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SOLAR TECHNOLOGY APPLICATIONS: A SURVEY OF SOLAR POWERED IRRIGATION SYSTEMS

Herbert W. Newkirk

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INTRODUCTION

Currently hundreds of thousands of irrigation wells are in use throughout the United States. Irrigation pumps range in size from a few horsepower to several hundred horsepower and are powered by natural gas, electricity, liquefied natural gas, and diesel fuel. Nearly 70,000 natural-gas-powered irrigation pumps are in use in Arizona, New Mexico, Texas, and California which represents 35% of all U. S. irrigated land. About 100,000 electrically-powered irrigation pumps are in use in California.

The literature shows that irrigation plays an important role in increasing the nation's available food supply. For example, it is estimated that in the United States a wholly irrigated farm produces nearly seven times more crop value per acre than an unirrigated farm.

Irrigation experts estimate that in the 50 states, 35 million acres were irrigated with 69 million acre feet of on-farm pumped water. Of this 35 million acres, groundwater provided irrigation for 26 million and pumped surface water irrigated 7.3 million. Both groundwater and surface water were used to irrigate the remaining 1.7 million acres.

On a national basis, census data indicate that irrigated agriculture provides 15% (\$3.1 billion) of U.S. agriculture exports and 20% of the value of the total national agricultural output. Approximately 30% of the U.S. cropland is dedicated to producing export foodstuffs, and 10% of the U.S. cropland is irrigated.

Irrigated farms in the 17 western states, which represents over 80% of the irrigated land in the United States, produced 20% (\$9 billion) of the total U.S. farm products in 1969. On the average, about half of the value of agricultural products sold in these states is derived from irrigated land.

For many of these pumping applications, solar energy could supplement needed power and conserve rapidly depleting fossil fuel supplies. The particular compatibility of irrigation and solar powered energy sources is attributed to certain characteristics that include intermittent pumping, inexpensive energy storage in the form of a water pond at the head of the field, the coincidence of the need for pumping with the period of maximum solar insolation (summer), and the decrease in evaporative losses from the crops during periods of degraded solar insolation.

This report is a single reference source that summarizes published information on solar powered irrigation systems. It includes literature references and a survey of on-going work in this field. Much of the material is tentative, rapidly changing, and highly variable in time and place, and therefore should be considered a guide. The report will be updated as additional information and references appear in the literature.

SOLAR POWERED IRRIGATION SYSTEMS

A. THERMAL SOLAR SYSTEMS

The utilization of solar thermal energy to lift water for irrigation was first described by the French engineer Solomon de Caux in 1615. Improvements continued over the years to World War I, after which there was a gap in research efforts because of the ready availability of cheap fossil fuels. Today, a modern system consists of a solar collector field, an energy storage facility, solar engine, water-pumping equipment, controls, and a water-storage area. Figure 1 shows a schematic diagram of a system that is typical of the unit being developed by the U.S. Department of Energy (DOE).

In operation, a preheated heat transfer fluid is pumped into the collector field. Solar energy from the 6,720 sq. ft. of sun-tracking parabolic trough collectors heat the fluid to 420°F. A thermal control valve opens to allow the fluid to flow either to a thermal storage tank or to the boiler/heat exchanger.

FIG. 1

In the boiler/heat exchanger, the transfer fluid is heated to a gaseous state, expands, and reaches a temperature of 325°F and a pressure of 220 psi. The heated, high-pressure gas drives the turbine which in turn operates the irrigation pump. In this closed-loop system, the heat transfer fluid, exhausted from the turbine, is then circulated through a regenerator heat exchanger, a condenser heat exchanger, then back through the cooling side of the regenerator heat exchanger. It is then returned to the boiler/heat exchanger as a liquid.

The heat transfer fluid flows from the boiler/heat exchanger either back to the thermal storage tank or to a mixing tank. The mixing tank limits the inlet temperature to the solar collectors and aids in controlling temperature of fluid leaving the collectors.

The water is taken from the storage pond for actual irrigation by a conventional pumping system. The conventional pump operates on demand to allow different types of irrigation equipment to be tested. When the system is not operating the irrigation pump, it can generate electric power and provide the heating needs for a greenhouse, a fish farm, a crop dryer, and a farm house.

BIBLIOGRAPHY AND SURVEY OF ON-GOING WORK

1. "The Utilization of Solar Heat for the Elevation of Water,"
Scientific American, October 3, 1885, p. 214.

SUMMARY: The apparatus at Auteuil, France, raises over 300 gallons of water per hour from a depth of 65 feet using 350 square feet of collecting area.

2. Ericsson, J.
"Sun Motor,"
Harper's Weekly 31: 10 Jan 1887

SUMMARY: A review of John Ericsson's work in developing a sun motor for pumping applications.

3. Willsie, H. E.
"Experiments in the Development of Power from the Sun's Heat,"
Engineering News 61 [19], 511, May 13, 1909.

SUMMARY: A brief outline of the state of the art in the production of power from solar heat and the efforts made to commercialize sun power systems primarily for irrigation purposes.

4. Shuman, F.
"Sun Power Plant,"
Proceedings, Manchester Association of Engineers, Discussion Session,
1913-14, Manchester, England, p. 405-443.

SUMMARY: A review of the various sun power plants that have been built to 1914.

5. Acherman, A. S. E.

"The Utilization of Solar Energy,"

Journal of the Royal Society of Arts, p. 538, April 30, 1915.

SUMMARY: A chronological review of the history of solar thermal engines and their applications. A complete reference list of previous work to date.

6. Molenaar, A.

"Water-Lifting Devices for Irrigation,"

Food and Agricultural Organization, United Nations, New York, 1956.

SUMMARY: A review of the application of water-lifting devices for irrigation purposes.

7. Mathur, K. N. and M. L. Khanna

"Application of Solar Energy to Small Scale Industries,"

Solar Energy 1 [1], January 1957, p. 34.

SUMMARY: The application of solar energy to the raising of water for irrigation and domestic purposes, to cooking and to power generation are discussed briefly; and the concentration of sugar cane juice and palm juice are examined in some detail. Results are tabulated for experiments on the evaporation of cane and palm juices conducted in the Laboratory and in the open fields, using solar concentrators with 9 in. square plane mirrors, designed by Gardner. Field experiments showed an efficiency of 30 percent, but it should be possible to reach 50 percent. The capital cost of the unit can be recovered in fuel savings within three seasons.

8. Hsu, S. T. and B. S. Leo

"A Simple Reaction Turbine as a Solar Engine,"

Solar Energy 2 [3-4], July-October 1958, p. 7-11.

SUMMARY: This article describes the design of a simple reaction turbine operating on saturated low pressure steam that could be generated by a solar boiler. The turbine was developed primarily to obtain a small power unit for irrigation purposes. Tests were therefore performed with the combination of turbine and a centrifugal pump. Horsepower curves and rotational loss curves are shown, and a comparison is also presented with five other small prime movers of varied design.

