SOLAR ENERGY APPLICATIONS IN TRANSPORTATION FACILITIES

A Literature Review

by

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Summer Undergraduate Trainee

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

This report presents the results of a survey of the literature and other sources to determine the types of application that have been made of solar energy in the transportation field. The use of solar energy for powering automatic traffic counters, variable message signs, railroad crossing signals, bridge or pavement de-icing, cathodic protection of bridge decks, heating asphalt, as well as space and water, are all described. A list of references and a bibliography on solar energy are provided.

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INTRODUCTION

In recent years, the United States has seen a substantial increase in the demand for and consumption of oil and other fossil fuels. Forecasts are that the domestic production of oil will not be sufficient to keep pace with this rapid increase in demand; therefore, alternative energy sources must be utilized. While no single solution to the energy problem is likely to emerge, it is increasingly clear that the sun will play a major role.

The years between 1974-76 saw more accomplished in promoting the idea of widespread use of solar power than did the four previous decades. It was within this period that the Energy Research and Development Administration (presently the Department of Energy) was instituted and annual funding for solar energy programs other than space oriented projects was increased from $1 million to $50 million. With the government taking an active role in solar research, private industry began to realize that substantial profit could be made in this new field. Corporations such as RCA, GE, and Martin Marietta, aided by government grants, began developing techniques and apparatus to use this "free" energy. The transportation industry was not far behind them.

Several innovative state highway and transportation departments, including those of Arizona, Colorado and New Mexico, initiated solar research and development programs. Recently these states have been joined by others, including the Commonwealth of Virginia.

PURPOSE

The objective of this literature review is to provide the Virginia Highway and Transportation Research Council with a summary of present and potential applications of solar energy in the transportation industry.

Many of the sources of information cited in this report were located in an open literature search and others were supplied by the offices of the Arizona Department of Transportation and Southern Railways and files within the Virginia Highway and Transportation Research Council.

REVIEW OF BASIC SOLAR PRINCIPLES

Much has been published on the basic principles of solar energy utilization, and it is not the purpose of this report to add to this material. Nevertheless, a brief discussion of basic terms and operating procedures is included for the reader's convenience. Should one desire additional information of this genre, the references compiled in this research are excellent sources of information.

Solar radiation (insolation) arrives at the surface of the United States at an average rate of about 1,500 Btu/ft^2/day (about 42×10^9 Btu/mi^2/day) [17×10^6 joule/m^2/day].[1] The type of device used to collect this insolation depends primarily on the use to which it is to be put. In general, flat plate collectors are used for the heating (or cooling) of buildings and domestic hot water systems. Solar cells (also referred to as photovoltaics) are used for converting sunlight directly into electricity.

Solar thermal collectors may be categorized as (1) low-temperature flat plate collectors with no concentration, (2) medium-temperature concentrating collectors typified by parabolic cylinders, and (3) high concentration, high-temperature collectors such as parabolic concentrators or concentrators composed of many flat mirrors focused at the same point.[2]

Figure 1 illustrates the basic components of a flat plate collector. Sunlight falls on the transparent covering (glazing) and is absorbed by the plate below. This plate then rises in temperature and transfers the heat to a medium (usually air or water) flowing on the back side of the collector. At the same time, the heated collector wastes heat to the surrounding atmosphere by convection to moving air currents, by conduction to the air and colder parts of the structure which hold the receiver, and by infrared radiation.[3]

This type of collector is ideally suited for those heating systems requiring temperatures of about 150°F (66°C) above ambient. However, should temperatures in excess of 300°F (149°C) be desired, the use of a concentrating collector is recommended. At present, concentrators are used primarily for efficient electrical power generation, for large-scale industrial and agricultural drying, for increasing the output of photovoltaics, and in other uses for which high temperature heat is essential.

