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A FEASIBILITY STUDY FOR UTILIZING SOLAR ENERGY TO AUGMENT
THE PROCESS STEAM AND SPACE HEATING NEEDS OF THE
WESTERN ELECTRIC ATLANTA WORKS

Western Electric P.O. No. AZ 240424
Georgia Tech Project No. A-1974

Conducted for:
Western Electric Atlanta Works
2000 Northeast Expressway
Norcross, Georgia 30071
Western Electric Project Monitor: Mr. E. D. Lassahn

Conducted by:
Applied Sciences Laboratory
Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

November 1, 1977
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November 1, 1977
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1. INTRODUCTION

This report documents the results of a feasibility study for utilizing solar energy to augment the process steam and space heating system at the Western Electric Atlanta Works. The study was conducted by the Engineering Experiment Station (EES) of the Georgia Institute of Technology (Georgia Tech) during the period of March 15, 1977 to July 31, 1977.

Participants in the study from the EES were:

Dr. Gordon R. Harrison, Director, Applied Sciences Laboratory/EES
Ms. Anita M. Fey, Project Director and Research Engineer, Energy and Environmental Analysis Division, Applied Sciences Laboratory/EES
Mr. Charles A. Murphy, Senior Research Engineer, Solar Energy and Materials Technology Division, Applied Sciences Laboratory/EES
Dr. Steve H. Bomar, Jr., Principal Research Engineer, Solar Energy and Materials Technology Division, Applied Sciences Laboratory/EES
Dr. Sam C. Barnett, Professor of Mechanical Engineering, Georgia Tech

Participants in the study from the Western Electric Atlanta Works were:

Mr. C. H. Westermeyer, Assistant Manager, Engineering
Mr. E. D. Lassahn, Department Chief, Engineering (Project Monitor)
Mr. Stanley Rice, Senior Engineer

In addition to this report, the following referenced documents were also generated during the study and contain some information not reproduced as part of this report.

1) Status Report dated 5-26-77.
3) A taped and transcribed presentation by the EES program participants presented July 28, 1977 to the staff of Western Electric Atlanta Works.
The technical proposal referenced above (Item 2) was completed and submitted to ERDA on 10 June 1977. This document proposed a three-year program for the detailed analysis and design (1st year) of a solar system to generate process steam for the Western Electric Atlanta Works, construction and integration of the system (2nd year), and operation and test of the system (3rd year). ERDA received 30 proposals in response to the request for proposals. The EES/Western Electric proposal was evaluated as one of the proposals reaching the final selection stage of the procurement. However, in late September 1977, notification was received from ERDA that the proposal was not selected for negotiation leading to a contract award. As of this writing, additional details concerning the evaluation and whether the proposal will be reconsidered later have not been received. A debriefing regarding the proposal evaluation has been requested.
2. BACKGROUND INFORMATION

Plant Facts

The Western Electric Atlanta Works is located on 173 acres at Norcross-Tucker Road and Interstate 85, 17 miles northeast of downtown Atlanta. (The plant is approximately 14 miles from the Georgia Tech campus via Interstate Highway 85). The plant is composed of a complex of buildings housing the Cable and Wire Manufacturing Division, the Cable and Wire Product Engineering Control Center, the Loop Transmission Apparatus Product Engineering Control Center, and the Transmission Media Laboratory of the Bell Telephone Laboratories. The main buildings are an L-shaped manufacturing building containing 1.3 million square feet and a 270,000 square feet office building including a cafeteria, library and auditorium. These entire facilities are heated and air conditioned. The complex contains four miles of paved roads and parking for 2350 cars. The plant also has 4½ miles of railroad tracks with its own 50-ton locomotive. The plant is the world's largest cable manufacturing facility and one of the major manufacturing facilities in Georgia and the Southeast.

The major products manufactured are exchange cable and switchboard wire and cable.

Exchange cable is used to connect one central office with another as well as to connect homes and businesses with the telephone central offices. Two types of exchange cable are manufactured: PIC (polyethylene insulated conductor) and pulp (paper pulp insulated conductor).

Switchboard wire and cable has many uses, but it is most commonly used to interconnect equipment within the telephone company central office. PVC (polyvinylchloride insulated conductor) is used for switchboard cable and wire.
The cable manufacturing process begins with metal bar stock (primarily copper) which is drawn to the desired wire diameter; after suitable processing, each small strand is insulated.

Strands are then twisted in pairs of bundles; bundles are finally packaged (final packaging configuration is dependent on the application) together into large water-proofed cable ready for a multitude of different field applications all over the world.

**Brief Energy Characterization of the Plant Complex**

The energy consumed by the plant complex is supplied by electricity, oil and gas.

Electricity supplies approximately one-half (in terms of Btu used) of the total facility needs. Electricity is used as the energy source for many of the wire processing steps such as electric furnaces, electric-powered machines, etc. in addition to lighting, air conditioning/air handling and controls.

Oil and gas fuel is used to supply (through steam generation) many processing steps and the heating and humidity control needs of the total facility. Steam is produced by three boilers (connected in parallel to the main steam header). These Babcox & Wilcox boilers, located in the powerhouse adjacent to the manufacturing building, are oil or gas fired and each has the capability (nameplate) of supplying 40,000 pounds of saturated steam per hour at a pressure of 100 pounds per square inch (gauge). The steam is distributed from the main header in large steam lines in two closed interconnected loops throughout the main manufacturing plant. Various manufacturing processes (pulp drying, paper pulp storage, sheathing, tinning, etc.) are supplied from these steam distribution loops. In addition, steam from this distribution network (header) is used via a heat exchanger to produce
hot water (approximately 150°F) which is distributed throughout the facility for space heating, humidity control, and general purpose use.

The base load (demand) of the plant for product process support is approximately a constant 9,000 pounds of steam per hour (1976 calendar year data). This represents approximately one-half of the total steam demand averaged over the year (space heating and humidity control represents the largest part of this additional demand which varies seasonally).

Energy use data from gas and oil consumption has been computed monthly for calendar years 1973 through 1976 (Figure 2-1 is an example of the graphs that exist for 1973 through 1976). In 1973, the total energy consumed from these data was computed to be approximately 230,000 MBtu. Data for calendar years 1975 and 1976 are somewhat more complete and indicate a total energy use from gas and oil to be approximately 211,200 MBtu and 214,100 MBtu's respectively. Product processing (industrial process steam) utilized approximately a constant 9,000 MBtu's per month (108,000 MBtu's/year) which is approximately one-half of total energy consumed.