9. Dannies, J. H.

"Solar Water Pumping,"

Solar Energy 3 [1] 29 (1959)

SUMMARY: The left-way cyclic process is described for obtaining water out of air using two working methods. The first one delivers drinking water out of air without any service, maintenance, etc. The second method requires opening a cover above the absorbent during the evening. In Central Europe, the water quantity obtained with the second procedure corresponds to 0.90 to 1.70 mm daily rainfall on a yearly average whereas in the North Sahara, about 150 to 200 miles off-coast, it is about 10 percent more. Water delivery from the first procedure is less.

10. Jenness, James R., Jr.

"Some Considerations Relative to a Solar-Powered Savery Water Pump,"

Solar Energy 5 [2] 58 (1961).

SUMMARY: The primitive Savery steam engine is described which could be adaptable to mass production at low unit cost. In spite of its low efficiency it may be useful as a solar-powered low-lift water pump.

11. Jordan, R. C.

"Conversion of Solar to Mechanical Energy,"

An Introduction to the Utilization of Solar Energy, A. M. Zarem

and D. D. Erway, eds., New York, McGraw-Hill, 1963, Ch. 7, p. 125-152.

SUMMARY: A water pump, developed in Italy, is operated with a standard Rankine vapor cycle heat engine using sulfur dioxide as the working medium. Sulfur dioxide is vaporized in the flat-plate collector and this vapor is used to generate electricity or to pump water. This Somor 2.5 horsepower solar engine system is manufactured by the Societa Motori Recuperi of Lecco, Italy.

12. Girardier, J. P. and H. Masson

"Solar Motors with Flat Collectors,"

Annales Des Mines: 33-8 (September 1964).

SUMMARY: An experimental solar motor is described which drives a pump lifting 8 to 10 liters water per minute from a depth of 13 meters.

The construction of a more efficient pump is also described. It has a collector of 300 m^2 capable of supplying about $40 \text{ m}^3/\text{hour}$ of water lifted from a depth of 8 to 10 m. This quantity of water represents the approximate daily requirement of a community of 500 persons.

13. Gilleland, F.

"Eneas Solar Water Pump,"

Sun at Work 10: No. 4, 12-14 (1965).

SUMMARY: A description of the pump capable of raising 150,000 gallons of water per day a distance of 40 feet using 175 square feet of collector area; sufficient for the irrigation needs of 100 acres.

14. Masson, H. and J. P. Girardier

"Motors with Flat-Plate Collectors,"
Solar Energy 10 [4] 165 (1966).

SUMMARY: An experimental solar motor has been operating since August 1962 which drives a pump lifting 8 to 10 liters water per minute from a depth of 13 meters.

This experiment being successful, the construction of a more efficient pump is also described. It has a collector of 300 m^2 capable of supplying about $40 \text{ m}^3/\text{hour}$ of water lifted from a depth of 8 to 10 m. This quantity of water represents the approximate daily requirement of a community of 500 persons.

15. Shergill, S. S. and R. P. Morgan

"Analysis of an Oscillating Engine for Power Production Based on the 'Drinking Bird' Principle,"
Proceedings of the Fourth Intersociety Energy Conversion Engineering Conference, September 25-26, 1969, Washington, D.C.

SUMMARY: A hypothetical oscillating engine was analyzed which works on the "Drinking Bird" principle. Calculations were performed for a toy device and for a larger engine suitable for pumping water. Applications are discussed for use of the engine as a small power source in developing countries.

16. Girardier, J. P. and H. Masson

"Utilization of Solar Energy for Lifting Water,"
Preprint, 1970 International Solar Energy Society Conference, Melbourne, Australia, March 2-6, 1970. Paper No. 6/116.

16. SUMMARY: The paper discusses solar engine installations with fixed, plane collectors. The results obtained and the economics of the systems are discussed in detail. One installation delivered 6.8 cubic meters/hr of water against a head of 34 meters using 88 square meters of collector area.
17. Beale, W., J. Rauch, R. Lewis and D. Muley
"Free Cylinder Sterling Engines for Solar Powered Water Pumps,"
Paper presented at the ASME Winter Annual Meeting, Washington, D.C.,
November 28 - December 2, 1971.

SUMMARY: Test results are given of a solar water-pump system. The water-pump system has demonstrated 10 w of delivered water power from a 0.3 sq m Fresnel lens at an engine absorber temperature of 460°C.
18. Swet, C. J. and H. G. Fox (John Hopkins University, Silver Spring, Maryland)
"Low Head Solar Water Pumping," Direct Use Without Intermediate Heat Engine, U.S. 8th Intersociety Energy Conversion Engineering Conference, Philadelphia, Pennsylvania, August 13, 1973. American Institute of Aeronautics and Astronautics, New York, 1973, A. H. Smith (Editor).

SUMMARY: A representative device is described that pumps water by the direct pressure of solar heated air. Cost and producibility are discussed, and the results are presented of a parametric design and performance study.
19. Maumouni, A.
"Energy Needs and Problems in the Sahelian and Sudanese Zones: Prospects of Solar Power,"
Ambia, Vol. 2 (6) p. 203 (1973).

SUMMARY: The author points out that solar energy water pumping devices should play a very large role within the frame of a balanced, general energy policy. A discussion is presented of the experimental Masson-Girardier solar engine for pumping water located near Niamey, Niger.

20. Salieva, R. B.

"Some Generalizations of Sample Water-Supply Calculations from Solar-Powered Pumping Plants,"

Applied Solar Energy, Vol. 10, No. 1-2, 1974, p. 67-70, Translation.

SUMMARY: The relationship between planned water consumption and water supply is investigated for a solar pumping system with stochastic variation in the solar radiation.

21. Salieva, R. B.

"Agricultural Calculations for Solar Pumping Systems,"

Geliotekhnika 11 [3-4] 112 (1975).

SUMMARY: The relationship between planned water consumption and water supply is investigated for a solar pumping system with stochastic variation in the solar radiation.

22. "Will Sun Power Water Deserts"

Engineering, p. 887, November 1975.

SUMMARY: A Fluidyne pump is described that can deliver water at 50 to 100 gal/h powered only by solar energy. The extremely simple design is self-starting and cycles automatically: air is displaced between a hot zone and a cold zone, rhythmically expanding and contracting. Pressure reversals on the output tube and the action of two non-return ball valves produce a pulsed delivery. Delivery rates are reported to be 50 to 100 gal/h at a lift of 8 ft.

23. Fiatte, F. and M. Clemot

"Water Pumping - A Practical Application of Solar Energy,"

Presented at COMPLES/UPM International Conference on Heliotekhnique and Development, Dhahran, November 2-6, 1975, Vol. 2, p. 331.

SUMMARY: Various solar water pumping installations are described, which are operating in Africa and Latin America.

24. Meinel, M. P.

"Solar Energy Applications to Water Pumping and Agriculture,"
Presented at COMPLES/UPM International Conference, Dhahran,
November 2-6, 1975, Vol. 2, p. 307.