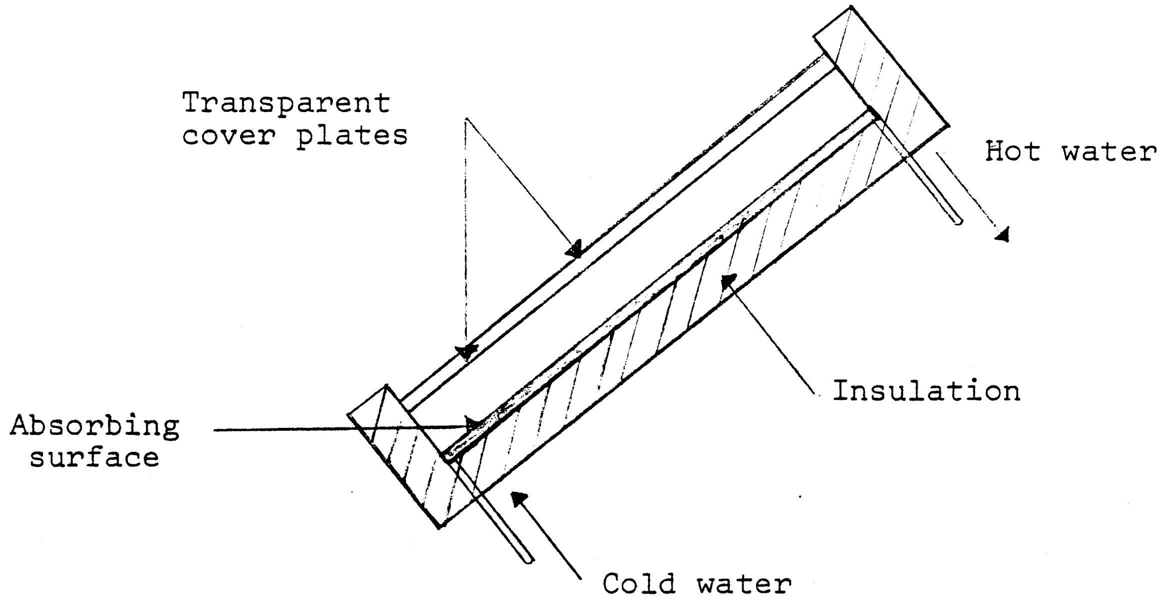

Figure 1. Flat plate solar collector.

Solar cells such as the one shown in Figure 2 offer a potentially attractive means for the generation of electricity both economically and technologically. However, due to their present prohibitive cost (upwards of $10 or $12 per peak watt), solar cells have seen significant use only within the space program.

Silicon, the second most abundant element on earth, is the primary material used for solar cells. (Other materials such as cadmium sulfide and gallium arsenide are also used, though not as extensively.) Silicon solar cells are made of two types of semiconductor silicon. One type (P type silicon) has a small number of boron atoms added to provide a slight positive electronic charge. The second (N type silicon) has phosphorus or arsenic atoms added. When these two types of silicon meet, a basic polarity difference develops across the junction. The extra electrons from the N type silicon move to the boron atoms in the P type silicon. This leaves the N type with a slight positive charge and the P type with a slight negative charge. When small packets of light (photons) strike the atoms in the cell, electrons escape the strong pull of the protons in the nuclei. The liberated electrons move toward the positively charged N type silicon and out into the circuit wire to the load that uses the electrical power.

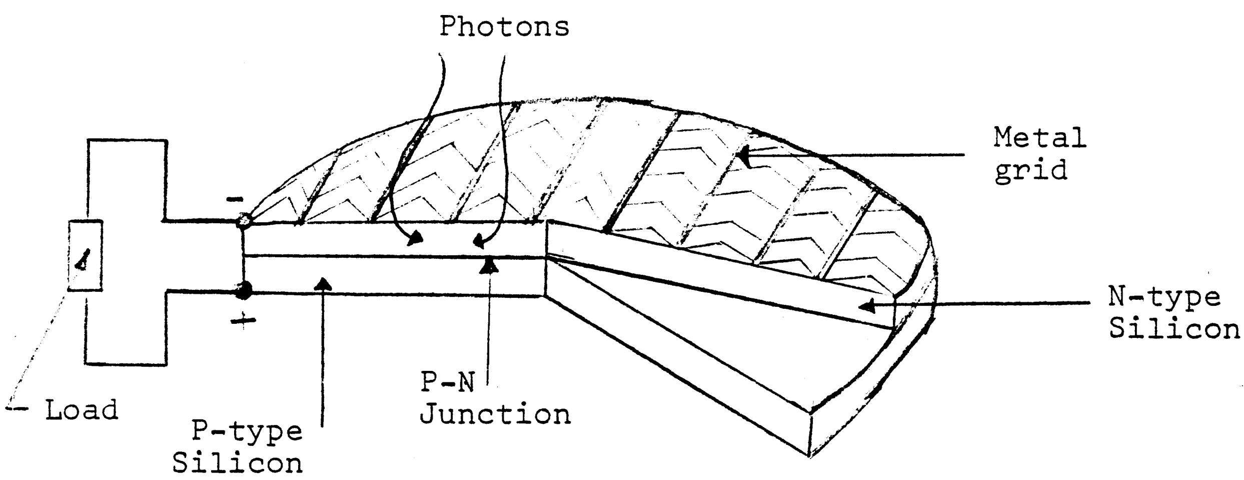

Figure 2. Solar cell.

APPLICATIONS IN TRANSPORTATION FACILITIES

Solar Energy as a Power Source for Cathodic Protection

In June of 1976 the National Park Service, in cooperation with Region 15 of the Federal Highway Administration, installed a solar panel between the lanes of the Dead Run Bridge, George Washington Memorial Parkway. The panel supplies the electrical power to operate a cathodic protection system used to prevent the corrosion of the reinforcing steel in the bridge deck.

Corrosion of the reinforcing steel is initiated by the penetration of deicing salt which eliminates the protection normally provided by the alkaline environment of the concrete. When this protection is removed, an electrical current flows from the surface of the steel through the concrete by means of the moisture in the concrete to another location in the steel. The area from which the current leaves the steel and begins to corrode is called the anode and the area at which the current enters the steel is the cathode. When the flow of current stops, the corrosion stops.[4]

Briefly then, cathodic protection, as part of Demonstration Project No. 34, is the external application of a direct current to the surface of the top mat of steel in sufficient amounts to overcome the internal current flow between the anode and cathode. The reinforcing steel then becomes a noncorroding, current-receiving cathode.[5]

The decision to employ solar energy as the cathodic power source was made primarily because the cost and installation of the solar power system was $4,620 as opposed to $13,954 for an installation using commercial electricity (a savings of $9,334), and (2) an additional savings from having no monthly charge for power.