Summary of Previous Studies

In early 1976, the Engineering Experiment Station conducted a program supported by the State Energy Office to identify, quantify and document potential in-State (Georgia) energy resources including examining priorities and performing economic assessment of the development potential. One of the prime in-State energy resources is solar energy. Motivated by the growing desire in the industrial communities to find alternative energy resources to alleviate the national gas shortage and fuel oil price escalation, a specific study was conducted to determine the economic and technical feasibility of utilizing solar energy needs of industrial facilities in Georgia. The Western Electric cable manufacturing plant was chosen for a specific case study.
Figure 2-1. 1976 Energy Usage in Western Electric Atlanta Works.
This study examined the total thermal energy (gas and oil) consumed during calendar year 1975. The total thermal energy used was approximately 211,200 MBtu's varying from a monthly use of approximately 24,000 MBtu in the winter months to a low of 13,000 MBtu during the summer. The boilers used primarily gas as a fuel during this period; however, the plant experienced 94 interrupted periods during which oil was utilized. Average cost of fuel was $1.12/MBtu.

A solar system was postulated and sized to approximately meet the thermal energy demand in August (approximately that required to meet the product processing needs). The average annual energy supplied from this system sized at 4577 kWt was 44,100 MBtu's or approximately 20 percent of the total demand or 40 percent of the product processing needs.

A solar system of the type desired was viewed to be technically feasible. A cost-benefit analysis of the resulting solar augmented system was conducted. The prime benefit resulting was the cost of fuel (gas and oil) saved. This would have amounted to $61,740 in 1975, if the solar system had been operative.

Rather than attempt to design a specific solar system of the size desired and to conduct costing of the system (very little pricing data were available), the cost-benefit analysis was performed in reverse. It was assumed that the present worth (cost in today's dollars) would be zero. This implies that the costs of fuel saved over the lifetime (30 years was used in this case) of the solar facility would be equal to the total costs of the solar facility. Treatment of the problem in this fashion produces important decision and management information, namely, the amount of capital investment allowable as a function of fuel costs.

The results of this study indicated that for the present price of fuel (1975, $1.12/MBtu), a capital cost of $440,000 could be invested in a solar
facility (4577 kW t) to produce a net present value (NPV) of 0 (breakeven). This was not economically feasible (a 4577 kW t facility could not be procured for this amount); however, fuel costs were increasing and cost of solar equipment was expected to decrease such that economic feasibility was forecast in the future. For example, when fuel costs increased from the value of $1.12/MBtu (primarily natural gas) to $2.23/MBtu, $1,000,000 could be invested for a solar facility with NPV of zero (see Figure 2-2).

This study was completed and the results documented in the summer of 1976.

In late February 1977, Western Electric contacted the Engineering Experiment Station (EES) to reassess the solar augmented system. The winter of 1976-1977 had been severe impacting heavily on gas and oil supplies. The gas supply available to the plant had been interrupted in early November 1976, and no significant amount of gas had been available since. (Complete reliance on oil was required; thus much higher fuel costs). Net overall impact on fuel cost for calendar year 1976 was an increase to $2.64 MBtu (more than double the cost in 1975).

Since March 15, 1977, EES in concert with Western Electric has been reassessing the feasibility of a solar augmented energy system. The results of this feasibility analysis are reflected in the following sections of this report.
Figure 2-2. Allowable Solar System Investment Capital vs Fuel Costs for a Net Present Value of Zero.
3. SOLAR SYSTEM STUDIES

General Guidelines

In assessing the energy consumption of the Western Electric Atlanta Works, the conclusion was reached that the most effective utilization of solar energy would be through a solar system capable of generating steam which would be injected into the main steam header distribution system of the plant. This solar generated steam could be effectively utilized without further plant modification in product processing operations or in heating and cooling the buildings. The solar system would be sized such that the steam generated could always be used by "idling back" the present oil and gas fired boilers (resulting in savings of oil and gas fuels).

The solar system would therefore require a concentrating collector field capable of producing comparable steam to that produced by the boilers and possibly some type of heat storage system as a buffer for control.

A solar system which would augment or furnish part of the steam needs of the plant evolved by examining solar collection systems, the energy available from the sun, and various system concepts (approaches), site locations and plant interfacing. These studies led to a proposed system concept, size, location and operation for which costs and cost-benefit studies were conducted. The following sections outline the evolution of the solar system deemed most appropriate.

Solar Collectors

Three types of solar collectors are available (Figure 3-1). These are the flat plate collector, the concentrating trough collector, and the concentrating cavity collector.

The flat plat collector is simply an array of flat, collecting modules which are located such that the sunlight incidence upon them is the best year-
TYPES OF SOLAR COLLECTORS

- FLAT PLATE
  - Generally used to heat water (water can be used to operate absorption air conditioner)
  - Cost efficient temperature limit - approximately 190°F
  - Generally considered "fixed," but may be adjusted several times annually to increase efficiency

- CONCENTRATING TROUGH
  - Used to heat water, generate steam or heat gases
  - Cost efficient temperature range - 190°F to 600°F
  - Track sun continuously using single-axis mechanism

- CONCENTRATING CAVITY
  - Used to produce steam or high pressure water, to heat suitable liquids to high temperatures, or to test materials to very high temperatures
  - Cost efficiency regime - above 600°F
  - Continuously track sun using two-axis mechanism

Figure 3-1.
round average. The collectors do not track the sun generally, although some have been designed for adjustment seasonally (two to six times a year) to improve the angle between the collector and the sun.

These types of collectors are considered to be suitable for temperatures—outlet temperatures—on the working fluid of about 190°F. These collectors are therefore not capable of generating steam but are being used for many solar heating and cooling applications.