SUMMARY: Several low-temperature solar water pumps are currently under evaluation in the Sonora desert. System studies at the University of Arizona indicate that higher temperature solar water pumps may be more cost-effective than the low temperature systems.

25. Fiatte, F. and M. Clemot

"Water Pumping - A Practical Application of Solar Energy,"
Proceedings of the International Conference, Dhahran, Saudi Arabia,
November 2-6, 1975; Published by Development Analysis Association,
Cambridge, Massachusetts, 1976, Vol. 2, pp. 331-339.

SUMMARY: This paper reviews the characteristics and advantages of Sofretes solar pumping installations. Existing 1 kW and 25 kW stations are described. These stations are integrated with buildings which can be used to house a school, a market, or a dispensary. The characteristics of the 1 kW and 25 kW pumping installations are shown in the following tables.

TABLE 1 CHARACTERISTICS OF A 1-kW PUMPING INSTALLATION

<u>COLLECTORS</u>	
Active area m^2	70
Area covered by collectors, m^2	100 to 120
Fluid circulation	Thermosiphon or circulator

ENGINE CIRCUIT AND PUMPS

Evaporator/condenser	Tubular elements
Fluid	Butane or freon
Expansion engine, 1000 cm^3	Two-cylinder
Rotation speed, rpm	200
Water pump	Hydraulic transmission

OPERATING CONDITIONS

Mean Solar Incident Radiation, $kcal/hr^2$	700
Air temperature, $^{\circ}C$	20
Pumped water temperature, $^{\circ}C$	20 to 30
Operating time, hr/day	5 to 7
Daily Output, m^3	30
Manometric height, m	20

TABLE 2 CHARACTERISTICS OF A 25-kW PUMPING INSTALLATION

<u>CHARACTERISTIC</u>	<u>VALUE</u>
Surface area of collectors, m^2	1,500
Engine fluid	Freon II
Turbine rotation speed, rpm	7,400
Pump	Electric, Centrifugal
Water pumped, m^3/hr	300
Manometric height, m	20

26. Rao, D. R. and K. S. Rao

"Solar Water Pump for Lift Irrigation,"
Solar Energy 18 405 (1976).

SUMMARY: Two types of solar water pumps have been developed and tested for lift irrigation. The pumps have no moving parts except for the check valves and no auxiliary power source or technical skill is required to run the pumps.

27. Mansoori, G. Ali

"Prospects for Solar Energy Utilization in Iran - Photothermal Methods,"
Iranian J. of Sci. & Tech. 5 55 (1976)

SUMMARY: State of the art of the photothermal methods of solar energy utilization is reviewed and the technical and economical feasibilities of adoption of these methods in Iran are investigated. It is shown that many of the photothermal utilization techniques are applicable in Iran due to both the favorable climatic conditions and the technological developments of the country. Although solar energy utilization may not be considered economical as yet, due to the present abundance of fossil fuels in Iran, generous investments on this technology could bring about an energy-independent future for the country.

CHARACTERISTICS OF SOLAR WATER PUMPS IN OPERATION (OR UNDER CONSTRUCTION AND PLANNING) IN AFRICA

Date and place of the start of operation	Collector Surface	Output	Manometric Height	Time of Operation
Institut de Physique Meteorologique Dakar (Senegal) 1966	12m ²	1200 l./hr	15m	5-6 hr
Institut de Physique Meteorologique Dakar (Senegal) 1968	88m ²	6m ³ /hr	25m	5-6 hr
Ecole Intr-Etat d'Ingenieurs de l'Equipment Rural Quagadougou (High Volta) 1971	30m ²	2m ³ /hr	20m	5-6 hr
Office de l'Energie Sohire Niamey (Niger) 1973	60m ²	6-7m ³ /hr	12m	5-6 hr
Chinguetti (Manuritania) 1973	72m ²	8-10m ³ /hr	23m	5-7 hr
High Volta Country-side model (planned)	50m ²	5m ³ /hr	30m	6 hr
Republic of Senegal (planned)	85m ²	8-10m ³ /hr	20m	5-6 hr
Republic of Algeria Wilaya des Oasis (planned)	30m ²	21.5m ³ /hr	30m	5-6 hr
Republic of Chad 5 village pumps (planned)	70-200m ²	5-10m ³ /hr	15-60m	5-7 hr

28. Larson, D. L., D. D. Fanmeir and H. B. Puckett

"Feasibility Study for Using Solar Energy for Irrigation Pumping,"
Progress Report, Soils, Water, and Engineering, University of Arizona,
Tucson, Arizona, July 1976.

SUMMARY: The use of solar energy to power irrigation pumping systems will require either more wells and a higher pumping rate so that adequate water can be pumped during the daylight hours or a system to store energy to operate the pumps 24 hours per day. Either method results in a high cost system. The water requirements for farming in the southwestern United States can be moderated if the cropping system is changed to spread the water needs over a longer period of the year and reduce the peak demand for water. Solar energy is economically feasible for irrigation pumping if the alternative energy costs rise from the present cost of \$25 per MW at 7 to 8 percent or more per year (excludes general inflation). The part time use of the solar irrigation pumping system raises the unit cost. If the system could be efficiently used for the entire year, not just 6 months out of 12 months, the unit costs would be much lower and the system could be justified for a lesser increase in fuel costs.

29. Alvis, Robert L. and Jerry M. Alcone

"Solar Powered Irrigation System,"
Sandia Report, SAND 76-0358, September 1976.

SUMMARY: A solar powered irrigation system is to be constructed on a working farm in the Estancia Valley of New Mexico. The system is to demonstrate that solar power can power an irrigation system and the performance data generated will be used to predict solar powered irrigation system feasibility on both a local and a regional basis. The program is jointly sponsored by ERDA and the State of New Mexico with New Mexico State University and Sandia Laboratories performing the duties of the program.

29. There are two system design approaches being considered. One, a low temperature system using flat-plate collector technology and its associated reduced cycle efficiency and two, using focusing-tracking collector technology and its associated higher cycle efficiency. This request is for engine proposals for either (or both) low temperature (420°F) peak temperature heat engine. The performance of each engine proposed will be analyzed with proposals received from collector suppliers in determining the best performing system per system cost. Only one system approach will be finally selected and purchased. The heat engine will consist of the necessary equipment to take thermal energy from a thermal storage reservoir, utilize a small amount of electrical energy for pumping and control, cool the condenser with the irrigation water pumped, and produce 25 shaft horsepower for pumping water. The engine will be directly coupled to a turbine irrigation pump through a right-angle drive and drive shaft and be engaged or disengaged by a manually operated clutch. The clutch is considered part of the engine. A total of 6,720 ft of collector area is planned and the pumping rate will be 700 gpm at a depth of 111 ft.

30. Clemot, Max G., J. Paul Durand, J. Pierre Girardier, and Marc Y. Vergnet

"Contribution of Solar Energy to the Development of Arid Zones: Solar Water Pumps,"

Central Treaty Organization Symposium on the Applications of Solar Energy Organized in Collaboration with the Materials and Energy Research Center, Araya Mehr University of Technology, Teheran, October 3-5, 1976.