The cathodic protection solar array, designed and manufactured by the Solarex Corporation, Rockville, Maryland, consists of 10 panels connected in parallel to produce a peak current of 33 amps at 2.4 volts.(6) The array is mounted on a 23-foot (7 m) high, 6-inch (152 mm) diameter mast adjacent to the bridge. Since seasonal angle corrections are not necessary, the panel is at an angle of approximately 45° (sufficient to prevent the accumulation of snow or ice on the panel surface during the winter months).

The most critical aspect of the design is the use of the correct size cable for connecting the solar array to the battery. (A lead-cadmium storage battery rated at 2,016 amp-hours and weighing 370 pounds [168 kilograms]was selected.) Because the total length of the cable is 60 feet (18.3 m) and because the current supplied to the battery from the solar cells is large, any resistance in the cable would create a severe voltage drop.(7) After much experimentation, it was determined that a size "0" wire for the cable would minimize this voltage drop.

The system has been in operation since June 1976 and has performed in a highly satisfactory manner. Several factors are responsible for this conclusion.

1. Since there are no moving parts, the system is virtually maintenance free. (The only required maintenance is the addition of water to the battery every 2-3 years.)

2. Because of their solid state construction, solar arrays have a high potential for a reliable and long operational life. (Repairs, if necessary, can be accomplished with minimal effort.)

3. Because the power output of solar cells increases when the temperature is lowered, solar cells perform well in extremely cold climates.

4. The peak current has been 27 amps, but this was not under ideal conditions.

5. Most important, the solar power system produces no adverse environmental effects.(8)

Solar Energy as a Means of Bridge Deicing

A U. S. DOT study has indicated that the preferential icing of bridge decks can be controlled with a heat pipe system that taps natural energy from the earth.(9) Although this system, shown in Figure 3, would eliminate operating expenses, the initial cost of \$20 to \$25 per ft.^{2} (\$220-\$270 per m^2) is prohibitive.

Since solar power is also both a renewable and natural energy source, a preliminary evaluation of a solar collector-heat pipe system was made to determine its advantages, if any, over a geothermal energy apparatus. Figure 3 is a schematic drawing of the solar design that was reviewed. Solar energy would be stored in a buried water tank and delivered to bridge heat pipes as needed and as controlled by a temperature-sensing system.(10)

Installation costs for earth and solar collector heat pipe systems were estimated to determine conditions for which these systems might be cost-competitive with traditional systems. Estimates showed that a solar collector-heat pipe system with pipes on 9-inch (229 mm) centers would cost about \$16 per ft.^{2} (\$170 per m^2) and \$18 per ft.^{2} (\$190 per m^2) to prevent icing on 5,000 ft.^{2} (465 m^2) bridges in New York City and Oklahoma City, respectively.(11) System costs would decrease to about \$13 per ft.^{2} (\$140 per m^2) as the size of the bridge increased to 20,000 ft.^{2} (1,858 m^2). By comparison, earth heat systems would cost approximately \$20 per ft.^{2} (\$220 per m^2) and \$18 per ft.^{2} (\$190 per m^2) for 5,000 and 20,000 ft.^{2} (465 m^2 to 1,858 m^2) bridges in either location.(12) Although they are first estimates, these values suggest that solar collector designs warrant further investigation and study.

Solar Power for Railroad Crossing Signals

While many people are talking about the feasibility of solar power, one railroad has turned the idea into a useful and money-saving reality. The Southern Railway's assistant vice-president of communications and signals, J. T. Hudson, says that solar energy is in practical use on the Southern today.(13) "We've gained a lot of valuable operating experience with the units we already have in place. They have demonstrated the cost savings possible with solar cells in remote locations where AC power or primary battery cells are just too expensive," said Hudson.(14)

Southern installed its first solar powered crossing signal in 1974 at Rex, Georgia (approximately 12 miles [19 km] south of Atlanta). Similar installations powering line-of-road signals and track circuits have since been added at Lake Ponchartrain, Louisiana, (near New Orleans), Figures 4, 5, and 6, and at Jackson, Alabama (near the Tombigbee River). The installations vary according to the load requirements and local sunlight conditions. The solar array at

