 100 = a_1 + a_2 A + a_3 Co + a_4 Co^2 + a_5 Co^3$$

where P is percent of possible total insolation, A is the air mass ratio, and Co is the opaque sky cover in tenths. Polynomial coefficients for the eighteen Southwest United States stations included in the study are given in Table 9.

Many of the potential study locations report temperature and precipitation data only. Thus a study was performed to determine if acceptable estimates of insolation can be obtained from temperature or with a multiple correlation involving temperature and precipitation. Correlation of temperature with total insolation, on a monthly basis, was performed for several Southern California locations. The data base for the investigation consisted of the monthly insolation data, from the Aerospace study, during the years 1962 and 1963 for each of the six stations: Los Angeles, Riverside, Los Angeles Airport San Diego, Santa Maria, and Inyokern. Temperatures were obtained from the monthly California Climatological Data summaries. Both the average monthly temperature and average maximum temperature were correlated with total insolation. The data were subjected to linear regression and correlation analysis by the method of least squares as previously described. The correlation coefficient r , was also calculated as follows:

$$r = \left[\frac{\left(\sum xy - \frac{\sum x \sum y}{n} \right)^2}{\left(\sum x^2 - \frac{(\sum x)^2}{n} \right) \left(\sum y^2 - \frac{(\sum y)^2}{n} \right)} \right]^{1/2}$$

The value of r indicates how closely the equation fits the data: the closer r is to +1, the better the fit.

The correlation and regression coefficients relating monthly values of total insolation with average temperature is shown in Table 6. The data for the six Southern California stations are plotted in Figures 21 through 26. Two regression lines are shown in the figures: one assumes the insolation is dependent, while the other line assumes temperature is the dependent variable. As indicated by the numbers in Table 10 and the relation shown in the figures, a strong correlation does not exist. A comparison of the predicted with the actual insolation for Los Angeles is shown in Figure 57. If insolation is assumed to be the dependent variable, the temperature correlation tends to overpredict the low insolation values and underpredict the high insolation values. With the temperature dependent, the sign of the error is more random but the magnitude

of the difference is potentially much greater. The predicted annual insolation in both cases are nearly identical to the actual annual insolation.

The stations studied represent a wide range of climatic regions. Included are Los Angeles Airport and San Diego where the climate is strongly modified by the ocean, and Riverside and Inyokern where the temperature makes wider excursions. Average maximum temperature may provide a better correlation than average temperature. However, no noticeable improvement in the correlation coefficient was obtained as indicated in Table 11. Correlations of temperature with total insolation based on hourly observations are another possibility. Previous results (Reference 4) for Riverside gave a hourly temperature-insolation correlation coefficient of 0.51 in 1962 and 0.40 in 1963. The present monthly basis analysis produced a correlation coefficient of 0.75 for Riverside in 1962 - 1963.

A multiple linear regression with average temperature and percent of days with precipitation as independent variables was performed for Riverside to determine if a higher correlation coefficient could be obtained. Using the procedure of Reference 11, the resulting multiple regression equation was

$$Q = -3.86 + 0.154 X_1 - 0.0141 X_2$$

where X_1 is the average monthly temperature and X_2 is the percentage of rainy days in the month. However, no change in the correlation coefficient ($r = 0.75$) was obtained with the multiple regression.

A knowledge of the direct component is needed to estimate the solar energy available for focusing collectors. Since regular measurements of direct normal radiation have only been made at a few locations in the United States, techniques for the calculation of direct radiation are required. The most used method is the linear regression model suggested by Jordan and Liu (Reference 12).

$$N = a + b P$$

where N is the direct normal radiation and P is the percent of possible total insolation. Coefficients of $a = -516 \text{ W/M}^2$ and $b = 19.17 \text{ W/M}^2$ were obtained from clear sky data recorded at Hump Mountain, North Carolina, over 55 years ago.

A similar formula was used by the Aerospace Corporation (Reference 4) in their insolation studies. Their formula is

$$N = \begin{matrix} -117 + 12.28 P & \text{if } P \geq 25\% \\ 0 & P < 25\% \end{matrix}$$

The Aerospace coefficients were determined from data at Blue Hill and Albuquerque in 1962. Differences in the two equations are probably due to cloud cover conditions, different locations, and different time periods involved in the data analysis.

Boes (Reference 13) suggests the use of different formulas (coefficients) for different seasons and for different locations. Seasonal linear regression coefficients for Albuquerque, Blue Hill and Omaha are given in the reference. However, in cases where one is concerned with averages over a long time interval or with making relative comparisons of different locations, the following general formula derived from the combination of the representative samples from all three locations was recommended:

$$N (W/M^2) = \begin{matrix} 0 & P \leq 30\% \\ -550 + 17.9P & 30\% < P \leq 85\% \\ 1000 & P > 85\% \end{matrix}$$

3.4 Seismic Activity

A seismic probability map of the United States was prepared by the Coast and Geodetic Survey (Reference 14) and is shown in Figure 58. The seismic risk map provides a general regional classification of the probabilities of seismic activity. Figure 59 shows the existence of damaging earthquakes in the United States through 1968. Damaging earthquakes are defined as those earthquakes which have an intensity of VII or greater according to the Modified Mercalli Scale. An abridged version of this scale is given in Reference 14 and a description of intensity VII is given below:

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars.

Figures 58 and 59 indicate that a more detailed examination of the southern California seismic histories is required. Reference 15 presents the basic seismological data obtained by the southern California network of the Seismological Laboratory, California Institute of Technology, from 1 January 1932 to 31 December 1972. This report catalogs earthquakes into 3 groups as follows: (1) Chronologically (15,340 events), (2) Richter magnitudes of 5.0 and above (262 events), and (3) Richter magnitudes of 6.0 and above (29 events). Epicenter maps of the earthquakes in southern California equal or greater than magnitude 5 is shown in Figure 60, equal to or greater than magnitude 6 in Figure 61. Major faults are also shown in Figures 60 and 61 and are reproduced in greater detail in Figure 62.