SUMMARY: Solar energy is the prime source of energy of the earth. However, up to now it was almost totally neglected as a solution for improving living conditions of people and countries.

30. Recent world events - fossil fuel depletion and their rising prices, willingness of developing countries and other countries to use new energy sources - put the highlight on solar energy. Doubtless solar energy is becoming the energy of tomorrow.

Activities of SOFRETES in this field since 1962, in cooperation with DAKAR University in SENEGAL, and its long experience (numerous units in operation since 1968) make solar energy already operational for today.

31. Alcone, Jerry M., Sharla G. Vandervender and Robert L. Alvis

"Solar Irrigation Program Plan,"

Sandia Report, SAND 76-0594, November 1976.

Sandia Report, SAND 77-0110, January 26-27, 1977.

SUMMARY: These reports describe the ERDA solar irrigation program plan through FY79. The goals of the plan are listed, the participants named, and their responsibilities outlined. ERDA has the program responsibility; ERDA field offices, the contractual responsibility; and Sandia Laboratories, the technical direction responsibilities. This document is intended to be used as a program guide for accomplishing the goals.

32. Larson, Dennis L., C. D. Sands, II, Charles Towle, Jr., and D. D. Fanomeier

"Feasibility of Using Solar Energy to Drive Irrigation Pumps,"

For presentation at the 1976 Winter Meeting of the American Society of Agricultural Engineers, Palmer House, Chicago, Illinois, December 14-17, 1976.

SUMMARY: The technical and economic feasibility of using solar energy to drive irrigation pumps have been studied to determine the conditions required for serviceable, competitive use of solar systems. Solar power plant component development, changes in irrigation and pumping practices, investment incentives and higher fuel prices may all be required for economical use of solar energy.

33. Larson, Dennis L., John D. Day, Delmar D. Fangmeier, William G. Matlock, George C. A. Morin, Charles D. Sands, II, and Charles L. Towle, Jr.

"Determination of the Feasibility of Using Solar Energy for Irrigation Pumping,"

A Final Report to the U. S. Department of Agriculture, Agricultural Research Service: Soils, Water and Engineering Department, University of Arizona, Tucson, Arizona - June 25, 1976 to December 31, 1976.

SUMMARY: The technical and economic feasibility of using solar energy to drive irrigation pumps was analyzed by the University of Arizona in conjunction with Texas Tech University and the University of Houston. This report describes irrigation and irrigation pumping conditions and discusses possible changes in irrigation and pumping practices which are desirable with conversion to solar power plant expenditure equivalent to displaced energy cost.

34. "Solar Powered Pump at an Advanced State"

Battelle Memorial Institute, Pacific Northwest Laboratories
Bulletin, 1977

SUMMARY: A 50 horsepower solar irrigation pump is to be installed on the Northwestern Mutual's Gila River Ranch, a 76,000 acre agricultural facility southwest of Phoenix, Arizona. The pump system includes a solar collector, a heat transfer fluid system and a vapor expansion engine.

35. "Set the Sun to Work"

Advertising literature (1977) of the Renault Motors International (Sofretes) La Bousidiere - R.N. 186, 2350 LePlessis-Robinson, France.

SUMMARY: The first solar pumping station was set up in 1966 in Senegal, where six others are being installed now; these

35. first installations have increased in number. They can be seen in Niger, Upper Volta, Mauritania, Mali, Brazil, Chad and Cameroon. Some of them are working already, others are being built. Mexico is planning an ambitious program covering more than the ten stations that have already been ordered, five of which are already installed and working perfectly. The list of references gives very complete details concerning the nature and the output of the stations already constructed and in operation.

36. "Sun Pumps Water, Too"

San Jose Mercury, Wednesday, February 9, 1977, p. 61.

SUMMARY: Acurex Corporation, Aerotherm Division, Mountain View, California, has been chosen as one of three firms to come up with a preliminary design for a solar system to pump irrigation water. Acurex, which has already designed a system for installation at San Luis de La Paz, Mexico, is planning to place the system in southern Arizona by the end of 1979.

37. "Irrigation Using Solar Energy"

NASA Literature Search Number 34584, February 18, 1977.

SUMMARY: Citations arranged by Accession Number from 1962 to February 18, 1977. Contains 24 citations.

38. Null, E. R.

"Solar/Stirling Power Plant Applications to Urban Water Pumping"

Paper presented at the Conference, Toward Incorporation of Alternate Energy Sources Into the National Energy Policy, May 2-4, 1977, Palm Springs, California.

38. SUMMARY: The Desert Water Agency, in association with Aeronutronic Ford, has developed a Solar/Stirling Engine Deep Well Water Pumping Project for general water pumping in the water service industries including irrigation and wastewater. The project involves collecting light energy with tracking mirrors, concentrating light energy to heat energy in a cavity receiver, transmitting the heat energy through a eutectic heat pipe and heat storage system to a Stirling (external heat) Engine, converting the heat to mechanical energy, and driving a deep well pump through a right-angle gear drive.

The electrical pumping units currently installed in the Agency's wells, which will be replaced by the solar system, lift water from 250 to 400 feet below ground and raise it to as much as 100 feet to 200 feet above ground. Average pumping heads approximate 500 feet.

Preliminary information indicates that urban pumping requirements for the ten million or so people in Southern California alone require between one-half and one billion kilowatt hours of electrical energy. Perhaps 25% of the plants could be converted to solar energy with the remaining 75% continuing on conventional electrical systems because of non-solar limitations.

39. "Arizona Solar-Powered Irrigation System Delivers 10,000 Gallons of Water Per Minute"

Solar Energy Intelligence Report, May 21, 1977, p. 88.

SUMMARY: Northwestern Mutual Life Insurance opened what it calls the world's largest solar-powered irrigation system on April 25, 1977 in Gila Bend, Arizona. Developed by Battelle Memorial Institute in a cooperative program with NML, the system has

39. a 50-horsepower pump capable of delivering up to 10,000 gallons of water per minute. According to Battelle, the system will be able to deliver up to 5.6 million gallons of water within ten hours.

40. Abernathy, G. H. and T. R. Mancini

"Design and Installation of a Solar-Powered Irrigation Pump"

Presented at the 1977 Annual Meeting of the American Society of Agricultural Engineers, North Carolina State University, Raleigh, North Carolina, June 26-29, 1977.

SUMMARY: A 25 horsepower (19 kW) irrigation pump driven by solar energy has been designed by Sandia Laboratories in cooperation with New Mexico State University. Installation is complete and initial operation has begun.

41. Larson, Dennis L.

"Solar Energy for Irrigation Pumping"

Presented at the Annual Meeting of the American Society of Agricultural Engineers, North Carolina State University, Raleigh, North Carolina, June 26-29, 1977.

