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batteries for solar energy systems ....

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BATTERIES FOR SOLAR ENERGY SYSTEMS PROGRAM AT SANDIA NATIONAL LABORATORIES

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Sandia has traditionally emphasized engineering research and development in nuclear ordnance design. In recent years our mission has expanded to include energy research and development. Energy programs now account for about 25 percent of our work. We also undertake assignments for other federal agencies, particularly the Department of Defense (DoD) and the Nuclear Regulatory Commission (NRC). Our solar projects are authorized and funded by the DOE.

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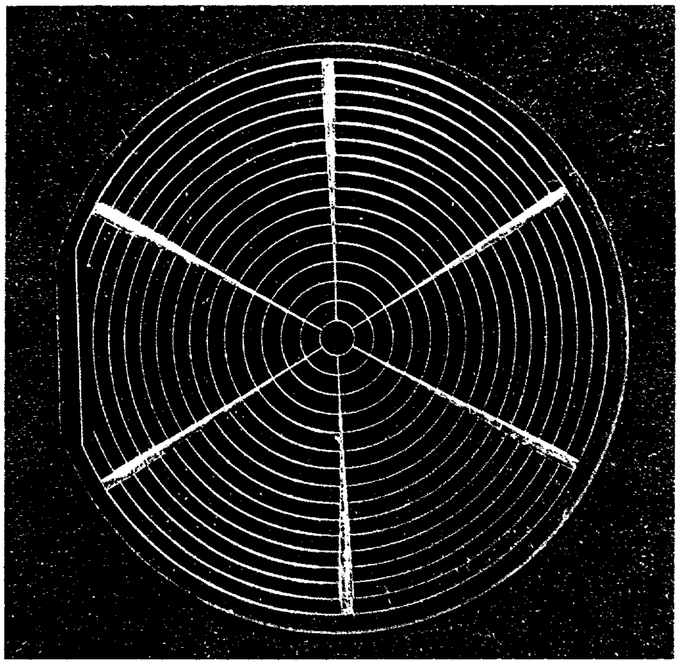
THE ENERGY PROBLEM

Increasing demands for oil and natural gas, and their rapidly diminishing supply, have combined to create a critical energy problem in the United States and other industrial nations of the world. In an attempt to reduce our dependence on the import of foreign oil, this country is now involved in an urgent search for sources of renewable energy that can be substituted for fossil fuels.

The primary source of all energy is the sun. Sunlight is the ultimate source not only of plant growth (and thus of food and wood), but also of the chemical energy of ages past that we are using now in the form of coal, oil, and gas. The sun supplies heat to evaporate water for rain, and it is the origin of wind energy. Our earth receives an enormous amount of energy from the sun. In one single day the incident solar energy (sunlight) dispersed on the surface of the earth exceeds, by a factor of 100, all of the energy used by the United States in an entire year. A little less than 1 percent of the energy derived from the sunlight that falls on the US could supply *all* our present needs — if it can be harnessed.



Typical photovoltaic cell

Because greater use of solar energy could reduce our dependence on fossil fuels, it is an attractive energy source. But this energy of the sun is diffuse, not concentrated. Also, it is intermittent — often available for only about one-third of a day — and it varies in intensity depending on weather, time, and geographical location.

For these reasons, large amounts of material resources are needed as well as a technology for collecting, concentrating, and conditioning this abundant resource. If solar energy is to become dependable and continuous, sunshine must be collected when it is plentiful and stored for later use.