Section 4

SYSTEM PARAMETERS

The objective of this task is to identify parameters that can be used as quantitative figures of merit for evaluation purposes. Various system figures of merit which include design, cost, performance, and operational characteristics, can be determined that will aid in the evaluation and selection of solar energy systems. A brief discussion of the parameters identified to-date is given below.

1. Cost/Unit Power Output

A major performance index which combines technical and economic considerations is the cost/unit output power. There are many different methods of presenting the cost parameter. The methods include capital costs, annual costs, cumulative costs and present worth. Capital cost is a significant parameter because the major cost difference between a conventional system and a solar energy system is the large capital cost of the solar system. The capital costs represents the initial cost of a system.

A popular approach in the calculation of costs is the annual cost method. Annual costs are determined by applying a capital recovery factor to the capital cost items and adding that to the annual operating and maintenance costs. Annual cost comparisons are useful for evaluating systems that have tradeoffs between capital and O&M expenses.

A method for determining the payback period, i.e., the time at which the conventional system and solar energy cost curves intersect, is the cumulative cost. Cumulative costs are simply the initial capital cost of the system with the annual operating and maintenance costs added as a function of time. This method includes inflation factors for fuel but does not include the cost of money.

In addition to the annual cost method, the present worth method also includes the value of money. Comparisons of economy on the basis of present worth is frequently used in commercial applications and represents comparisons of the sums necessary to endow a given number of years service. Operating costs over a period of years are reduced to an equivalent capital cost at the beginning of operation through use of the present worth factor. This method determines the total capital commitment for a system in present value dollars and is frequently referred to as life cycle costs.

2. Annual Energy Savings/Cost of Solar Energy System

A more complex parameter than the cost/unit power output ratio is the annual energy savings/cost of solar energy system.

In addition to system efficiency and equipment costs this parameter involves conventional energy costs. The cost of the solar energy system can either be installed (capital) cost or an annual cost. Incremental system costs, defined as the cost of the solar energy equipment over and above the cost of conventional equipment, is sometimes used in the determination of the cost parameters.

3. Capital Cost/Collector Area, Output Power/Collector Area

System cost and performance parameters are often given in terms of unit collector area because collector costs represents the major element in system cost and collector area represents the major design parameter.

4. Annual Solar Energy Utilized/Total Energy Required (Utilization Ratio)

This ratio is the fraction of the annual energy load to be carried by solar energy and is a measure of the relative size of the solar energy system. Least system cost per unit output usually occurs at utilization ratios less than 1.0.

5. Annual Solar Energy Utilized/Annual Incident Energy (System Efficiency)

The annual system efficiency is determined by not only the component (collector, storage, conversion, etc.) efficiencies but also on

utilization considerations such as the match between supply and demand of solar energy.

In the evaluation of total energy systems with the various figures of merit, caution must be used because results are only valid when comparing systems with identical ratios of energy outputs. Cost and performance parameters are sensitive to the ratio of thermal load to energy input (or ratio of thermal load to electrical load). The output requirements will also have a large influence on the optimum system configuration.

Section 5

SUBSYSTEM ANALYSES

5.1 Energy Storage

A multi-tank steam storage scheme was analyzed as a potential subsystem candidate. This system stores saturated steam at a given temperature and pressure and delivers the steam at the same conditions as required (see schematic on Figure 63). Saturated water is used as a piston to maintain steam pressure during discharge being pumped from tank to tank. During recharge, the incoming steam reverses the process and pumps the water from tank to tank back into the reservoir. Saturated steam stored at 450°F and a feedwater temperature of 200°F will supply approximately 950 BTU per cubic foot of steam stored. This storage method would be attractive where constant temperature steam is required by the system. The charge and discharge cycles have been analyzed and the principle of operation analytically verified. A performance algorithm has been developed which when given the storage volume and temperature, the available heat capacity and required pumping power can be determined.

A saturated water storage system with a steam converter was also analyzed. In this scheme, the water is stored at saturated conditions and as stored energy is required, the water is pumped through an evaporator flashing the system return water into steam. This subsystem can potentially furnish more energy per unit volume than the previously multi-tank system if the steam can be generated at a much lower temperature than the stored water. As the required steam supply temperature is reduced, the available energy increases rapidly. For a steam temperature of 435°F and a feedwater temperature of 200°F, 1075 BTU/ft³ is available. The ratio of stored water to steam weight flow is approximately 50. If 350°F steam is acceptable with the same feedwater return conditions, 6250 BTU/ft³ would be available with a mass flow rate ratio of 8.5.

5.2 Absorbtion Refrigeration

Initial studies indicate that absorbtion refrigeration subsystems may look attractive for use with a solar system. Analyses procedures have been developed for both lithium bromide for non-freezing cooling requirements and amonia-water for lower temperature requirements. The lithium bromide subsystem when matched to design conditions have COP's from 0.7 to 0.8 with an outlet temperature of 50°F while an amonia-water subsystem has COP's from 0.4 to 0.5 with an outlet temperature of 30°F. Figure 64 is a schematic of a typical amonia-water absorbtion system.

5.3 Heat Transfer Systems

Heat exchanger analytical procedures have been developed for preliminary performance, sizing, and weights. These techniques are compatible with the Northern Research Heat Exchanger Optimization Computer Program which is available for use on this program. The preliminary method allows the conductances on each side of the heat exchanger to be estimated from which the physical dimensions and weight may be determined. Most methods start with heat exchanger dimensions from which performance is calculated and result in much more trial and error. The procedure developed here can utilize all of the "cores" available within the computer program, including the optimization sub-routine. In addition, a penalty equation is included with weighting factor variables such as size, weight, and cost and the program will optimize the heat exchanger to a minimum value of the equation.