SUMMARY: On-farm solar power plants could be used independently or in conjunction with supplementary energy sources to drive irrigation pumps. Independent solar power plant capacity probably will not be fully utilized for pumping even with energy or water storage. Some methods for using the solar energy effectively and economically, including modified demand, are examined in this paper.

42. McClure, G. M.

"Northwestern Mutual Life Insurance Company/Battelle Solar Irrigation Pump Project"

Presented at the Solar Irrigation Workshop, Albuquerque, New Mexico, July 7-8, 1977.

42. SUMMARY: This paper described the design and operation of the world's largest known solar-powered irrigation water pump. The solar system was designed and built by the Columbus Laboratories of Battelle Memorial Institute for Northwestern Mutual Life Insurance Company for installation at their Gila Bend Ranch southwest of Phoenix, Arizona. The pump was installed during the early months of 1977 and completed during April 1977. It is capable of developing 50 hp (3713kW) and pumping 10,000 gallons (38m²) of irrigation water per minute at peak operation.

A major portion of the program involved system analysis using computer modeling in the design of the components and in optimizing the system. The present system consists of parabolic tracking solar collectors having a total projected area of 6,070 sq. ft. (564 square meters): a Rankine-cycle power unit comprised of a turbine/gearbox, boiler, condenser, regenerator and preheater; and a low-lift, high-volume-flow propeller pump.

During the longest day of the year in Arizona, the system delivers about 5.6 million gallons (21,000 m²) of water over a period of 9.5 hours. At night, during storms, the collector array automatically rotates to a downward-facing position to lessen the chance of damage or soiling of the reflective surface.

43. "Peru Tests Feasibility of Solar Energy for Use in Irrigation"

Editorial in World Environment Report, September 26, 1977, p. 2.

SUMMARY: LIMA: The Peruvian Government is planning to install experimental solar energy equipment in Puno - the southern region beside Lake Titicaca - to test the feasibility of using it for irrigation purposes.

44. Lukens, Laurance L., Audrey M. Perino, and Sharla G. Vandevender

"Preliminary Economic Analysis of Solar Irrigation Systems (SIS)
for Selected Locations"

Paper SAS D 77 - 140 3, November 1977, Sandia Laboratories

SUMMARY: This paper describes a preliminary analysis of the economic feasibility of stand-alone solar irrigation systems (SIS) for certain applications in various locations. The economic feasibility was determined by comparing the life cycle cost (LCC) of the solar system to the LCC of conventional systems. The systems analyzed in this paper were point studies and do not represent either worst case or best case conditions. Therefore, general conclusions should not be drawn on the results presented here. The results show that for these cases, economic feasibility is dependent on utilization of the SIS for production of energy in addition to that required to water crops. In southern Arizona, the LCC of the SIS, when used only to pump water, ranges from 3 to 1.7 times that of a conventional electric system for start-up dates of 1980 and 1990. For the same system, the LCC ratio ranges from 1.6 to 0.9 when 100% utilization of the system capacity is achieved. The feasibility of a hybrid system was also examined for Arizona. This system purchased 21% of the required power, yet the hybrid LCC was only 90% of that of a conventional electric system with a 1990 start-up date.

PATENTS

1. Tellier, C.

"Equipment for the Activity of a Pump Apparatus for Solar Heat,"
German Patent No. 34749; August 15, 1885.

SUMMARY: A pump is described for lifting water in irrigation systems or for solar home heating and cooling installations.

2. Bonaventura, Filiberto A. and Donald E. Plympton

"Solar Energy Pump,"
Patent No. 2,688,922; September 14, 1954.

SUMMARY: This patent relates to a solar energy pump, more particularly for use in pumping water or other liquids by means of solar energy.

3. Bonaventura, Filiberto A. and Donald E. Plympton

"Solar Energy Pump,"
Patent No. 2,688,923; September 14, 1954.

SUMMARY: This invention relates to a solar energy pump, more particularly for well-water pumping.

4. Glickman, Leonard

"Sunshine Hydro Electricity,"
Patent No. 3,903,700; September 9, 1975.

SUMMARY: A solar heat generator is reported having a plurality of pipes therein carrying an expansible fluid supplied from a fluid storage tank to a motor. The fluid is heated in the solar heat generator by the sun's energy and expands and pressurizes to drive the motor which, in turn, drives a water pump for pumping water from a lower reservoir to an upper reservoir.

5. Thureau, Pierre and Michael Bremont

"Pumping System Using Solar Energy,"

Patent No. 3,937,569; February 10, 1976.

SUMMARY: A pumping system is described comprising a pumping unit formed by a motor and a pump and adapted to raise a liquid from an underground level to a utilization level. The vaporizable fluid flows in a closed circuit between a solar evaporator and a condenser, the said motor being disposed in the outgoing branch between the evaporator and the condenser, and a circulator being disposed in the return branch. The motor comprises a motor chamber which is connected by an internal bistable distributor either to the evaporator when said distributor is in an intake state, or to the condenser when said distributor is in an exhaust state, said motor chamber being partly limited by a flexible wall free to move between an intake stroke end position and an exhaust stroke end position, the flexible wall triggering the changes of state of the distributor by reaching its two end positions.

6. Fletcher, James C.

"Solar-Powered Pump,"

Patent No. 3,972,651; August 3, 1976.

SUMMARY: A solar-powered pump is described which is particularly suited for intermittently delivering a stream of water. The pump is characterized by a housing adapted to be seated in a source of water having a water discharge port disposed above the water line of the source, a sump including a valved inlet port through which water is introduced to the sump, disposed beneath the water line, a displacer supported for vertical reciprocation in said housing, an air passageway extended between the vertically spaced faces of the displacer, a tipple disposed adjacent to the water discharge

6. port adapted to be filled in response to a discharge of water from the housing, and a line so interconnecting the tipple and the displacer that the displacer is moved upwardly in response to a filling of the tipple and moved downwardly once water is discharged from the tipple. Air above the displacer is expanded in response to solar energy impinging on the housing, transferred into pressurizing relation with the sump for forcing water from the sump.

B. THERMOELECTRIC SOLAR SYSTEMS

Thermoelectric solar systems collect radiant energy by a system of mirrors and convert it directly into electricity by focusing on thermoelectric generators. The generated power then drives an electric motor, which is connected to a water pump. The electric motor and the pump are the only moving parts in the whole irrigation system. Figure 2 shows a schematic drawing of a typical system.

The key element of the entire system is the thermoelectric generator consisting of a black coated container that houses stacks of electric elements (circular wafers). These elements are made of semi-conductor material and have the unique ability to generate electrical energy when a temperature difference occurs between the ends of each stack. The thermoelectric elements are connected together electrically. Generally, it is common practice to operate the generator at temperatures near 1100°F at the hot end. However, to extend generator lifetime and reduce the initial cost of the system, especially the mirror, operating temperatures are generally in the 825-850°F range. The cooler end of the generator is usually maintained at 150°F.

FIG. 2 A schematic drawing of a typical thermoelectric solar irrigation system.