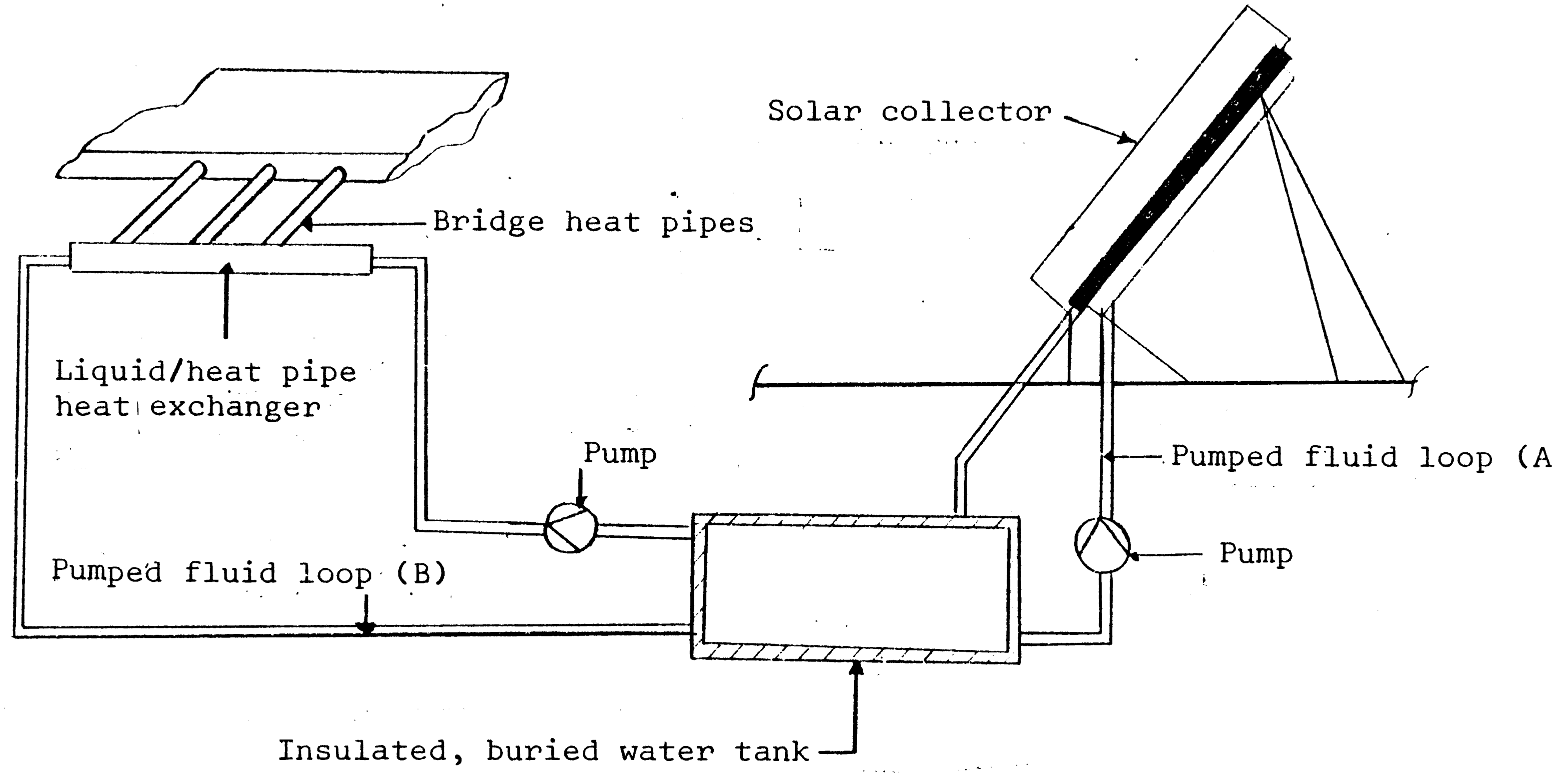

Figure 3. Schematic of solar collector/heat pipe design to prevent icing on highway bridge deck.