5.4 Rankine Cycles

Both steam and organic Rankine cycles have been investigated and the analytical methods developed. The primary emphasis has been on the organic Rankine cycle as much less information is available on the organic fluids. To date the most attractive fluids investigated are Dowtherm A for high temperatures and Refrigerant 11 (R11) for lower temperatures. Dowtherm A has a maximum operating temperature of about 750°F and R11 about 300°F. Algorithms for both fluids have been developed. The thermal efficiency of Dowtherm A with a turbine inlet temperature of 310°F, a turbine efficiency of 0.70, and a

feedwater regenerator is approximately 0.25 (Figure 65). An R11 subsystem with a turbine inlet temperature of 300°F, a turbine efficiency of 0.70, and a feedwater regenerator has a thermal efficiency of approximately 0.18.

If the Dowtherm A system is cascaded above the R11 system so that the Dowtherm A condenser is the boiler for the R11 system, the overall efficiency is approximately 0.38. This system is shown schematically in Figure 66. The investigation of the organic Rankine cycles is continuing.

Section 6

FUTURE WORK

In the next quarter, subsystem work will continue and will be integrated with system selection analysis. The data received from the surveyed industries will be reduced as they become available, the preliminary system screening accomplished, and work begun on the final designs of the selected industrial facilities. Program results to date will be presented on January 26, 1976 as part of the ERDA Semi-Annual Review.

REFERENCES

1. 1972 Census of Manufactures, U.S. Dept. of Commerce, MC72(SR)-6, July 1973.
2. "Industrial Applications of Solar Energy - Technical Proposal," MDC-G5345P, April 1974.
3. United States Environmental Data Services, "Weather Atlas of the United States", June 1968, Reprinted by Gale Research Company, Detroit, 1975.
4. Aerospace Corporation, "Solar Thermal Conversion Mission Analysis; Volume III, Southwestern United States Insolation Climatology," Report No. ATR-74(7417-16)-2, November 1974.
5. Bennett, I., "Correlation of Daily Insolation With Daily Total Sky Cover, Opaque Sky Cover and Percentage of Possible Sunshine," Solar Energy, Volume XII, pp. 391-393, 1969.
6. Bennett, I., "A Method for Preparing Maps of Mean Daily Global Radiation," Archiv for Meteorologie, Geophysik and Bioklimatologie, Series B, 13 (2): pp 216-248, 1964.
7. Bennett, I., "Monthly Maps of Mean Daily Insolation for the United States," Solar Energy, Volume IX, pp. 145-158, 1965.
8. Lof, G. O. G., et. al., "World Distribution of Solar Radiation," Solar Energy, Volume X, pp. 27-37, 1966.
9. Smiley, V.N., "Insolation Measurements in Nevada", Paper presented at the International Solar Energy Congress and Exposition, Los Angeles, California, July 1975.
10. Tuan, Y. F., et. al., "The Climate of New Mexico, Chapter XIV, Solar Radiation," State Planning Office, Santa Fe, New Mexico, 1973.
11. Snedecor, G.W., "Statistical Methods" Iowa State University Press, Ames, Iowa, 1956.
12. Jordan, R., and Liu, B., "The Interrelationship and Characteristic Distribution of Direct, Diffuse and Total Solar Radiation," Solar Energy, Volume IV, pp. 1-19, 1960.
13. Boes, E.C., "Estimating the Direct Component of Solar Radiation" Paper presented at the International Solar Energy Congress and Exposition, Los Angeles, California, July, 1975.
14. U.S. Coast and Geodetic Survey, "United States Earthquakes 1968".
15. Hileman, J.A., et. al., "Seismicity of the Southern California Region 1 January 1932 to 31 December 1972," Seismological Laboratory, California Institute of Technology, 1973.

Table 1

SOUTHWESTERN INDUSTRY GROUPS

STANDARD INDUSTRIAL CLASSIFICATION (SIC) CODE	INDUSTRY GROUP
20	Food and kindred products
22	Textile mill products
23	Apparel, other textile products
24	Lumber and wood products
25	Furniture and fixtures
26	Paper and allied products
27	Printing and publishing
28	Chemicals and allied products
29	Petroleum and coal products
30	Rubber and plastics products, n.e.c.
32	Stone, clay, and glass products
33	Primary metal industries
34	Fabricated metal products
35	Machinery, except electrical
36	Electrical equipment and supplies
37	Transportation equipment
38	Instruments and related products
39	Miscellaneous manufacturing industries

Table 2
FACTORS USED TO COMPUTE KILOWATT-HOUR
EQUIVALENTS OF FUELS

Kind Of Fuel	Unit Of Measure	Kilowatt-Hour Equivalent Per Unit Of Measure
Coal	Short Ton	7,677
Coke	Do	7,618
Fuel Oil:		
Distillate	Barrel (42 gal.)	1,707
Residual	Do	1,842
Natural Gas	MCF	303.3×10^3
Other Fuels	Dollar	170

Table 3.

GEOGRAPHIC LOCATION OF ENERGY INTENSIVE INDUSTRIES

SIC	NUMBER OF ESTABLISHMENTS								KEY
	TEXAS	NEVADA	COLORADO	UTAH	NEW MEXICO	ARIZONA	CALIFORNIA	OKLAHOMA	
201	298	--	69	40	19	26	283	NA	Meat Products
202	111	48	44	40	16	20	293		Dairy Products
203	94	3	20	15	--	11	448		Canned & Frozen Food
2033	25	--	5	8	--	--	160		Canned Fruits & Vegetables
204	209	--	64	25	--	18	234		Grain Mill Prods.
206	59	--	25	16	--	7	137		Sugar
2063	1	--	13	1	--	1	10		Beet Sugar
262	4	--	--	--	--	1	12		Papermills, exc. Bldg. Paper
2621	4	--	--	--	--	1	12		" "
263	5	--	--	--	--	--	19		Paperboard Mills
2631	5	--	--	--	--	--	19		" "
281	79	5	10	9	8	7	91		Industrial Chems.
2812	4	1	--	--	8	7	--		Alkalies & Chlor.
2819	28	3	--	--	3	--	38		Ind. Inorganic Chem.
282	35	--	--	--	--	--	51		Plastic Mat'ls & Synthetics
2911	59	--	3	5	4	--	39		Petroleum Ref.
322	15	--	--	--	--	--	38		Glass & Glassware
3241	20	--	--	--	--	--	18		Hydraulic Cement
325	61	--	13	6	--	10	55		Struct. Clay Prods
3251	38	--	8	6	--	10	17		Brick & Struct. Clay Tile
327	537	39	147	72	60	119	766		Concrete Gypsum & Plaster Prod.
3271	36	2	14	8	12	16	74		Concrete Block & Brick
331	49	--	5	5	--	--	80		Blast Furnace & Basic Steel Prods.
3312	17	--	3	3	--	--	28		Blast Furnace & Steel Mills
333	13	3	--	5	2	9 (Cu)	()		Primary NonFerrous Metals
3334	3	--	--	--	--	--	48		Primary Aluminum