The concentrating cavity collector systems are capable of generating extremely high temperatures. They generally are considered for applications where temperatures over 600°C are required. Figure 3-2 illustrates a current concept of a central power station solar electric generating facility using a concentrating cavity receiver. Here hundreds of mirror arrays tracking the sun reflect (focus) the sunlight into a single cavity atop the tower. The tower unit is a steam boiler. From the sun energy collected, steam is produced which passes down the tower into a turbogenerator. The turbogenerator generates electricity which flows out into the distribution network. Integral to the operation of this system is a thermal storage subsystem (see Figure 3-3). Its purpose is to provide buffering for periods when clouds pass over the mirror field or for operation after sunset or after the sun radiation is so low that it will not power the boiler.

Concentrating trough collectors are designed as long cylindrical or parabolic reflectors. The highly polished reflecting surface is generally anodized aluminum sheeting. This type collector is manufactured by a number of different suppliers and appears to be most appropriate for the applications at Western Electric. Because of its importance to this application, a number of somewhat different versions will be presented and discussed.
Figure 3.2: Solar Power Tower.
A THERMAL STORAGE SYSTEM FOR SOLAR ELECTRIC POWER PLANTS

Ralph F. Altman
Steve H. Bomar, Jr.
Charles A. Murphy

June 1977

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332
Figure 3-4 presents a photograph and Figure 3-5 some characteristics of a trough collector designed and built by Acurex Aerotherm. The surface is highly polished and anodized aluminum. At the focal point (line focus) is a long absorbing receiver tube through which the working fluid flows. The concentrated solar energy heats this fluid as it flows in the absorbing receiver tube. The fluid (water or oil) enters at relatively low temperature and emerges at temperatures up to 600°F. The collector is capable of tracking the sun along one axis using a drive mechanism and sun sensor to maximize collection of the sun radiation.

A similar collector is manufactured by Hexcel Corporation (see Figures 3-6 and 3-7). The reflecting surface is an aluminized, modified acrylic, plastic film. As before, single axis sun tracking is used.

A collector of similar performance characteristics but different design is manufactured by ITEK (see Figures 3-8 and 3-9). For operation of this collector, the receiver tube is stationary and the individual mirror slats rotate such that line focus of the sun's radiation remains on the fixed receiver tube.

Figures 3-10 and 3-11 presents information on a similar kind of collector manufactured by Polisolar, Ltd. In this case, an array of trough collectors are built into a single frame. Operation with single axis tracking is similar to the previous collectors.

Sheldahl manufactures the solar linear collector shown in Figures 3-12 and 3-13. This collector has a stationary collector tube with rotating glass mirror slats with single axis tracking.

The faceted fixed mirror concentrator collector manufactured by Scientific Atlanta is shown in Figure 3-14 and its operating characteristics are briefly summarized in Figure 3-15. In this collector, the mirrors are fixed
Model 3001 High-Temperature Concentrating Solar Collector

Low-cost, versatile concentrator for high-temperature applications.

Description

The Model 3001 Acurex Concentrating Collector is a reflecting parabolic trough solar collector. It is designed to heat liquids or gases to temperatures between 250°F and 600°F. In this temperature range, the Acurex Collector is highly cost-effective compared to other flat-plate and concentrating collectors now on the market. Typical applications include water heating, air heating, steam generation, and space cooling.

The Model 3001 Collector is assembled in modules 10 feet in length. Eight modules are normally coupled together to form a line of collectors which is driven by a single drive system at the middle of the line. This arrangement can be modified to suit any specific application.

The aperture of the reflecting parabolic trough is 6 feet with a rim angle of 90°. The reflecting surface is aluminum lighting sheet mounted on a painted structure.

Each collector is equipped with a 1.25-inch mild steel receiver tube. This receiver tube is coated with either black paint or selective black chrome over nickel plate (for applications over 250°F). A pyrex glass jacket encloses the receiver tube.

The heated fluid in the receiver tube can be water, organic liquid, or air. A central plug in the receiver tube creates an annular passage that produces high liquid convective coefficients with an acceptable fluid pressure drop. The size of the plug is based on the specifications of the overall system.

Figure 3-4. Acurex Aerotherm High Temperature Concentrating Solar Collector.
ACUREX - AEROTHERM MOD. 3001 HIGH TEMPERATURE CONCENTRATING COLLECTOR

- Type - parabolic trough
- Operating temperature limit - 600°F
- Reflecting surface - highly polished and anodized aluminum sheet
- Tracking - reflector/absorber assembly tracks sun as a unit
- Aperture width - 6 feet
- Module length - 10 feet

Figure 3-5.
PARABOLIC TROUGH CONCENTRATOR
HEXCEL CORPORATION D.S. 1550

- All metal frame
- Receiver pipe is copper or steel with a variety of surface finishes.
- Troughs are fabricated from treated aluminum honeycomb with aluminum skins for excellent corrosion resistance.
- Reflective film is aluminized modified acrylic.
- Module Size - in 20' lengths
- Aperture - up to 9'

WORKING FLUIDS
- Air to 600°F
- Water to 350°F
- Oil to 600°F

TRACKING FEATURES
- Shaded photo-transistor sensor
- Excellent tracking accuracy
- Full inversion of troughs for storage

CONTROL OPTIONS
- Day/night operation sensor
- Over temperature protection
- Adjustable cloud and/or insolation operational limits
- Adjustable wind intensity protection
- No flow protection

Figure 3-6. Hexcel Parabolic Trough Concentrator.
HEXCEL CORPORATION D.S. 1550 PARABOLIC TROUGH CONCENTRATOR

- Type - parabolic trough
- Operating temperature limit - 600°F
- Reflecting surface - aluminum skin with aluminized modified acrylic film
- Tracking - reflector/absorber assembly tracks sun as a unit
- Aperture width - up to 9 feet
- Module length - 20 feet

Figure 3-7.
Figure 3-8.
ITEK POWER COLLECTOR

- Type - segmented focused reflector
- Operating temperature limit - not stated
- Reflecting surface - various, including both glass mirror and film coated aluminum
- Tracking - reflectors track sun, absorber remains stationary
- Aperture width - 6.6 feet
- Module length - 20.5 feet

Figure 3-9.
Figure 3-10. Polisolar Concentrating Collector.
POLISOLAR LTD. CONCENTRATING SOLAR COLLECTOR

- Type - parabolic trough
- Operating temperature limit - \( \approx 540^\circ F \)
- Reflecting surface - highly polished anodized aluminum
- Tracking - reflector/absorber assembly tracks sun as a unit
- Aperture width - 2 feet
- Module length - 10.5 feet