BIBLIOGRAPHY AND SURVEY OF ON-GOING WORK

1. Vladimirova, L. N. and B. A. Garf

"The Optico-Mechanical Part of the SV-1 Solar Water-Raising Unit"

Geliotekhnika (Applied Solar Energy), Vol. 2, No. 2, pp. 45-49, 1966.

SUMMARY: An experimental solar device for pumping water on pasture land in the Central Asian republics was designed and constructed at the Krzhizhanovskii Power Engineering Institute in the course of 1964 and 1965.

A solar thermoelectric generator, generating a 25-a current at 20 V, is employed as the solar energy converter in this unit. The generator feeds a DC motor coupled to a water pump.

It is proposed to operate the SV-1 installation in conjunction with a thermal power generator. Nevertheless, it can be used with success in a number of other thermal processes such as steam generation, boiling of water, saline water conversion, refrigeration, etc.

2. Vladimirova, L. N. and B. A. Garf

"Optico-Mechanical Section of a Thermoelectric Solar Water-Pumping Unit"

Semiconductor Solar Energy Converters, V. A. Baum (ed.). London, England: Consultants Bureau (1969) pp. 111-117. (In Russian)

SUMMARY: A description is given of a reflector and a mechanism for 24-h rotation of a solar unit. An original feature is the system for controlling the rate of rotation of the reflector by a drive, based on the uniform flow of sand through a small aperture. The special features of the reflector, the control mechanism, and of the mounting are described. A method for designing the optico-mechanical section of an SV-1 solar water-pumping unit is discussed in detail from the point of

view of strength and rigidity. Design formulas are given, as well as the results of wind tests on an aerodynamic model of the reflector.

3. Teplyakov, D. I., R. R. Aparisi, Ya. G. Kolos, R. A. Zakhidov, and A. Annaev

"Calorimetric Investigation of a Solar Radiation Concentrator for a Thermoelectric Water-Pumping Unit"

G. M. Krzhizhanovskii Power Institute, Moscow, Russia. Semiconductor Solar Energy Converters, V. A. Baum (ed.). London, England: Consultants Bureau (1969). (In Russian)

SUMMARY: The purpose and results are given of a comprehensive investigation of the concentration field of a paraboloid mirror of 5 m diameter, assembled from shaped reflecting aluminum elements. The investigation was carried out using calorimetric methods and special calorimeters. It was possible to determine and find optimum values of the parameters of energy absorption by a semiconducting thermoelectric generator. The distribution of the radiant flux along the walls of cavity absorbers of various types were determined and an axial asymmetry in the flux distribution was found.

4. Baum, V. A., G. A. Alatyrtsev, Yu. N. Malevsky, and N. G. Milevskaya

"Solar Thermoelectric Generator (STEG) for Water-Raising Plant"

Presented at the 1970 International Solar Energy Society Conference, Melbourne, Australia, March 2-6, 1970. Paper No. 7/30.

SUMMARY: In the period 1965-1967 at the G. M. Krzhizhanovskii Institute of Power Engineering, an automatic solar water-raising plant was developed. The key element of the plant is an electric generator which is heated at the focus of a concentrator 5 m in diameter and operates in conjunction with an electric pump having the capacity of 0.25 kW (16 amp, 16.5 v). The following research has been carried out:

4.
 - a. Investigation of volt-ampere characteristics of each thermoelectric module and of the generator as a whole depending on the temperature of hot junctions.
 - b. Determination of the efficiency of the solar thermoelectric generator allowing for the actual losses in the structure.
 - c. Study of the electric pump operational modes depending on the generator parameters.
 - d. Determination of possible technical characteristics of the system with respect to efficiency and height of raising the water. At a temperature of hot junctions about 200°C and that of cold junctions -75°C, the plant efficiency was 1.2 m³ per hour of water at a raising height of 25 meters.

In the near future we can look forward to the practical use of semiconductor converters at temperatures up to 1,000°C, manufactured from materials possessing high thermoelectric quality factors which provide for the conversion of heat energy to electrical energy at a level of 15 percent efficiency.

5. Alatyrtsev, G. A., Yu. N. Malevskii, and N. G. Milevskaya

"Laboratory Tests of a Thermoelectric Generator for a Solar Water Pumping Plant"

Geliotekhnika (Applied Solar Energy), Vol. 8, No. 1, pp. 3-7, 1972.

SUMMARY: The paper outlines the results of laboratory studies of a number of thermal and electric characteristics of a thermoelectric generator for a solar water-pumping plant.

C. PHOTOVOLTAIC SOLAR SYSTEMS

Photovoltaic solar systems convert radiant energy directly into electricity to power pumps and other equipment for irrigation purposes. Direct thermodynamic cycles and mechanical generators are avoided in these systems through the use of an electrical conversion device. Figure 3 is a schematic drawing of the device, called a solar or photovoltaic cell. The cell is usually comprised of a wafer of single crystal silicon suitably doped with either boron or phosphorous to increase its sensitivity to light. When sunlight strikes the cell, about 10% of the light energy is absorbed and transferred to electrons in the form of an electric current equal to about one-fourth of a watt of power. The electrons are collected by the grid on the cell's upper surface and flow through an external load to the bottom surface of the cell. The direct current is then fed into the inverters that transform it into alternating current to power the irrigation motor and other loads.

A fundamental limit on the performance of all of these devices results from the fact that light photons lacking the energy required to lift electrons from the valence to the conduction bands (the "band gap" energy) cannot contribute to photovoltaic current; the energy given to electrons, which exceeds the minimum excitation threshold, cannot be recovered as useful electrical current. Most of the photon energy not recovered as electricity is converted to thermal energy in the cell.

A typical system consists of hundreds of these cells. Individual cells will probably range in size from a few millimeters to a meter in linear dimension. Figure 4 is a schematic diagram of a typical system, which is similar to the one being built by the Massachusetts Institute of Technology (MIT) under contract to the Department of Energy (DOE). The system consists of south-facing panels containing surface-mounted photovoltaic solar cells, batteries for energy storage, direct current inverters, an electric irrigation pump, and a storage pond.

The likelihood of photovoltaic solar-powered irrigation becoming feasible within 5 to 10 years depends upon reducing the cost of the cells. The DOE goals call for reducing this cost by nearly 30 times between 1978 and 1986, or from the current \$15 a watt to 50 cents a watt.

FIG. 3 Schematic diagram of a typical photovoltaic solar cell (adapted from figure in "25 Kilowatt Photovoltaic Powered Irrigation Experiment," R. W. Matlin, paper presented at Solar Irrigation Workshop and Demonstration, Albuquerque, New Mexico, July 7-8, 1977).

FIG. 4 A schematic diagram of a typical solar photovoltaic irrigation system.

BIBLIOGRAPHY AND SURVEY OF ON-GOING WORK

1. Lidorenko, N. S., F. Kh. Nabiullin, A. P. Landsman, B. V. Tarnizhevskii, E. M. Gertsik, and L. F. Shulmeister.

"An Experimental Solar Power Plant"

Geliotekhnika (Applied Solar Energy), Vol. 1, No. 3, pp. 5-9, 1965.