Table 4

GEOGRAPHIC LOCATION OF
SELECTED INDUSTRIES

SIC CODE	KEY	NUMBER OF ESTABLISHMENTS							
		TEXAS	NEVADA	COLORADO	UTAH	NEW MEXICO	ARIZONA	CALIFORNIA	OKLAHOMA
2033	Canned Fruits & Vegetables	25	--	5	8	--	--	160	10
2063	Beet Sugar	1	--	13	1	--	1	10	--
2812	Alkalies & Chlorine	4	1	--	--	8	7	--	--
2911	Petroleum Refining	59	--	3	5	4	--	39	15
3241	Hydraulic Cement	20	--	--	--	--	2	18	3
3251	Brick & Structural Clay Tile	38	--	8	6	--	10	17	9

Table 5

NOAA - ENVIRONMENTAL DATA SERVICE
INSOLATION AND CLIMATOLOGICAL DATA STATIONS

	<u>INSOLATION</u>		<u>SKY COVER</u>	<u>SUNSHINE</u>
	<u>TOTAL</u>	<u>DIRECT</u>		
<u>ARIZONA</u>				
1. Flagstaff			X	X
2. Fort Huachuca	X			
3. Page	X			
4. Phoenix	X		X	X
5. Tucson	X	X	X	X
6. Winslow			X	
7. Yuma			X	X
<u>CALIFORNIA</u>				
8. Bakersfield			X	
9. Blue Canyon			X	X
10. Davis	X			
11. El Centro	X			
12. Eureka			X	X
13. Fresno	X		X	
14. Inyokern	X			
15. Long Beach			X	
16. Los Angeles Airport	X		X	
17. Los Angeles	X		X	X
18. Mt. Shasta			X	
19. Oakland			X	
20. Red Bluff			X	X
21. Riverside	X			
22. Sacramento			X	X
23. Sandberg			X	
24. San Diego			X	X
25. San Francisco Airport			X	X
26. Santa Maria	X		X	
27. Stockton			X	
<u>COLORADO</u>				
28. Alamosa			X	
29. Colorado Springs			X	
30. Denver			X	X
31. Grand Junction	X		X	X
32. Grand Lake	X			
33. Pueblo			X	X

Table 5 (Continued)

NOAA - ENVIRONMENTAL DATA SERVICE
INSOLATION AND CLIMATOLOGICAL DATA STATIONS

	<u>INSOLATION</u>		<u>SKY COVER</u>	<u>SUNSHINE</u>
	<u>TOTAL</u>	<u>DIRECT</u>		
<u>NEVADA</u>				
34. Elko			X	
35. Ely	X		X	X
36. Las Vegas	X		X	X
37. Reno	X		X	X
38. Winnemucca			X	X
<u>NEW MEXICO</u>				
39. Albuquerque	X	X	X	X
40. Clayton			X	
41. Roswell			X	X
<u>OKLAHOMA</u>				
42. Oklahoma City	X		X	X
43. Stillwater	X			
44. Tulsa			X	X
<u>TEXAS</u>				
45. Abilene			X	X
46. Amarillo			X	X
47. Austin			X	X
48. Big Spring	X			
49. Brownsville	X		X	X
50. Corpus Christi			X	X
51. Dallas			X	
52. Del Rio			X	
53. El Paso	X		X	X
54. Fort Worth	X		X	
55. Galveston			X	X
56. Houston			X	X
57. Lubbock			X	X
58. Midland	X		X	
59. Port Arthur			X	X
60. San Angelo			X	
61. San Antonio	X		X	X
62. Victoria			X	
63. Waco			X	
64. Wichita Falls			X	
<u>UTAH</u>				
65. Flaming Gorge	X			
66. Milford			X	X
67. Salt Lake City	X		X	X
68. Wendover			X	