Figure 3-11.
Figure 3-12. Sheldahl Solar Linear Array Thermal System.
SHELDahl SLATS\textsuperscript{TM} - SOLAR LINEAR ARRAY

THERMAL SYSTEM

- Type - segmented focused reflector
- Operating temperature limit \(-630^\circ\text{F}\)
- Reflecting surface - focused glass mirror
- Tracking - reflectors track sun, absorber remains stationary
- Aperture width - 10 feet
- Module length - 10 or 20 feet

Figure 3-13.
Figure 3-14. Scientific Atlanta Faceted-Fixed Mirror Concentrator.
SCIENTIFIC ATLANTA FFMC™-FACETED-
FIXED MIRROR CONCENTRATOR

- Type - segmented flat mirror
- Operating temperature limit - 600°F
- Reflecting surface second surface mirror
- Tracking - reflector segments stationary, absorber moves through arc to track sun
- Aperture width - 6.7 feet
- Module length - 10 feet

Figure 3-15.
but the absorber tube (receiver) rotates through an arc such that the reflected and line focused radiation from the sun always falls on the receiver tube.

The Acurex Aerotherm concentrating collectors were selected for more detailed system consideration in this study. The selection was influenced somewhat because these collectors have been utilized in other operating systems and thus better and more complete performance data are available. These collector units are installed and being evaluated in a test facility at Sandia/Albuquerque (see Figures 3-16 and 3-17). In this application the heat transfer fluid is oil operating up to a maximum temperature of 550°F. The collectors are oriented east-west and are currently in operation. Other applications using these collectors are also complete. Such as the solar powered shallow-well irrigation system located east of Albuquerque in Willard, NM (Figures 3-18 and 3-19) and the solar water heating system at the Campbell Soup Plant, Sacramento, California (Figures 3-20 and 3-21).

With a collector system selected, the next step in designing a solar system is to examine data regarding the location of the sun and the amount of radiation (energy) available seasonally to the collectors at the particular location of the system.

Energy Available From the Sun

Charts and data are available to specifically identify the path of the sun for any particular latitude location on earth. Atlanta is located at 33.75° north latitude.

Solar noon is defined as the time when the sun is at its highest point above the horizon. In Atlanta, solar noon is at approximately 12:30 p.m. during the Eastern Standard Time period and 1:30 p.m. during Daylight Saving Time. The solar equinoxes (March and September) are when days and nights are approximately equal in length; the summer solstice (June) and the
Figure 3.16: Acurex Aerotherm Concentrating Collectors in Sandia-Total Energy System.
ACUREX - AEROTHERM COLLECTOR

- Installation at Sandia/Albuquerque in total energy system
- Working fluid in collectors - oil
- Oil operating temperature - 550°F

Figure 3-17.
Solar-Powered Shallow-Well Irrigation System

Concentrating Solar Collectors supply energy to pump water for the Southwest's agriculture.

Description

Today, there are several hundred thousand shallow irrigation wells on farms and ranches in the southwestern states of California, Arizona, New Mexico, and Texas. The pumps on most of these wells are powered by fossil fuels, primarily natural gas. Inevitable increases in the cost of these fuels — and the threat of shortages — may make many of these wells unprofitable to operate in the foreseeable future.

To explore solar energy as a way of driving these wells, Acurex Solar Concentrating Collectors are being used in an experimental solar-powered irrigation system near Albuquerque, New Mexico. Sponsored by the Energy Research and Development Administration (ERDA) and the state of New Mexico, the project is designed to prove that solar energy is a technically and economically sound source of power for supplying water to America's agriculture.

Currently available technology is being used in all components of the experimental solar system. Performance data from this system will prove that the concept is feasible, and guide the commercial production of similar solar-powered irrigation systems in the near future.

Figure 3-18. Acurex Aerotherm Solar-Powered Shallow-Well Irrigation System.
ACUREX - AEROTHERM SOLAR POWER
SHALLOW - WELL SYSTEM

- Project purpose - provide irrigation water from shallow well
- Location - near Albuquerque, NM
- Type collectors - parabolic trough Mod. 3001
- Working fluid in collectors - oil
- Oil operating temperature - 420°F

Figure 3-19.
Solar Industrial Process
Hot Water System

Solar water heating installation at the Campbell Soup plant, Sacramento, Ca.

Acurex and Campbell Soup Company, under ERDA sponsorship, are working together to investigate how solar energy can be used to heat water for industrial applications. Acurex first made a thorough study of the hot water needs at the Campbell Soup Company's plant in Sacramento, California. Following this study, Acurex designed a solar water-heating installation that will supply hot water at the required temperature of 190°F.

The solar heated water will be used to wash empty and full soup cans on one of many parallel can-washing lines. An adjacent line will be used for comparison. The system is currently being built and should be operational by late 1977. It will be tested for a full year to provide complete information on efficiency, reliability, and operating costs.

Description
Acurex's solar field design uses an optimum mixture of flat plate and concentrating solar collectors. The flat plate collectors are single-glazed with a non-selective surface on the metal absorber. These flat plate collectors will preheat the water. Final heating will take place in the trough-shaped parabolic concentrating collectors.

The installation will supply 190°F water at a rate of 12,000 gallons per day during the peak season. At other times during the year, the same amount of water will be supplied at a lower temperature. This water will be brought up to the required 190°F by a steam heat exchanger. A storage tank will be used to ensure that hot water is available for two 8-hour shifts. The complete heating system is diagrammed on the back of this sheet.

Design

Figure 3-20. Acurex Aerotherm Solar Industrial Process Hot Water System.
ACUREX - AEROTHERM SOLAR HOT WATER SYSTEM

- Project purpose - heat water for can-washing at Campbell Soup Plant
- Location - Sacramento, CA
- Type collectors - flat plate and parabolic trough
- Water temperature -
winter solstice (December) is when the sun reaches its highest or lowest position respectively in the sky at solar noon.

The sun's energy reaches a particular location through either direct or diffuse radiation. These are measured as direct and total (direct plus scattered) radiation. For concentrating or focusing collectors, the direct radiation is the component of importance. Flat plate collectors are sensitive to total radiation. The direct radiation available at any location is measured using instruments that track the sun (plane of collection is perpendicular to a direct line to the sun). Total radiation is normally measured using a flat non-tracking horizontal surface detector.