SUMMARY: Silicon photovoltaic cells (solar batteries) are the most highly developed and efficient of the various devices for the direct conversion of solar energy into electricity. So far, however, solar batteries have been used only to power spacecraft and in some cases, at power levels of the order of several watts, for domestic purposes (powering transistor radios, etc.). Therefore, the planning and construction of a photoelectric solar power plant with a capacity of the order of from several hundred watts to one kilowatt as a part of the national economy is quite a technical innovation.

The function of this installation was to provide power for water pumps in the grazing areas of the southern regions of the USSR. The project was an experimental one to evaluate the performance and reliability of the design and operating characteristics of the plant and to determine the direction of further developments in this field.

The results obtained with this experimental solar power plant for raising water show that the use of such devices is technically promising. The design and automatic control system tested proved to be operationally reliable and simple to use. The experience gained in designing and testing this first experimental model will determine the future direction of developments in this area.

2. Tarnizhevskii, B. V., I. G. Savchenko, and B. Ya. Rodichev

"Results of an Investigation of a Solar Battery Power Plant"

Geliotekhnika (Applied Solar Energy), Vol. 2, No. 2, pp. 25-30, 1966.

SUMMARY: Two different versions of a photoelectric battery solar power plant were tested in 1964 and 1965. The 1964 version and the results of its test operation are described in Reference 3. The experience gained in the operation of the first experimental model was utilized in further developments.

Since the maximum power delivered by the power plant is approximately twice the amount drawn by the pump motor, the 1965 model power plant should be capable of powering two such motors. This was confirmed by putting into the electrical circuit a rheostat equivalent to one pump motor. The total power consumption in this experiment was close to the maximum deliverable by the solar batteries. Therefore, the daily output per power plant on a clear day may be estimated at 30 m^3 of water at a pressure of 15-20 m (water column).

The results of this investigation have confirmed the possibility and technical feasibility of using a solar photoconverter power plant for water raising.

3. Tarnighevskii, B. B. and V. Ya. Rodisher

"Characteristics of Solar-Powered Water Pumping Systems"

Geliotekhnika, 4 (3) 31 (1968). Applied Solar Energy (USSR). (English translation) 4 (3) 21 (1968).

SUMMARY: Solar photoelectric power plants have been built for driving electric water pumps. Some aspects of the interaction between the pump and the solar generator connected with the power-utilizing efficiency were examined.

Systems consisting of a solar generator, an electric pump and a storage battery to provide internal power are characterized by a large number of interrelated parameters (direct solar flux density, generator power, power requirements of the pump, voltage impeller speed, pump capacity, developed head, etc.).

The results show that for a pump lifting water through 15 m for a period of 9 hrs (one working day for the solar generator) the output is 12.5 and 10 m³ for installed generator powers of 375 and 255 W, respectively. These daily outputs illustrate the possibility, for example, of watering 1000 head of sheep with a relatively low-powered solar generator.

4. Shulmeister, L. F., G. V. Elevich, A. V. Egorov, and B. V. Tarnizhevskii

"Control System for a Photoelectric Solar Water-Pumping Unit"

Semiconductor Solar Energy Converters, V. A. Baum (ed.), New York: Consultants Bureau (1969), pp. 42-45. (Translated from Russian.)

SUMMARY: A block diagram is given of a control system for a solar energy converter driving a water-lifting pump. It consists of two independent systems: a sun-tracking system and an automatic control of the water pump. The operating principles of the tracking system and an automatic control system are described. The apparatus and construction of sensors, made of photoelectric converters, are described. A storage battery, working as a buffer for solar batteries, was intended to drive the tracking system and to trigger the drive of the water-raising pump. The tracking system was of the relay type with a relatively high tracking accuracy. The unbalance signal was amplified by a transistor amplifier. A time relay was included in the tracking system to stabilize the tracking accuracy by extending the insensitive zone and making the system more stable. A brief technical description is given of the control system.

5. Tarnizhevskii, B. V. and B. Ya. Rodicher

"Tests on a Photoelectric Solar Unit for Pumping Water"

Semiconductor Solar Energy Converters, V. A. Baum (ed.), New York: Consultants Bureau (1969), pp. 37-41. (Translated from Russian)

SUMMARY: The results are presented of tests of a prototype photoelectric solar energy converter constructed for the purpose of pumping water. The unit consisted of three 5 x 1 m panels, on which silicon photocells and concentrating mirrors were mounted. The panels were rotated equatorially. By means of the mirrors, the solar energy was concentrated by a factor of 2.5 on the surface of the silicon cells. This increased the output power of the photocells by a factor of about 2. The total cell area was 3.6 m². The efficiency of the cells was 3.5%. The optimum voltage was 45 V and the maximum output power, 248 W. The electrical characteristics were measured for various solar radiation densities. The thermal conditions of the operation of the photocells, which were provided only with natural air cooling, were studied. The photocell temperature under various external conditions did not exceed 54°C. The effect of dust on the mirror and photocell batteries was studied. A two-week exposure without dusting the mirrors and photocells reduced the short-circuit current by 8.5%. A mass-produced electric pump unit of the "Kama" type was driven by the solar converter and used to pump up water. The pumping of water was carried out using a special arrangement, by means of which tests under various conditions could be carried out. The dependence of the pump discharge rate on the density of the direct solar radiation flux was obtained for various values of the water head. The power consumed by the pump drive was close to the maximum power of the battery of cells at a given solar radiation level.

6. Lidorenko, N. S., V. Ya. Tarnizhevskii, G. B. Rodichev, Levitskii and Khandovietov

"Solar Water-Raising Installation Incorporating Photoconverters at the Ovezshikh Watering Point in the Turkmen SSR"

Geliotekhnika, (Applied Solar Energy), Vol. 6, No. 2, pp. 52-55, 1970.

SUMMARY: A solar power installation incorporating photoconverters was constructed in April 1969 at the Ovezshikh watering plant in the Bakhardenskii region of the Turkmen SSR. The system was developed at the All-Union Institute for Current Sources (VNITT) for water raising purposes. This was the first practical Soviet solar installation based on the principles of direct conversion of solar energy into electric power to be used in agriculture.

Experience has shown that the pump is, in fact, too fast for the well. Four to five hours of continuous operation of the pump is found to empty the well completely. In order to prevent the complete emptying of the well and dry operation of the pump, attempts were made to operate the pump from two-thirds of the output of the solar battery (the battery mounted on one of the three steering frames was switched off). However, even in this case, the pump output was about $2.2 \text{ m}^3/\text{hr}$ at 260 W.

The first stage of the solar still (600 m^2) is nearing completion, and when it is ready the entire system will become operational and will be transferred to the agricultural authorities.