STATION	LATITUDE	LONGITUDE	ELEVATION (FT)	DAILY MAX. TEMP. (°F)	DAILY MIN. TEMP. (°F)	RECORD HIGH TEMP. (°F)	RECORD LOW TEMP. (°F)	NORMAL TOTAL PRECIPITATION (IN.)	MAX. MONTHLY PRECIPITATION (IN.)	MAX. IN 24 HRS PRECIPITATION (IN.)	MEAN TOTAL SNOWFALL (IN.)	MAX. MONTHLY SNOWFALL (IN.)	MAX IN 24 HRS SNOWFALL (IN.)	MEAN WIND SPEED (MPH)	MAX. WIND SPEED (MPH)	% OF POSSIBLE SUNSHINE	MEAN SKY COVER
LOS ANGELES CALIF	34°03'N	118°14'W	270	74.0	54.8	110	28	14.68	14.94	6.11	T	0.3	0.3	6.2 W	49 N	73	4.0
LOS ANGELES CALIF	33°56'N	118°24'W	97	69.7	54.0	110	30	12.63	11.07	6.19	T	T	T	74 W	62 W	-	4.7
SANTA MARIA CALIF	32°52'N	120°27'W	236	68.4	45.7	130	21	13.37	9.69	3.07	T	T	T	7.0 WNW	-	-	4.2
SAN DIEGO CALIF	32°44'N	117°10'W	13	71.4	55.1	111	31	10.40	7.60	3.07	T	T	T	6.6 WNW	51 SE	67	4.7
PHOENIX ARIZ	33°26'N	112°01'W	1117	84.7	53.3	116	19	7.20	5.56	3.07	T	0.6	0.6	6.0 E	75 SW	86	3.4
TULSON ARIZ	32°07'N	110°56'W	2584	81.3	54.1	111	16	11.00	7.93	3.93	1.4	6.8	6.8	8.2 SE	71 SE	86	3.8
YUMA ARIZ	32°25'N	114°36'W	194	87.1	57.9	116	24	3.03	2.68	2.42	T	T	T	7.8 N	54 S	91	2.7
ALBUQUERQUE N.M.	35°08'N	106°37'W	5311	69.2	44.1	104	-17	8.13	3.33	1.92	9.7	14.7	14.2	8.9 SE	50 SE	77	4.2
GRAND JUNCTION COLO	39°07'N	108°32'W	4843	64.4	40.6	105	-15	8.29	3.48	1.57	26.0	33.7	9.1	8.3 ESE	66 S	70	5.1
LENO RIVER NEVADA	39°30'N	119°47'W	4404	66.7	30.1	103	-11	7.15	5.25	2.37	26.4	29.0	16.9	6.3 WNW	80 SW	80	4.5
LAS VEGAS NEVADA	36°05'N	115°10'W	2162	78.7	52.6	115	8	3.90	2.59	2.59	1.2	16.7	5.0	8.8 SW	64 SW	86	3.4
HOUSTON TEXAS	3°57'N	102°11'W	2951	77.2	51.5	107	2	14.24	6.73	5.99	3.1	7.7	5.9	10.6 SSE	67 W	-	4.5
FT WORTH TEXAS	32°50'N	97°03'W	537	76.5	55.0	108	4	31.32	12.64	5.91	2.8	12.1	12.1	11.3 S	73 N	-	5.2
EL PASO TEXAS	31°45'N	106°24'W	3918	77.2	49.4	106	-8	7.89	6.29	2.89	4.3	10.1	7.8	5.7 N	70 NW	83	3.8

TABLE 6. ANNUAL CLIMATIC SUMMARIES

Table 7

COEFFICIENTS FOR LINEAR REGRESSION Q/Q_0 WITH S/S_0

STATION	a	b	DATA SOURCE
Phoenix, Ariz.	.30	.44	Bennett ⁴
Tucson, Ariz.	.24	.53	Bennett ⁴
Fresno, Calif.	.18	.51	Bennett ⁵
Grand Junction, Col.	.40	.36	Bennett ⁵
	.39	.37	Bennett ⁴
Ely, Nevada	.42	.33	Bennett ⁴
	.41	.34	Bennett ⁵
	.54	.18	Lof ⁶
	.31	.50	Smiley ⁷
Las Vegas, Nevada	.34	.43	Bennett ⁴
	.30	.50	Smiley ⁷
Reno, Nevada	.28	.47	Smiley ⁷
Albuquerque, N. M.	.41	.37	Lof ⁶
Brownsville, Tex.	.35	.31	Lof ⁶
El Paso, Tex.	.35	.43	Bennett ⁴
	.32	.46	Bennett ⁵
	.54	.20	Lof ⁶

TABLE 8
MEAN DAILY TOTAL INSOLATION IN LANGLEYS
(DATA FROM REFERENCE 8)

Month	New Mexico					Texas				Colorado	Arizona	
	Albuq (a)	Clayton (c)	Raton (c)	Roswell (b)	Silver Cty (c)	Amarillo (b)	El Paso (a)	Lubbock (c)	Midland (a)	Alamosa (c)	Tucson (a)	Winslow (c)
JAN	301	291	309	316	389	279	337	300	300	320	319	295
FEB	385	376	386	392	471	356	436	384	374	410	416	399
MAR	493	479	483	490	559	459	549	483	486	503	483	510
APR	619	593	588	603	698	553	659	581	562	621	643	643
MAY	689	633	630	638	744	606	718	612	614	662	716	711
JUN	730	691	655	661	727	644	727	647	632	714	726	732
JUL	673	642	637	632	634	638	671	630	623	659	625	631
AUG	624	590	574	574	588	587	631	584	570	593	555	582
SEP	540	507	495	491	509	496	562	489	491	525	562	538
OCT	430	413	420	420	488	394	462	418	406	428	501	447
NOV	322	305	307	309	353	307	360	328	325	324	359	334
DEC	270	259	268	257	313	248	306	272	272	273	301	271
ANNUAL	506	482	479	482	539	464	535	477	471	503	517	508

(a) from measured data

(b) estimated from percent of possible sunshine

(c) estimated from sunrise to sunset cloud cover

TABLE 9

Total Insolation Estimator Coefficients

Parameter	Group I ^a	Group II ^b	Group III ^c
a_1	+83.018	+78.953	+78.335
a_2	- 3.847	- 2.233	- 2.817
a_3	- 4.4074	- 2.9536	- 6.2334
a_4	+ 1.10129	+ 0.64274	+ 1.41585
a_5	- 0.110903	- 0.084663	- 0.128537
Mean Values (P)	59.5105	62.8547	60.8421
<p>a. Group I includes Los Angeles Airport, Riverside, Santa Maria, California; Omaha, Nebraska; Ely, Nevada; and El Paso, Texas.</p> <p>b. Group II includes Fort Worth, Texas; Dodge City, Kansas; and Tucson and Phoenix, Arizona.</p> <p>c. Group III is characteristic of Fresno, California.</p>			

Table 10

CORRELATION OF AVERAGE TEMPERATURE WITH TOTAL INSOLATION

STATION	REGRESSION COEFFICIENTS				CORRELATION COEFFICIENT r
	INSOLATION DEPENDENT		TEMPERATURE DEPENDENT		
	a kw-hr/m ²	b kw-hr/m ² °F	a °F	b °F-m ² /kw-hr	
LOS ANGELES	-6.63	0.18	51.4	2.44	0.67
RIVERSIDE	-4.39	0.15	42.8	3.53	0.75
LOS ANGELES AIRPORT	-4.02	0.16	53.0	1.80	0.51
SAN DIEGO	-5.36	0.17	50.2	2.45	0.64
SANTA MARIA	-4.73	0.18	49.8	1.22	0.47
INYCKERN	-1.43	0.12	30.8	5.23	0.79