Figure 3-22 is a picture of the weather station at Georgia Tech used to measure weather information important to the utilization of solar radiation. The station, installed in 1976, provides sun data, wind speed, rainfall, temperature and humidity.

Figure 3-23 shows direct and total solar energy available on a very clear day. Figure 3-24 is similar data on a cloudy day (note the sharp interruptions as clouds pass through the collection path). Any design of a solar system must be capable of withstanding and operating with these interruptions.

Figure 3-25 presents the integrated direct solar radiation available as a function of solar time for the winter solstice, summer solstice and the equinoxes. Very little difference is noted in the amount of direct radiation available for these different time periods. The average annual solar direct radiation intensity is shown in Figure 3-26 and is the data used for the conceptual design of the solar system.

Figure 3-27 indicates the anticipated system efficiency as a function of radiation intensity for different desired temperature levels of the working fluid in the collector. For the conceptual design of the Western
Figure 3.22: Georgia Tech Weather Station.
Figure 3.23: Solar Insolation Chart, March 23, 1977.
Figure 3.24: Solar Insolation Chart, July 20, 1977.
Figure 3-25. Solar Direct Radiation Intensity Curves Representing the Solstices and Equinoxes.
Figure 3-26. Average Annual Solar Direct Radiation Intensity Curve.
Figure 3-27. Solar System Efficiency vs. Direct Solar Radiation Intensity.
Electric system, the average temperature of the working fluid was selected to be 400°F. This 400°F working fluid can be used to produce 125 psia steam. This selection results in the system design parameters presented in Figure 3-28 and a net power curve for a typical no-cloud day as presented in Figure 3-29.

These design parameters define the energy available from the sun to be used in system concept designs.

System Concepts

Three system conceptual designs were examined. The first approach examined was a forced recirculation boiling concept where the collectors would actually serve as boiling tubes (see Figures 3-30 and 3-31). The water pumped into the collectors would pass out of the collectors as water-steam and be piped to a conventional steam separator. The separated steam would then pass through a pressure reducing valve and be injected into the plant steam header. This system would operate in parallel with the existing boiler system. Feedwater from the existing feedwater system would feed both systems.

There is one principal problem with this system. It would like to operate on nice, very uniform sun-days. The Atlanta area does not have many. Therefore, when uniform solar radiation is not available, the system supplied must be able to react to fast interruptions to achieve any efficiency in operation. This is not viewed to be compatible with the present system (see Figures 3-32 and 3-33). In this system, the hot collector fluid (water) at high pressure is flashed into steam which passes through a throttling valve into the main steam header. Condensate is returned back into the feedwater system. This system appears to suffer the same deficiency of the first system; namely, due to sharp interruptions
NET SOLAR DIRECT ENERGY

- Daily collection - 780 Btu/ft\(^2\)
- Annual maximum available - 723,000 Btu/ft\(^2\)/yr
- Actual design basis annual - 250,000 Btu/ft\(^2\)/hr
- System efficiency - 35%

Figure 3-28.
Figure 3-29. Net Solar Energy Into System vs. Solar Time.
Figure 3-30. Schematic of Forced Recirculation Boiling Concept.
FORCED RECIRCULATION SOLAR BOILER

- Operates as a forced recirculation boiler
- Replaces conventional fuel with solar energy
- Utilizes conventional steam separation methods
- Requires no thermal storage and uses water (steam) throughout system

HOWEVER

- Requires either uninterrupted sun energy (no clouds) or supplied system must be able to accommodate surges

Figure 3-31.
Figure 3-32. Schematic of Pressurized Water Collector System.
PRESSURIZED WATER SYSTEM

- Similar in operation to forced recirculation system

**BUT**

- Also requires either uninterrupted sun energy (no clouds) or, supplied system must be able to accommodate surges

Figure 3-33.
in the sun's radiation intensity, it would be difficult to integrate with (or augment) the present in-plant steam system.

The third system examine was a low pressure heat transfer oil working fluid/collector system presented in Figures 3-34 and 3-35. This system incorporates not only collectors and a boiler but also a storage system as a buffering stage. The system would operate as follows:

When sun energy is available, oil in the cold tank would be pumped through the collectors, heated, and into the hot tank. This operation can take place independent of any steam generation. When adequate hot fluid is collected and steam is desired, the hot fluid is pumped through a natural circulation boiler back to the cold tank. The steam produced as the hot oil passes through the boiler is separated in a conventional drum separator and injected into the main steam header. This system allows for controlled operation during periods of interrupted sun radiation due to clouds, etc.

During periods of good sun energy, the operation of the system is represented by the curve and data presented in Figures 3-36 and 3-37. The system would start collecting energy at about 7:30 a.m. solar time. Approximately two hours later sufficient energy is collected and stored in the hot tank to produce steam. Steam is then produced at a constant rate during the day and for approximately one hour after sunset. During this period, the gas and oil fired boilers would be idled back proportionately to save fuel. These two systems could thus be integrated easily and managed and controlled efficiently. The size of the solar system is indicated to be capable of generating 4600 lbs. of steam per hour.

With this system concept selected, sites for its location were examined. **Site Selection**

Three possible sites were examined for location and integration of the solar system. These are indicated in Figure 3-38. Site 1 is behind
Figure 3-34. Schematic of Low Pressure Oil Collector System.
OIL WITH STORAGE SYSTEM

- Accommodates operational interruptions in collector system
- Provides easy integration into existing process/heat steam system header and day-by-day operational management
- Utilizes conventional natural circulation boiler
- Design/operation information available

Figure 3-35.
Figure 3-36. Operation of Solar Power Steam System Curve.
OPERATION OF SOLAR PROCESS STEAM SYSTEM

- Initiate solar collector operation about 7:30 AM solar time
- Initiate solar boiler operation about 9:15 AM solar time and increase to uniform boiling rate over 30 minute period
- Simultaneous to solar boiler start-up, reduce output of fossil boiler correspondingly
- Terminate solar collector operation about 4:30 PM solar time
- Initiate turn-down of solar boiler about 5:45 PM and decrease to shut-down over 30 minute period
- Simultaneous to solar boiler turn-down, increase output of fossil boiler correspondingly

Figure 3-37.
Figure 3-38. Site General Arrangement-Western Electric Atlanta Works.
the plant; Site 2 is west of the west parking area and Site 3 is along the north side of the roof of the main plant.