7. Rodichev, B. Ya.

"Technical-Economic Characteristics of Photoelectric Water-Pumping Plants"

Geliotekhnika (Applied Solar Energy), Vol. 9, No. 2, pp. 42-47, 1973.

SUMMARY: A photoelectric pumping system was designed which, since 1969, has been used at the Ovez-Shikh stock watering station on the Bakharden State Farm in Central Kara Kum.

Three years of practical agricultural use of the plant has shown that the problems involved in its design have been successfully solved, in the main: the plant has adequate useful service life, does not require constant attendance, and is reliable in operation. There have been isolated failures, which were easily eliminated during periodic inspections.

It is conceded that utilization of the photoelectric plant rather than the gasoline-electric unit offers a substantial economic advantage for all the theoretical cases considered, when we look at the entire service life of the plant. Thus, even despite the present-day extreme cost of photoelectric converters, the use of independent solar plants based on such devices proves to be more favorable under appropriate conditions than the employment of internal-combustion engines.

8. "Solar-Powered Pump"

Electrical Review, July 23, 1975.

SUMMARY: A 5 m² solar cell panel, which delivers a maximum of 300W, is being used to pump water from a depth of 15 m in an experimental installation in France. The pump is being investigated for possible use in the dry areas of many countries where these conditions prevail.

The installation has been built by the French LEP laboratory in conjunction with the Philips Company of Holland. It is calculated that with 3,000 h of sun per year, the pump could deliver 1,000 m³ per year for each square metre of solar panel.

9. "Solar Energy Drives a Water Pump"

(Ver. Dtsch. Ing.) Z.; 117: No: 15-16, 743 (August 1975) (In German)

SUMMARY: The solar cell has an area of 5 m² and produces a maximum of 300 W. The pump operates to a maximum depth of 15 m, which corresponds to practical applications in developing countries, and produces 1000 m³ water per year and per square meter of cell area at 3000 hours sunshine per year. Short-term over-production is stored in batteries, and long-term over-production is stored as potential energy in a water reservoir.

10. Durand, H. and G. J. Naaier (Lab d'Electronique et de Physique Appliquee, Limeil-Brevannes, France)

"Water Pumps Driven by Photovoltaic Modules"

Presented at COMPLES/UPM International Conference on Heliotechnique and Development, Dhahran, Saudi Arabia, November 2-6, 1975.

Published by Development Analysis Association, Cambridge, MA, 1976, Vol. 2, pp. 315-330.

SUMMARY: Two water pumping systems including a kilowatt-size photovoltaic generator combined with a short-term storage battery are described. One system consists of a 300 watt-peak solar generator and a 1.8 kW pump. Another one consists of a 500 watt-peak generator coupled to a 400 watt pump. A comparison with a thermal steam-engine shows definite advantages in favor of the photovoltaic solution. The expected drop in prices and improvements of solar panels would make megawatt size stations economical for large-scale irrigation and full electrification of arid and remote areas.

11. Matlin, R. W.

"25 Kilowatt Photovoltaic Powered Irrigation Experiment"

Paper presented at the Solar Irrigation Workshop and Demonstration, Albuquerque, New Mexico, July 7-8, 1977.

SUMMARY: The first step toward the realization of large-scale irrigation systems utilizing photovoltaics will be made during the summer of 1977 by the construction and operation of a sub-scale experimental unit of approximately 25 kW peak power. This experiment, jointly developed between MIT/Lincoln Laboratory and the University of Nebraska-Lincoln under the sponsorship of ERDA, will drive a 10-horsepower pump that will be interconnected with a gated pipe irrigation system and a reuse pit of two acre feet capacity.

The use of the photovoltaic power during the non-irrigating portions of the year would add to the economic attractiveness of the system, as well as providing relief for another energy intensive agricultural operation that will be increasingly affected by the growing fossil fuel shortage. It is, therefore, planned to switch the power during the fall and winter from the irrigation system to a nearby corn drying bin where a natural air drying technique will be tested utilizing photovoltaic powered circulation fans.

The design considerations of this photovoltaic power system are discussed in this paper along with its operational characteristics.

12. Matlin, R. W. and M. T. Katzman

"The Economics of Adopting Solar Photovoltaic Energy Systems in Irrigation"

Massachusetts Institute of Technology, Lincoln Laboratory,
Lexington, Massachusetts 02173. Paper C00/4094-2, July 11, 1977.

SUMMARY: An economic analysis concerning the adoption of solar photovoltaic energy systems in irrigation has been made compared to conventional fossil fuel energy sources. The basis for this analysis is presented along with a discussion as to the time of initial profitability, the time of optimal investment, the effects of the tax system, the cost per acre that would make irrigation unviable, and possible government incentives that would promote the deployment of photovoltaic irrigation systems between the time of initial profitability and the time of optimal investment.

13. Pope, M. D. and R. W. Matlin

"Field Tests of Photovoltaic Power Systems"

Paper presented at the 1977 Photovoltaic Solar Energy Conference, Luxembourg, September 27-30, 1977.

SUMMARY: Selected topics discussed are: (1) a 25 kW peak agricultural experiment built in the state of Nebraska, (2) a 100 kW peak load center application planned for use in the U.S. National Park Service, and (3) a 1.6 kW peak power system installed at the Chicago Museum of Science and Industry. Other project activities are briefly discussed. The Chicago Museum power system operates the electric lighting load for ERDA's new energy exhibit known as "The Energy Lab." The exhibit, along with its photovoltaic power system was placed in

operation at the Museum in mid-August 1977. A 100 kW peak load center is being designed for use in Natural Bridges National Monument, which is a U.S. National Park located in southern Utah. It will service a variety of loads, including water pumping and diversified loads for rangers' residences, maintenance shops and the Park's visitor center. A 25 kW agricultural experiment is now in operation in Mead, Nebraska. It was turned on in late July and was used for irrigating corn. It is now being converted for its first alternative usage, namely, forced-air drying of the harvested corn crop. Other usages are also planned. An economic analysis was performed concerning the use of photovoltaics for agricultural applications. The study centered on those regions of the U.S. wherein crop irrigation is employed extensively; however, off-season usages of the electricity from the array for other agricultural purposes were considered in the cost-benefit analysis. In addition to region, other parameters which were varied in the study were: discount rates, fuel cost escalation and support system costs. The studies indicate that under favorable conditions photovoltaics would be a viable option for the American farmer in the early to mid 1980s. Under less favorable conditions, the economic use of photovoltaics would be delayed to the 1990s.

14. Hundemann, Audrey S.

"Solar Water Pumps" (Citations from the Engineering Index Data Base)
Report for 1970-November 1977. NTIS/PS-77/1161/7GA, December 1977,
38 pages.

SUMMARY: Design concepts and the technical and economic feasibility of using solar energy to pump water are discussed in abstracts from worldwide literature. Topic areas cover the use of solar heat actuated Rankine cycle engines and free cylinder Stirling engines for solar powered water pumps, pumps driven by photovoltaic modules, and application of solar pumps to irrigation and electric power generation. (Contains 31 abstracts)

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