TABLE 11

CORRELATION OF TEMPERATURE WITH TOTAL INSOLATION

STATION	CORRELATION COEFFICIENT	
	AVERAGE TEMPERATURE	AVERAGE MAXIMUM TEMPERATURE
LOS ANGELES	0.67	0.68
RIVERSIDE	0.75	0.74
LOS ANGELES AIRPORT	0.51	0.42
SAN DIEGO	0.64	0.50

NATIONWIDE INDUSTRIAL ENERGY CONSUMPTION

NATIONWIDE INDUSTRIAL CONSUMPTION OF NATURAL GAS

Figure 2.

NATIONWIDE INDUSTRIAL CONSUMPTION OF FUEL OIL

Figure 3.

NATIONWIDE INDUSTRIAL CONSUMPTION OF ELECTRICITY

GROWTH OF
NATIONWIDE
INDUSTRIAL
ENERGY
CONSUMPTION

Figure 5.

-04-

GROWTH OF
NATIONWIDE
INDUSTRIAL
CONSUMPTION OF
FUEL OIL

Figure 7.

GROWTH OF
NATIONWIDE
INDUSTRIAL
CONSUMPTION OF
ALL TYPES OF
ENERGY

Figure 1.

-43-

SIC 28 ENERGY CONSUMPTION

Figure 9.

Figure 10.

-45-

Figure 11.

-94-

SIC 32 ENERGY CONSUMPTION

Figure 12.

SIC 26 ENERGY CONSUMPTION

Figure 13.

SIC 20 ENERGY CONSUMPTION

Figure 14.

Figure 15.

Figure 16.

Figure 17.

Figure 18.

Figure 19.

Figure 20.

Figure 21.

Figure 22.

Figure 23.

Figure 24.

Figure 25.

Figure 26.

Figure 27.

Figw 8.

Figure 29.

Distribution of Industrial Energy Consumption by Standard Industrial Classification

Figure 30.

FIGURE 31 MEAN PERCENTAGE OF POSSIBLE SUNSHINE, MARCH AND JUNE (REFERENCE 3)

FIGURE 32 MEAN PERCENTAGE OF POSSIBLE SUNSHINE, SEPTEMBER AND DECEMBER (REFEREN 3)

FIGURE 33 MEAN PERCENTAGE OF POSSIBLE SUNSHINE, ANNUAL (REFERENCE 1)

FIGURE 34 MEAN MONTHLY TOTAL HOURS OF SUNSHINE, MARCH AND JUNE (REFERENCE 3)

FIGURE 35 MEAN MONTHLY TOTAL HOURS OF SUNSHINE, SEPTEMBER AND DECEMBER
(REFERENCE 3)

FIGURE 36 MEAN TOTAL HOURS OF SUNSHINE, ANNUAL (REFERENCE 3)

FIGURE 37 MEAN SKY COVER, MARCH AND JUNE (REFERENCE 3)

FIGURE 38 MEAN SKY COVER, SEPTEMBER AND DECEMBER (REFERENCE 3)

FIGURE 39 MEAN SKY COVER, ANNUAL (REFERENCE 3)

FIGURE 40 MEAN DAILY SOLAR RADIATION, MARCH AND JUNE (REFERENCE 3)

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FIGURE 41 MEAN DAILY SOLAR RADIATION, SEPTEMBER AND DECEMBER (REFERENCE 3)

FIGURE 43 SOUTHWEST UNITED STATES BOUNDARY

◦ REPRESENTATIVE CLIMATIC REGIONS IN SOUTHWESTERN UNITED STATES

◦ TIME PERIOD 1962 - 1963 (2 year data base)

◦ HOURLY DATA ON MAGNETIC TAPE
(optionally available on 7-track BCD or 9-track EBCDIC tapes)

◦ TAPE 1

ALBUQUERQUE, N.M.

*INYOKERN, CA

YUMA, AZ

*EDWARDS A.F.B., CA

*RIVERSIDE, CA

◦ TAPE 2

LOS ANGELES CIVIC CENTER, CA

LOS ANGELES AIRPORT, CA

SAN DIEGO, CA

SANTA MARIA, CA

FRESNO, CA

◦ TAPE 3

TUCSON, AZ

SALT LAKE CITY, UT

PHOENIX, AZ

ELY, NV

GRAND JUNCTION, CO

◦ TAPE 4

OMAHA, NE

FORT WORTH, TX

DODGE CITY, KS

MIDLAND, TX

EL PASO, TX

◦ CONTENTS:

◦ IDENTIFYING INFORMATION

◦ DATE, TIME, SOLAR POSITION

◦ INSOLATION

◦ EXTRATERRESTRIAL, NORMAL INCIDENCE, TOTAL
PERCENT OF POSSIBLE TOTAL INSOLATION

◦ WEATHER DATA

◦ TEMPERATURE, HUMIDITY, SKY COVER, CLOUDS

◦ WINDS

FIGURE 44 Insolation Climatology Data Base (REFERENCE 4)

Figure 45 Southern California Weather Regions (Reference 4)

FIGURE 46. SOUTHERN CALIFORNIA TOTAL INSOLATION VARIATIONS

FIGURE 47. SOUTHERN CALIFORNIA DIRECT INSOLATION VARIATIONS

NOTES:

1. □ DATA AVAILABLE ON AEROSPACE TAPES
2. REFER TO TABLE 1 FOR STATION LIST

FIGURE 48 INSOLATION STATIONS

FIGURE 49 SUNSHINE STATIONS

FIGURE 50 SKY COVER STATIONS

FIGURE 51. CORRELATION BETWEEN MEAN MONTHLY RADIATION AND MEAN MONTHLY TEMPERATURE

FIGURE 52. CORRELATION BETWEEN MEAN MONTHLY RADIATION AND MEAN MONTHLY TEMPERATURE

FIGURE 53. CORRELATION BETWEEN MEAN MONTHLY RADIATION AND MEAN MONTHLY TEMPERATURE

FIGURE 54. CORRELATION BETWEEN MEAN MONTHLY RADIATION AND MEAN MONTHLY TEMPERATURE

FIGURE 55. CORRELATION BETWEEN MEAN MONTHLY RADIATION AND MEAN MONTHLY TEMPERATURE

FIGURE 36. CORRELATION BETWEEN MEAN MONTHLY RADIATION AND MEAN MONTHLY TEMPERATURE

FIGURE 57. COMPARISON OF ACTUAL TO PREDICTED INSOLATION

ZONE 0 - No damage.