Site 2 does not offer efficient layout of the collectors and is some distance from steam line connections.

Site 3 suffers from roof loading, difficulty in interfacing with the existing system, and, of course, the problem and consequences of managing hot oil on the roof.

Site 1 appears to be the most ideal location (see Figure 3-39). A six-inch steam line connected into the main steam header is already available at this site. Electrical power is also available plus it appears to be a convenient and efficient construction site causing minimum interference with the other activities of the plant.

This site will easily accommodate 46,080 square feet of collectors which would be capable of supplying an average steam rate of 4600 lbs/hr. as indicated in Figure 3-36 or a total of $1.15 \times 10^{10}$ Btu annually. This equals approximately 18% of the process steam demands of the plant on an averaged annual basis (see Figure 3-40).

Site 1 was thus selected as being the most appropriate and was further examined for shadowing as a function of the seasonal location of the sun. No shadowing problems would be encountered from the present adjacent structures.

The system size was further examined in regard to average and maximum steam rate, annual energy displaced, and heat exchanger size. The design curves which resulted are presented in Figure 3-41. These curves provide basic engineering design information should a larger collector area (than the 46,080 square feet selected) be advantageous in the future.

The next step in the study was to provide system cost estimates based on the above selected parameters.
SITE GENERAL ARRANGEMENT

0 AREA 1

- Existing steam/water lines connect to steam loop
- Facility electrical power already available
- Facility fire protection water available
- Provides convenient and efficient construction site
- Construction activity would not interfere with other operations

Figure 3-39.
SITE AREA 1 SOLAR SYSTEM SIZE

- Collector area possible - 46,080 ft$^2$
- System average steam rate - 4,600 lb/hr
- Annual energy from system - $1.15 \times 10^{10}$ Btu
- Fraction of process steam provided - 18 percent

Figure 3-40.
Figure 3-41. Steam Rate, Annual Energy Displacement, and Heat Exchanger-Area vs. Collector Area.
System Cost Estimates

The cost estimates were broken down into the segments shown in Figure 3-42. Each segment was treated separately and cost curves as a function of system size were generated for each. The costing data thus generated as a function of system performance and size are summarized in Table 3-1 and Figure 3-43.

The system sized for site location 1 is highlighted in Figure 3-42. This system, containing 46,080 square feet of collectors operating as indicated in Table 3-1 and Figure 3-43, is estimated to cost $1,727,394.

Artist Conception of the System

Figure 3-44 presents an artist's conception of the system as described in the previous sections. The collector field is east-west oriented on Site 1 and is roughly square (335' x 345') in layout. The illustration shows the collectors, the hot and cold storage tanks, and the boiler. The steam produced is fed underground through an existing steam line to the main steam distribution header in the plant.

Summary

The previous sections indicate that a solar steam generating system to augment the present gas and oil fired boilers at the Western Electric Atlanta Works is technically feasible and system concepts, performance and cost have been examined and defined. The remaining activity to be addressed regarding overall feasibility and acceptability is cost effectiveness. A cost-benefit study was made of the system and the results of this study are presented in the following section.
COST ESTIMATING BREAK-DOWN

- Collector field
- Boiler
- Storage Tanks
- Controls and electrical equipment
- Site preparation and foundations
- Piping, valves, pumps, etc.
- Storage fluid
- Design/construction engineering
- Contingency

Figure 3-42.
## Performance/Cost vs Size Comparisons of Conceptual Solar Silam Generating Systems

<table>
<thead>
<tr>
<th>Collector Area, ft²</th>
<th>3,000</th>
<th>5,000</th>
<th>20,000</th>
<th>46,080</th>
<th>50,000</th>
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</thead>
<tbody>
<tr>
<td>Peak Energy Steam Equivalent, LB/HR</td>
<td>450</td>
<td>750</td>
<td>3,000</td>
<td>6,900</td>
<td>7,450</td>
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<tr>
<td>Average Steam Rate, LB/HR</td>
<td>300</td>
<td>500</td>
<td>2,000</td>
<td>4,600</td>
<td>4,950</td>
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<td>Annual Energy Displacement, 10^3 Btu</td>
<td>0.75</td>
<td>1.25</td>
<td>5.0</td>
<td>11.5</td>
<td>12.5</td>
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<tr>
<td>Annual Process Energy Fraction*</td>
<td>0.01</td>
<td>0.02</td>
<td>0.08</td>
<td>0.18</td>
<td>0.20</td>
</tr>
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</table>

### System Cost Estimates

<table>
<thead>
<tr>
<th>Component</th>
<th>3,000</th>
<th>5,000</th>
<th>20,000</th>
<th>46,080</th>
<th>50,000</th>
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<tr>
<td>Collector Field</td>
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<td>$116,200</td>
<td>$356,500</td>
<td>$702,794</td>
<td>$747,740</td>
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<td>Boiler</td>
<td>4,100</td>
<td>5,500</td>
<td>11,700</td>
<td>21,481</td>
<td>22,882</td>
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<td>Storage Tanks</td>
<td>15,800</td>
<td>23,500</td>
<td>69,300</td>
<td>99,346</td>
<td>105,470</td>
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<td>Controls &amp; Electrical</td>
<td>14,400</td>
<td>17,600</td>
<td>30,700</td>
<td>43,017</td>
<td>44,357</td>
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<tr>
<td>Site Preparation &amp; Foundations</td>
<td>9,200</td>
<td>13,100</td>
<td>34,500</td>
<td>62,171</td>
<td>65,600</td>
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<tr>
<td>Piping, Valves, Pumps, Etc.</td>
<td>45,300</td>
<td>64,800</td>
<td>171,000</td>
<td>307,723</td>
<td>324,694</td>
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<td>Storage Fluid</td>
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<td>30,600</td>
<td>70,852</td>
<td>76,500</td>
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<tr>
<td>Design/Const. Eng.</td>
<td>31,200</td>
<td>43,700</td>
<td>111,300</td>
<td>194,705</td>
<td>205,378</td>
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<tr>
<td>Contingency</td>
<td>30,200</td>
<td>43,800</td>
<td>122,312</td>
<td>225,312</td>
<td>238,893</td>
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<tr>
<td>Total Cost Estimate</td>
<td>$231,700</td>
<td>$335,850</td>
<td>$937,900</td>
<td>$1,727,394</td>
<td>$1,831,519</td>
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</table>

*Note: Based on 8,000 LB/HR steam operating 24 hrs/day, six days/week, 52 weeks/year.
Figure 3-43. Solar Steam Generating System Installed Costs vs. Collector Area and Average Steam Rate.
Figure 3.44: Artist Illustration of the System.
4. COST BENEFIT ANALYSIS

A cost benefit analysis was performed to evaluate the economic feasibility of the solar system defined and described in Section 3.