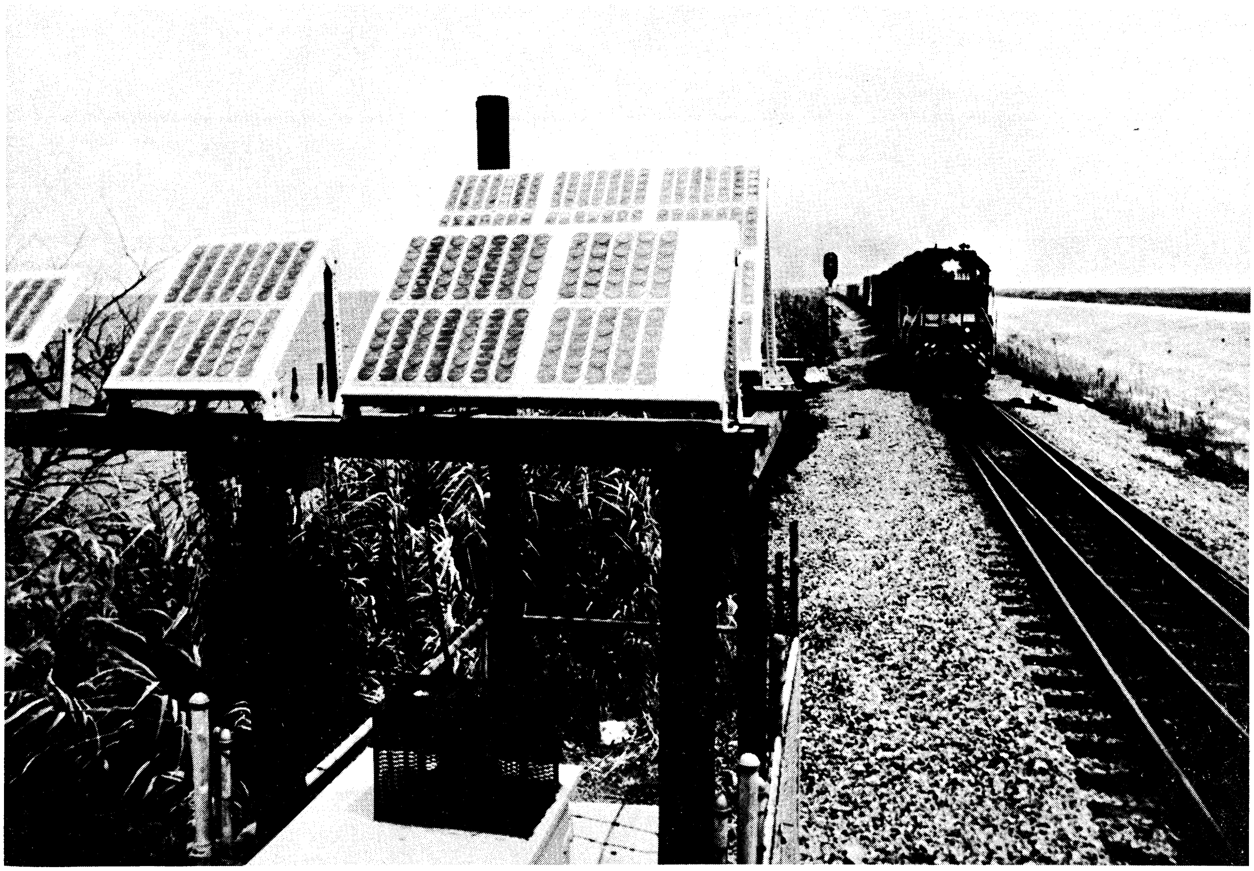

Figure 4. Solar accumulators, in the foreground, provide current to charge the storage batteries which provide the power operating these signals near the southern end of the Lake Pontchartrain trestle on Southern Railway's line into New Orleans. (Photo supplied by the Office of the Assistant Vice-President, Southern Railway Company.)

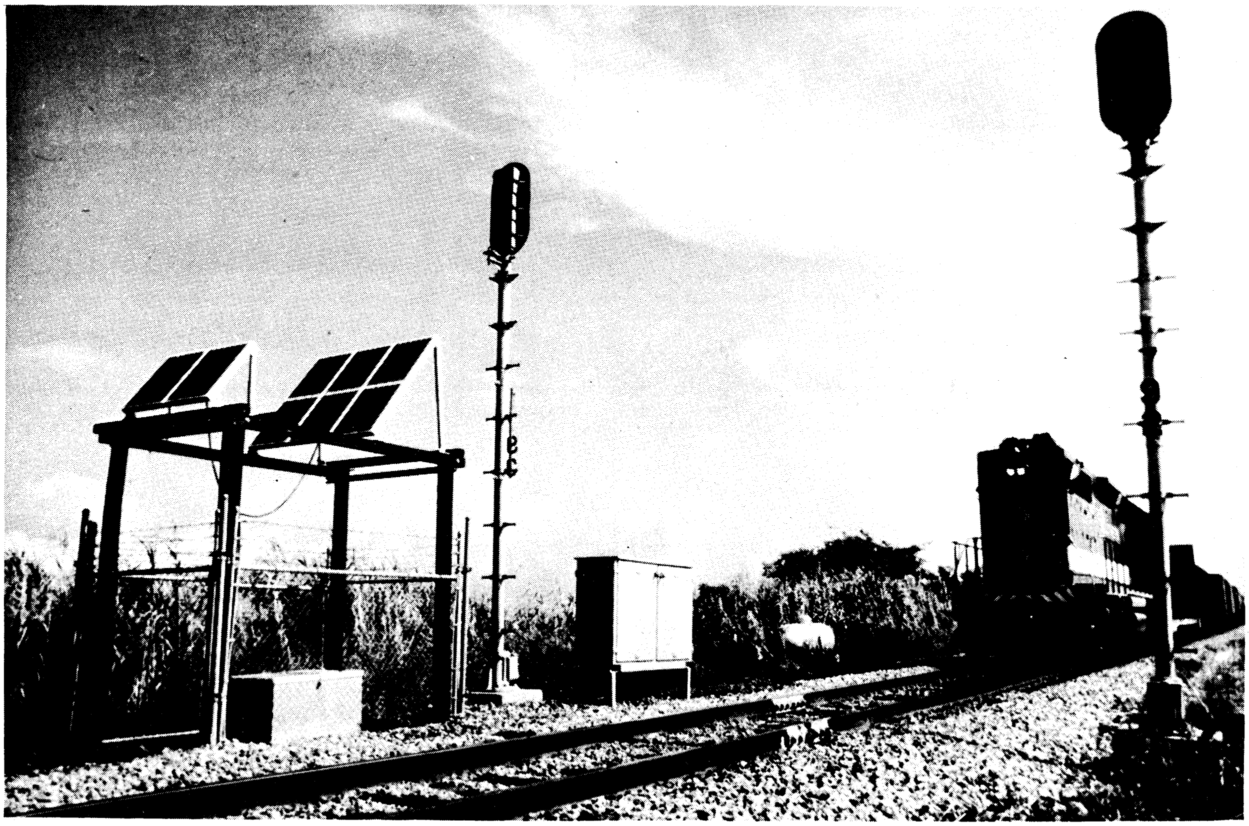

Figure 5. Solar power installation near the south end of Lake Pontchartrain trestle on Southern Railway's line into New Orleans. Solar accumulators (at left) provide current to charge the storage batteries (in the fence-enclosed case below). (Photo supplied by the office of the Assistant Vice-President, Southern Railway Company.)