ZONE 1 - Minor damage; distant earthquakes may cause damage to structures with fundamental periods greater than 1.0 seconds. corresponds to intensities V and VI of the M.M.* Scale.

ZONE 2 - Moderate damage; corresponds to intensity VII of the M.M.* Scale.

ZONE 3 - Major damage; corresponds to intensity VIII and higher of the M.M.* Scale.

M.M.* refers to the Modified Mercalli Intensity Scale

FIGURE 50 SEISMIC RISK MAP FOR CONTERMINOUS UNITED STATES (REFERENCE 14)

FIGURE 59 DAMAGING EARTHQUAKES IN THE UNITED STATES THROUGH 1968 (REFERENCE 14) (4)

1932 THROUGH 1972. EVENTS EQUAL OR GREATER THAN MAGNITUDE-5 (REFERENCE 15)

Figure 60

MULTIPLE TANK STEAM STORAGE CONCEPT (CHARGED)

TYPICAL AMMONIA-WATER REFRIGERATION
SYSTEM

Figure 65.

PREPARED BY: _____
CHECKED BY: _____
DATE: _____
TITLE: _____

DIVISION _____

PAGE: _____
MODEL: _____
REPORT NO.: _____

CASCADED ORGANIC RANKINE CYCLE

Figure 56.

Information Contact:

Please supply the following information. If not available in form requested, state in your own terms. If not completely available, estimate to your best judgment. Please state base year or period _____. (If seasonal operation, give periods please.)

1. Total Electrical Power Consumption _____ KWH
 - a. Purchased _____ KWH
 - b. Generated at Plant _____ KWH
 - c. Power sold or supplied to others _____ KWH
2. Total Gas or Fuel Oil Consumption _____ BBL
 - a. What kind of gas _____ Heating Value _____ Btu/ft³
 - b. What kind of fuel oil _____ Heating Value BTU# _____
3. Total Steam Consumption _____ #/hr or BTU/hr
 - a. Generated at Plant _____ #/hr or BTU/hr
 - b. Purchased _____ #/hr or BTU/hr
 - c. Is heat source gas or fuel oil? _____ If not, what? _____
#/hr and heating value BTU/# _____
4. Power Used for General Purposes
 - a. Space Heating _____ KWH or _____ BTU/hr
 - b. Space Cooling _____
 - c. Lighting _____
 - d. Misc. Specify _____
 - e. Start-up and Shutdown Requirements _____ KWH or _____ BTU/hr
5. Process Power (Manuf., Treatment, Preparation)
 - a. Electrical
 - 1) Motors _____ KWH (Volts _____)
 - 2) Process Heat _____ KWH (Volts _____)
 - 3) Other (specify) _____ KWH

 - 4) Start-up and Shutdown Requirements KWH (Volts _____)
 - b. Gas Fired (Specify Natural Gas, LPG, LNG, etc.)
 - 1) Direct fired _____ BTU/hr or MCF/hr
 - 2) Other (specify) _____ BTU/hr or MCF/hr
 - 3) Start-up and Shutdown Requirements _____ BTU/hr or MCF/hr

Sq. Ft.

6. Plant Space

- a. Manufacturing
- b. Office
- c. Support
- d. Roof (used/unused)
- e. Parking
 - 1) Roof
 - 2) Subterranean
 - 3) Adjacent lot
 - 4) Adjacent structure
- f. Building Perimeter
- g. Research

7. Personnel Numbers

- a. Manufacturing
- b. Office
- c. Support
- d. Research

8. Building

- a. Construction Type
- b. Amount of Glass and distribution
- c. Compass orientation
- d. Roof construction
- e. Roof load limitations

9. Special Areas

Describe areas with unique requirements and describe the special requirements (e.g. - computer rooms, laboratories).

10. Planned modifications to process equipment which offer potential for solar energy utilization.

11. Describe your manufacturing/Treatment Process in words or by diagram; then enter information about the processes in the following table. Include information on special Start-up and Shutdown procedures where pertinent.

Appendix 1
Page 4

Process Step Description	Production Rate Peak/Average	Energy Consumption Rate	Oper. Temp. °F	Duty Cycle		
				Hr. /Dy	Dys/Wk	Wks/Yr
			5 Press.			

Information Contact:

Please supply the following information. If not available in form requested, state in your own terms. If not completely available, estimate to your best judgment. Please state base year or period annual. (If seasonal operation, give periods please.)