In this type of study all costs and benefits are quantified. Once this has been done, a systematic evaluation of the project will determine whether, and to what extent, its benefits outweigh its cost. Several methods of evaluation are available. The one chosen was "rate of return" based on the net present value formula. What actually is the net present value? It is a single number that represents the value of all present and future benefits and cost, discounted to reflect their present value or worth.

Diagramatically, the net present value is as shown in Figure 4-1. In year zero there is an initial capital investment represented by a large arrow in the negative direction. In years one through twenty, the estimated life of the facility, there are annual operating costs and benefits represented by small arrows in the positive direction. These arrows vary due to the annual fluctuation in net benefits (benefits minus costs). The largest arrow appears in year one, because government investment tax credit is added to the annual benefits in that year. The formula for computing net present value is shown in Figure 4-1. To compute the rate of return on investment the net present value is set equal to zero, that is, the annual benefits derived are set equal to the costs (initial plus annual) and the resultant equation is solved for the rate of return on investment (d).

At this point an interactive computer program was utilized and the values of the economic parameters used are shown in Figure 4-2. The economic parameters in question were: method of depreciation; amortization time; percent of investment tax credit permissible by the federal tax regulations; annual cost of fuel considering price increases. Several
Figure 4-1. Net Present Value Diagram

\[
NPV = -C_0 + \sum_{t=1}^{n} \frac{B_t - C_t}{(1+d)^t}
\]

- \(C_o\) - Initial Capital Investment
- \(B_t\) - Annual Benefits
- \(C_t\) - Annual Operating and Maintenance Costs
- \(n\) - Life of Facility in Years
- \(d\) - % Rate of Return on Investment
ECONOMIC PARAMETERS

Depreciation

A) Methods - Double Declining Balance
   Sum of Years Digit
   Straight Line

B) Amortization Time
   5  10  20 years

Investment Tax Credit
   10%  25%

Fuel Cost ($/MBtu)
   $2.60  $3  $3.50

Annual Fuel Price Increase
   2%  4%  10%

Figure 4-2.
computer runs, approximately 50, were made using various combinations of these values to test for the model sensitivity. The base line scenario is represented by the values underlined in Figure 4-2. A double declining balance method of depreciation was used with a 20-year amortization time (assumed to be the life of the solar facility). The present investment tax credit of 10% and present fuel cost of $2.60/MBtu was used. A 10% annual fuel price increase was felt to be a conservative estimate of the fuel price escalation.

The fuel price escalation experienced over the past five years is shown in Figure 4-3. In 1972, the average price of natural gas was $0.30/MBtu. Four years later in 1976, this price had risen to $1.11 MBtu and the frequency and duration of industrial interruptions had increased substantially. The replacement for natural gas (No. 2 fuel oil) in 1972 was $0.62/MBtu; in 1976 that rose to $2.10/MBtu. The annual percent increase is shown in Figure 4-3. There is no reason to believe that these increases will not continue in the future.

With the previously discussed parameters and their values, the project cost and rate of return was calculated for a system with a maximum steam rate of 6900 lbs/hr and an average steam rate of approximately 4600 lbs/hr. This system would cost an estimated 1.7 million dollars (see Figure 4-4).

The project cost is broken down as shown in Figure 4-5. The collector cost is as noted, the largest cost component comprising about 40% of the total cost. It is also recognized that the solar equipment industry is in its infancy stage and through time and with mass production and demand, the cost of collectors is the item most likely to decline.

Figure 4-6 indicates the rate of return Western Electric would receive as a function of investment. This graph indicates the effect of any govern-
<table>
<thead>
<tr>
<th>Year Range</th>
<th>Oil (%)</th>
<th>Gas (%)</th>
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<tr>
<td>1972-1973</td>
<td>95%</td>
<td>20%</td>
</tr>
<tr>
<td>1973-1974</td>
<td>67%</td>
<td>53%</td>
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<tr>
<td>1974-1975</td>
<td>--</td>
<td>56%</td>
</tr>
<tr>
<td>1975-1976</td>
<td>12%</td>
<td>29%</td>
</tr>
</tbody>
</table>

Figure 4-3.
BASELINE SCENARIO

- Maximum steam rate at solar noon: 6,900 lbs/hr
- Average steam: 4,584 lbs/hr
- Collector field: 46,309 sq.ft.
- Energy displaced: 11,577 MBtu
- Project cost: $1.7 Million

Figure 4-4.
# PROJECT COSTS

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td>Collector</td>
<td>$702,784</td>
</tr>
<tr>
<td>Boiler and Steam Separator</td>
<td>21,481</td>
</tr>
<tr>
<td>Storage Tanks</td>
<td>99,346</td>
</tr>
<tr>
<td>Controls and Electric Equipment</td>
<td>43,017</td>
</tr>
<tr>
<td>Site Preparation and Foundation</td>
<td>62,171</td>
</tr>
<tr>
<td>Storage Fluid</td>
<td>70,852</td>
</tr>
<tr>
<td>Piping, Valves, Pumps, Strainers and Traps</td>
<td>307,723</td>
</tr>
<tr>
<td>Design and Construction Engineering</td>
<td>194,705</td>
</tr>
<tr>
<td><strong>SUB-TOTAL</strong></td>
<td><strong>1,502,082</strong></td>
</tr>
<tr>
<td><strong>CONTINGENCY @ 15%</strong></td>
<td><strong>225,312</strong></td>
</tr>
<tr>
<td><strong>TOTAL ESTIMATED COST</strong></td>
<td><strong>$1,727,394</strong></td>
</tr>
</tbody>
</table>

Figure 4-5.
Figure 4-6. Western Electric Investment vs. Rate of Return
ment funding on Western Electric's rate of return. The rate of return has a broad range—from slightly less than zero—for full investment in the system, to a 24% rate of return for an investment of approximately $40,000 as contained in the proposal to the U. S. Energy Research and Development Administration (Section 1).