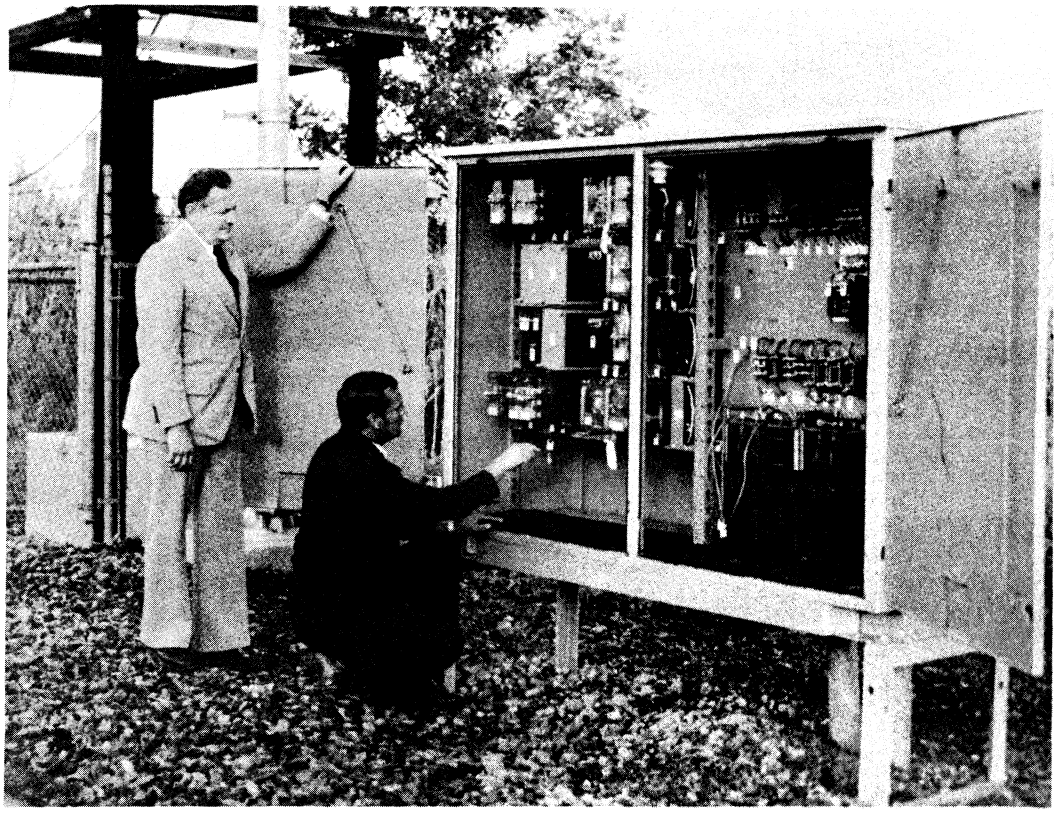

Figure 6. John Norris, left, superintendent of Southwest District, Communications and Signals, Atlanta, Ga., and Kenneth Atwell, C & S supervisor, Slidell, La., inspect a signal case. In the cases at left are the relays; the lower right holds batteries that store the energy collected by solar accumulators. (Photo supplied by the office of the Assistant Vice-President of the Southern Railway Company.)

Rex, for instance, supplies power for train motion detectors and dual flashing-light crossing signals. Solar power is generated through a 45-ft.^{2} (18 m^2) array of 119 2-in. (5 cm) diameter silicon modules which keep the bank of 168 amp-hour lead-calcium batteries charged.(15) Typical current requirements for signal track circuits vary from 1 amp for an unoccupied circuit up to 5.5 amps for an occupied circuit. The solar cells supply power to the rail circuit, recharging the storage batteries during daylight hours while the batteries take over at night.(16)

Southern operates four other solar installations. Three of these are on the levee at Lake Ponchartrain. Solar installations at those locations were particularly economical since the local power company estimated that costs to run a primary AC power line would be as high as $50,000, if permission from local levee boards could be obtained. At one tower approach location on the levee, the solar installation powers four track circuits, three line-of-road signals, and a dragging equipment detection circuit. At the two other locations, two track circuits and two line-of-road signals are dependent on solar power.

At Jackson, Alabama, approach and home signals and circuits for a drawbridge on the Tombigbee River are powered by a solar panel array. Southern will also power a drawbridge approach lock-out circuit (which prevents the bridge operator from raising the bridge once a train has activated the circuit) with solar energy at this location later this year.

With the success of these first projects, Southern has begun to look into several more ambitious uses of solar power ranging from possible heating purposes at small enclosures to powering remote microwave relay stations now emergency-powered by propane gas-burning generators.(17)

Solar Heat for Denver Bus Facility

In the summer of 1977, the Regional Transportation District opened a new 256,000 ft.^{2} (23,800 m^2) bus storage and maintenance facility in Denver, Colorado. The facility has the distinction of being the largest known solar-assisted heating installation in the world and the first federally funded solar heated transportation facility in the United States. Construction of the building was supported by an 80% grant from the Urban Mass Transportation Administration of the Department of Transportation.