1. Total Electrical Power Consumption 68,500,000 KWH
 - a. Purchased all KWH
 - b. Generated at Plant -- KWH
 - c. Power sold or supplied to others none KWH
MCF
2. Total Gas Consumption 1,768,000
 - a. What kind of gas Natural Heating Value 1065 Btu/ft³
 - b. What kind of fuel oil Heating Value BTU#
3. Total Steam Consumption 150,000 #/hr or BTU/hr
 - a. Generated at Plant all #/hr or BTU/hr
 - b. Purchased none #/hr or BTU/hr
 - c. Is heat source gas or fuel oil? Nat'l Gas If not, what?
#/hr and heating value BTU/#
4. Power Used for General Purposes Annual
 - a. Space Heating KWH or BTU/hr
 - b. Space Cooling
 - c. Lighting 4,600,000
 - d. Misc. Specify
 - e. Start-up and Shutdown Requirements KWH or BTU/hr
5. Process Power (Manuf., Treatment, Preparation)
 - a. Electrical
 - 1) Motors 63,900,000 annual KWH (Volts some 4160 most 440)
 - 2) Process Heat None KWH (Volts)
 - 3) Other (specify) KWH
 - 4) Start-up and Shutdown Requirements KWH (Volts)
 - b. Gas Fired (Specify Natural Gas, LPG, LNG, etc.)
 - 1) Direct fired 186,000 x 10⁶ BTU/yr - product dryer
 - 2) Other (specify 1,674,000 x 10⁶ BTU/yr - process boilers
23,000 x 10⁶ BTU/yr - heating
 - 3) Start-up and Shutdown Requirements BTU/hr or MCF/hr

6. Plant Space- See attached note
- a. Manufacturing
 - b. Office
 - c. Support
 - d. Roof (used/unused)
 - e. Parking
 - 1) Roof
 - 2) Subterranean
 - 3) Adjacent lot
 - 4) Adjacent structure
 - f. Building Perimeter
 - g. Research

	90,000

7. Personnel Numbers

- a. Manufacturing
- b. Office
- c. Support (Maintenance, lab)
- d. Research

MINE	SURFACE
189	60
	14
111	67

8. Building See attached note
- a. Construction Type
 - b. Amount of Glass and distribution
 - c. Compass orientation
 - d. Roof construction
 - e. Roof load limitations

9. Special Areas

Describe areas with unique requirements and describe the special requirements (e.g. - computer rooms, laboratories).

NONE

Attachment:

Item 6 Plant space and item 8 Building Construction.

Surface facilities cover an area of 3,570,000 sq. ft. or 82 acres. Process buildings cover 222,700 sq. ft. They are of the steel frame, transite wall, transite roof type construction and are unheated, and minimally lighted. Roof areas are virtually unused. Support buildings cover approximately 30,000 sq. ft. and are concrete block or steel frame/transite cover construction. Heating, air conditioning, and lighting vary with occupancy. Some buildings are cooled to maintain proper operating temperature for electrical switch gear. The main office building is concrete block with flat, tarred roof. It is single story and tee shaped with the top bar of the tee facing Northwest. Glass is predominantly on the top bar of the tee facing either Northwest or Southeast. There is approximately 250 sq. ft. of glass on a total wall area of about 5,000 sq. ft. Roof load design is 18 lb/sq.ft. dead load and 16 lb/sq.ft. live load. Roof area is partially covered with air conditioning ducts, etc.

10. Planned modifications to process equipment which offer potential for solar energy utilization.

None at present.

11. Describe your manufacturing/Treatment Process in words or by diagram; then enter information about the processes in the following table. Include information on special Start-up and Shutdown procedures where pertinent.

See attached flow sheet.

Ore is mined 1650 ft. below the surface using seven electrically driven mining machines and one conventional drilling and blasting area. All loading and hauling is done by electrically driven equipment and belt conveyors. Ore is hoisted to the surface using an electrically driven ASEA friction type hoist with counter balanced skips-each skip having a 12.5 ton capacity.

Surface operations can convert 3,000,000 tons per year of mined ore into three size grades of muriate of potash (potassium chloride, KCL) totaling 600,000 tons per year and two distinct waste streams. Major ore constituents are halite (NaCl), sylvite (KCl), insoluble clays, a group of sulfate minerals, and naturally occurring moisture.

The leach-crystallization technique of ore processing is used. Main process steps are:

- 1) removing clay (desliming), washing and slimes disposal;
- 2) dissolving (leaching) potassium chloride away from other ore constituents in steam heated vessels;
- 3) disposing of coarse waste (tailings);
- 4) clarifying the potassium chloride loaded brine (hot thickening);
- 5) cooling this brine to crystallize 98+% pure potassium chloride;
- 6) drying, sizing and storing the product for later shipping, and ;
- 7) compacting, crushing and sizing some of the smallest product (standard) into the largest product (granular). Only standard and the intermediate-sized coarse products are made in the crystallizers.

ENERGY CONSUMPTION
OF
MAJOR EQUIPMENT ITEMS

Appendix 2
Page 5

(USE BTU/HR, KW, CU. FT/HR OF GAS, ETC.)

Process Step Description	Production Rate Peak/Average	Energy Consumption Rate	Oper. Temp. °F	Duty Cycle		
				Hr./Dy	Dys/Wk	Wks/Yr
Mining elect.	560 tph/420tph	17,125,000kwh/yr	750°F	19.5	7	52
Crushing elect.	400tph/370tph	4,223,000kwh/yr	ambient	24	7	52
Desliming & Leaching elect.	400/370	11,088,000 kwh/yr	2150°F	(with an average 93% operating factor and downtime distributed about equally between scheduled (8-12 hour outages) and unscheduled outages.)		
gas		1,484,000 mmbtu/yr	1500°F			
Coarse Tailings elect	240tph/222tph	5,430,000kwh/yr	1500°F	↓	↓	↓
gas		11,000 mmbtu/yr				
Fine Tailings elect	/55tph	10,973,000kwh/yr	ambient			
Crystallization elect	/74tph	10,511,000kwh/yr	206-750°F			
gas		179,000mmbtu/yr				
Product Handling elect	110tph/74tph	4,079,000kwh/yr	3500°F			
gas		186,000mmbtu/yr				
Compaction elect	25tph/19tph	4,506,000kwh/yr	ambientsurroundings some points 400°F internally	8	5	52
Product rescreen & Load elect		565,000kwh/yr	ambient			
Miscellaneous gas		23,000mmbtu/yr	-----			
Total elect		68,500,000kwh/yr				
Nat'l gas		1,883,000mmbtu/yr				

Note: Natural gas consumption is expressed in terms of heat value delivered to the plant. Power " " " " " KWH delivered to the plant, and support requirements totaling 48% of the total are distributed to the productive areas.