All these values were based on the base-line scenario which assumes no government incentives. Presently Congress is discussing and will soon vote on several bills. Two of these are a 25% investment tax credit on solar equipment, and a five-year accelerated method depreciation allowance.

If these incentives were passed, the result would be a favorable shift upward (see Figure 4-7) of Western Electric's rate of return varying from slightly less than zero to 24% to a range of 2% to 30% depending on the amount invested. This computed rate of return is after taxes.
With Government Incentives

Without Government Incentives

Figure 4-7. Western Electric Investment vs. Rate of Return.
5. CONCLUSIONS AND RECOMMENDATIONS

A solar steam generating system which would displace part of the present gas and oil fired boiler system steam production has been conceptually designed and a preliminary performance analyses has been completed. The conceptual system design is currently technically and commercially feasible and would integrate efficiently with the present steam distribution system.

The selected site for a solar facility would accommodate a solar system of the following size and performance:

<table>
<thead>
<tr>
<th>Collector Area</th>
<th>46,080 ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Energy Steam-Equivalent</td>
<td>6,900 lbs/hr</td>
</tr>
<tr>
<td>Average Steam Rate</td>
<td>4,600 lbs/hr</td>
</tr>
<tr>
<td>Annual Energy Displacement</td>
<td>11.5 x 10⁹ Btu</td>
</tr>
<tr>
<td>Percent of Annual Process Energy Supplied*</td>
<td>18%</td>
</tr>
</tbody>
</table>

The capital cost of the system was estimated to be $1,727,394.

The investment rate of return was determined using net present value method of analysis based on:

- a 20 year facility life
- energy cost increasing at a compound 10 percent per year over inflation
- current tax regulations on investment credit
- accelerated depreciation.

The results of the analysis indicated that the rate of return on investment would be about one-half of one (0.5) percent negative which clearly illustrates the unattractive nature of such an investment from the financial point of view. However, careful examination should be made of the overall energy

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*Based on 8000 pounds per hour steam usage operating 24 hours per day, 6 days per week, 52 weeks per year.
situation in the world before basing future plans or actions solely on the traditional economic analysis. The future energy picture remains very unsettled regarding availability, cost, and government actions. For example, there is an indication that all industry presently using gas and oil as a fuel may be forced to convert to coal unless the gas and oil is used specifically as a feedstock for product processing. In other words, if the industry can successfully function with coal as a fuel, as in Western Electric's case, then gas or oil will be restricted from use by that industry. This, in essence, would force the conversion to coal or some alternate fuel such as solar. The cost-benefit analyses conducted during this study were based on solar investments being repaid through savings in the cost of gas and oil not used. The study did not consider economic comparisons resulting from converting the present gas and oil-fired boilers to coal.

In final deliberations, it would appear that those industries that have implemented self-directed initiatives to reduce dependence on gas and oil for heating, cooling and steam production will be given special consideration. For example, a solar-augmented gas and oil-fired system could be an encouraged and accepted approach and thus prevent forced conversion to a coal system (which possibly would be much more costly to reach considering all cost factors).

The previous discussion may be more speculative than fact, however, it does point out the many future considerations which must be weighed and assessed in reaching decisions regarding future energy actions or reactions. It is extremely difficult to define the future economic parameters related to energy sufficient to base management judgments and decisions totally on direct economic assessments without factoring into the considerations, the possible impacts of priority curtailment or stringent controls imposed
by embargo. This uncertainty must be offset by having alternate plans ready for implementation.

In view of the above, it is recommended that Western Electric consider the installation of a small pilot solar steam generating facility having 3000 to 5000 square feet of collectors. Such a system would provide "hands-on" operational capability and understanding and would endow Western Electric with more effective understanding of the energy supplementation possibilities using solar energy for the Atlanta Works as well as serve as a Corporate model and data-acquisition base.

The estimated performance and costs for such a pilot solar steam generating system are as follows:

<table>
<thead>
<tr>
<th>Collector Area, ft²</th>
<th>3,000</th>
<th>5,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Energy Steam Equivalent, lb/hr</td>
<td>450</td>
<td>750</td>
</tr>
<tr>
<td>Average Steam Rate, lb/hr</td>
<td>300</td>
<td>500</td>
</tr>
<tr>
<td>Annual Energy Displacement, 10⁹ Btu</td>
<td>.75</td>
<td>1.25</td>
</tr>
<tr>
<td>Percent of Annual Process Energy Supplied</td>
<td>.01</td>
<td>.02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System Cost Estimates</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector Field</td>
<td>$76,900</td>
<td>$116,200</td>
</tr>
<tr>
<td>Boiler</td>
<td>4,100</td>
<td>5,500</td>
</tr>
<tr>
<td>Storage Tanks</td>
<td>15,800</td>
<td>23,500</td>
</tr>
<tr>
<td>Controls and Electrical</td>
<td>14,400</td>
<td>17,600</td>
</tr>
<tr>
<td>Site Preparation &amp; Foundations</td>
<td>9,200</td>
<td>13,100</td>
</tr>
<tr>
<td>Piping, Valves, Pumps, etc.</td>
<td>45,300</td>
<td>64,800</td>
</tr>
<tr>
<td>Storage Fluid</td>
<td>4,600</td>
<td>7,650</td>
</tr>
<tr>
<td>Design/Construction Engineering</td>
<td>31,200</td>
<td>43,700</td>
</tr>
<tr>
<td>Contingency</td>
<td>30,200</td>
<td>43,800</td>
</tr>
<tr>
<td>TOTAL COST ESTIMATE</td>
<td>$231,700</td>
<td>$335,850</td>
</tr>
</tbody>
</table>

It is assessed that the Western Electric Atlanta Works offer an excellent application for a solar system and, as such, opportunities for
government assistance in providing funds for a larger system should continue to be pursued.