The solar energy system consists of four subsystems: a solar collector, a storage unit, a space heater, and a boiler. Together, these subsystems can provide up to 40% of the building's heating requirements.[18]

The roof of the 252-bus facility supports the 1,390 solar collectors. Each collector measures 3-1/2 x 8 ft. (1.1 x 2.4 m) and together they provide a collector area of 39,037 ft. (3,627 m). Estimates are that the facility will have a usable output of 5,600 million Btu's (5.9 trillion joules) a year that will result in a savings of 51,000 gallons (193 cu.m) of No. 2 fuel oil yearly. At current fuel costs and with a 7% inflation factor, the unit will pay for itself in 16 years.[19,20]

Solar Energy Use by the Arizona Department of Transportation

Since the 1974 oil embargo and subsequent energy shortage, the Arizona Department of Transportation has led the nation in finding applications for solar energy relating to highway transportation. At present, solar energy provides a variety of services for the Department, ranging from heating water to operating automatic traffic counters.

In May 1977, the Department activated a solar-powered sign to warn of dust storms on Interstate 10 south of Phoenix. According to officials the sign has performed perfectly, and the photovoltaic system has shown no adverse effects from hot desert temperatures.[21]

Encouraged by the success of these current projects, the Arizona researchers are studying new ways to use solar energy at a rest area on Interstate 8 near Gila Bend.

At present, the Department maintains two solar-assisted water heaters for use in washrooms at two rest areas near Phoenix. The water is heated by collectors during the day and stored overnight in large tanks to be used without supplemental heating the following morning.[22]

Plans for the Table Top rest area on Interstate 8 call for the use of solar power to provide space heating and cooling, to pump well water, and to provide lighting at night, in addition to heating water. This rest area is scheduled for completion some time in late 1979.[23,24] Consideration is being given to installing an exhibition center at this site to show motorists how the sun's power is harnessed at the area.

Arizona engineers are also involved in applying solar technology to existing projects, including one in which emulsified asphalt for road maintenance is heated in a tank at the Department's maintenance camp in Oracle, 39 miles (63 km) southeast of Tucson. The Oracle unit (see Figure 7) was put in service in June 1977, and has needed very little help from the electrical back-up system. According to Don Cornelison, a Department maintenance engineer, the heater "is proving rather effective" and should pay for itself within 25 years (2002). The cost of the system was $16,000, which includes costs for construction of a supporting platform and installation of the $3,369 unit. The annual cost of electricity to heat the asphalt had been as high as $880.(25)

The solar power system was developed by Solar Utility Systems, Inc., of Phoenix based on Departmental specifications. The system, referred to as the "Sun Demon", was not designed to totally eliminate the use of conventional sources of energy but to provide a means of reducing annual energy consumption. The "Sun Demon" employs a single glazed (Tedlar), flat plate collector mounted on a platform in an unshaded position to absorb the sun's energy. The orientation is a 45° slope facing due south. Each of the collectors is a 4 ft. x 8 ft. (1.2 m x 2.4 m) module and contains 29.4 $ft.^2$ (2.7 m^2) of absorber plate area. The Department used eight "Sun Demon" collectors for this installation, thereby providing 235.2 $ft.^2$ (21.9 m^2) of collector area. The system also employs a custom designed "Solar Stat", an automatic differential control thermostat which activates a Roper Rotary pump, which in turn circulates a lightweight mineral oil through the collectors and a heat exchange built into the lower portion of the storage tank. This action takes place when the temperature of the collector becomes 12F° (6.7 C°) higher than that of the stored asphalt. When the temperature equalizes within 3F° (1.7 C°), the control turns off the pump. If the system is shut down for any length of time, i.e., overnight, the collectors drain and the fluid returns to the storage tank.(26)

For those periods when solar energy is not available, a 6 kw electric probe heater is used to provide the power to maintain the asphalt emulsion at the proper temperature. This back-up system is used only in the event that the emulsion temperature drops below 75°F (24°C).

On a sunny day, this unit produces up to 2,000 Btu's/min. (2,110 KJ/min), heating the asphalt to 125°F (52°C). Electronic instruments provide an automatic printout of the temperatures inside and outside the 8,000-gal. (30.3 m^3) tank every 2 hours.

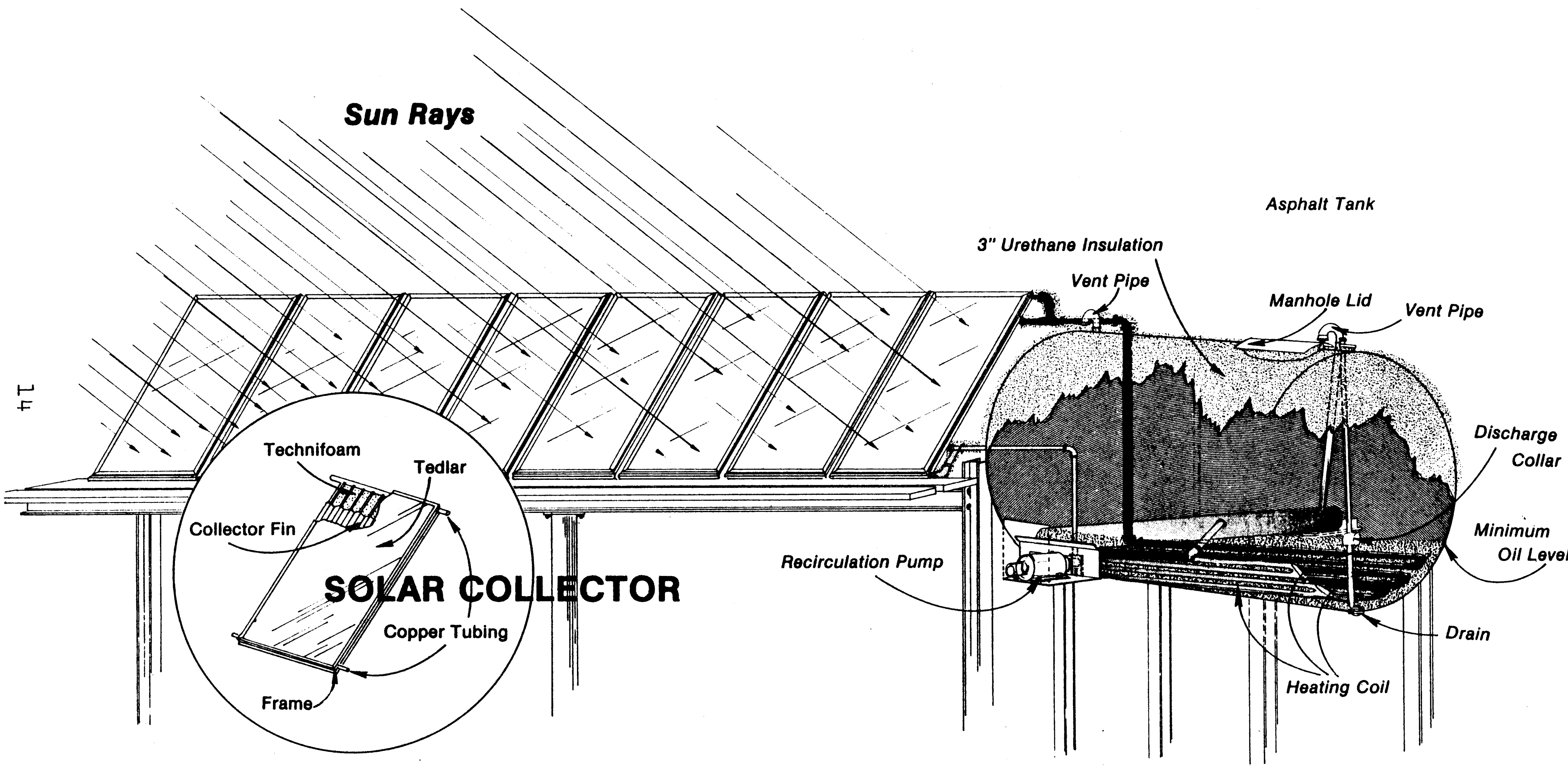

Figure 7. Oracle solar site.

The Department decided to use the solar heater after an application for a natural gas service was denied. Similar systems will be used elsewhere in the state if the test at the camp is successful.(27)

In addition to the unit used in heating asphalt, the Department has another solar oriented project under way. In May 1977, it was decided to purchase one solar cell panel from Motorola, Inc., to evaluate in the field the possibility of replacing some conventionally powered permanent counting equipment with equipment powered with solar energy. This decision was based upon the cost evaluation of commercial power and the solar cells as given in a Departmental memo. The memo stated that "based on the cost data supplied by your section, the solar power option would appear to be cheaper in the long run".(28)

The unit selected for the test was a 36-cell (8 watt) silicon array with a 12-volt voltage regulator. It was estimated that this configuration along with 4 "gel-cell" batteries would be sufficient to power the counting equipment with a back-up sufficient for 14 consecutive cloudy days.(29)

Initial installation of the solar array took place in September 1977, and it began operating on October 1, 1977. Since then the automatic traffic counters in Glendale have been operating 24 hours per day entirely on solar power. The Department's Planning Division, encouraged by the efficiency of the solar-powered recorders, is planning to use solar power at other installations, particularly those in remote areas of the state.

CONCLUDING REMARKS

As stated at the beginning of this report, the objective of the literature review was to provide the Virginia Highway and Transportation Research Council with a summary of solar energy applications within the transportation industry. As evidenced by the material presented, Arizona, located in the southwestern part of the United States, has done a significant amount of work towards utilizing solar energy. Other states outside this region are also beginning to realize the potential value of solar energy in the quest for viable alternative energy sources and research on numerous applications is under way.

In Virginia the potential of solar energy is to be determined for several type operations in several projects, under way or being planned, at the Highway and Transportation Research Council. These projects are similar in scope to those already undertaken by other states. As in Arizona, a project involving a solar powered automatic traffic counter is under way, and a proposed working plan calls for the retrofit of two area facilities for solar-assisted heat.

In addition to the studies under way in the United States, efforts are being made by other countries to develop solar energy as a viable new source. Japan, in 1974, launched a national program of research and development to introduce alternative energy technologies in an organized way. Thus, the "Sunshine Project" was born. The main thrust of "Sunshine" was to develop solar heating and cooling to the extent that home units would be cost-competitive by 1985. However, a few solar applications in transportation were also developed, such as an unmanned lighthouse on the Nagasaki coast powered by two solar cell panels.[30] In another transportation application, scientists in Great Britain are studying the feasibility of using solar cells to power dirigibles.

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