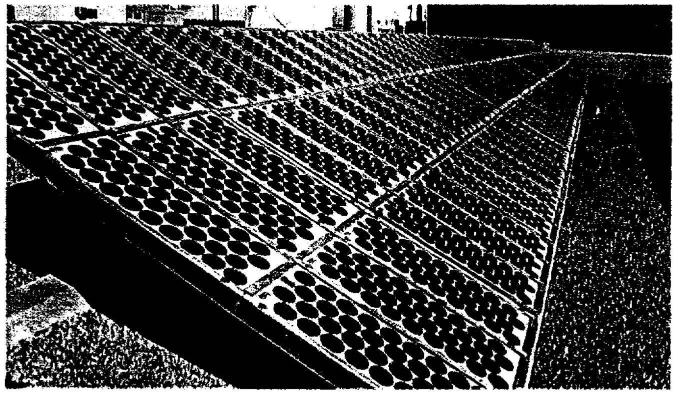
ELECTRICITY FROM THE SUN

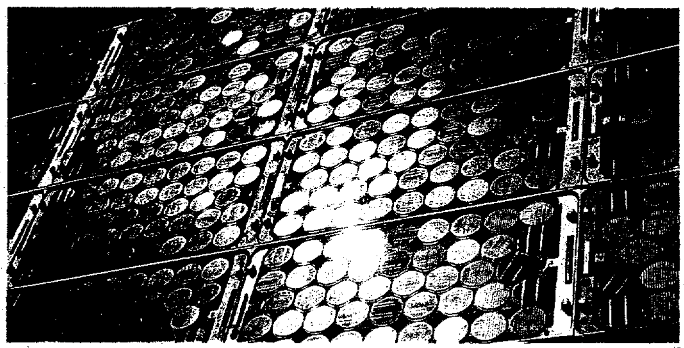
Electricity can be generated from sunlight either directly with photovoltaic arrays, or indirectly from wind-driven generators or heat produced in solar collectors.

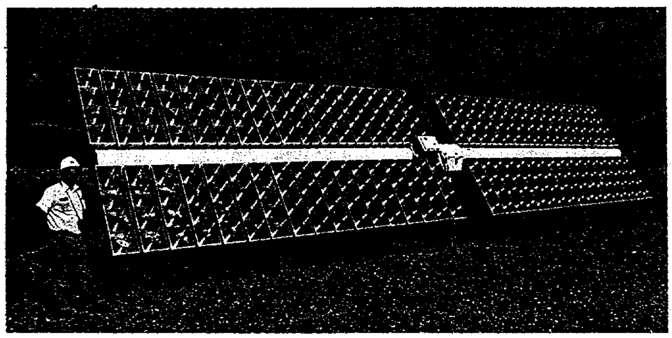
PHOTOVOLTAIC CONVERSION — Photovoltaic arrays consist of many solar cells made of certain materials that generate electricity when illuminated. Although the photovoltaic principle has been known to scientists for many years as an outgrowth of modern semiconductor research, its practical development began only in the 1950s as a way to provide power for hundreds of spacecraft. (Space vehicles and satellites carry batteries and arrays of solar photovoltaic cells.)

Almost all commercially produced solar cells have been made from thin wafers of pure silicon 4 inches or less in diameter. In silicon cells, a nonreflective surface coating is applied to the silicon disk like the one in the photo to maximize the absorption of sunlight. Individual cells are then joined together in series, in parallel, or in a combination of both to make up solar arrays with the desired power and energy outputs. (Series connections produce higher voltages, while parallel connections produce higher currents.) The power output of an array of photovoltaic cells at a maximum level of insolation (density of solar radiation) is expressed in peak watts, Wp.

Manufacturing solar cells is highly specialized and expensive, and cost has been a major obstacle to terrestrial applications of photovoltaic technology. However, materials research and development has reduced the cost of solar cells by more than 80 percent in the last 10 years. Further significant cost reduction is expected within the







A photovoltaic concentrator array (Martin Marietta)

next 5 years. One technique under investigation is concentrating arrays in which the lenses focus the sunlight onto smaller cells, reducing the area of silicon required and hence the cost.

Only a few years ago the cost of photovoltaic arrays was about $50 per Wp; the cost is soon expected to drop below $5. The US Department of Energy (DOE) has established a 1986 cost goal for photovoltaic arrays of less than $1 per Wp. If this goal is met, solar electricity can compete economically with established sources of electrical energy.

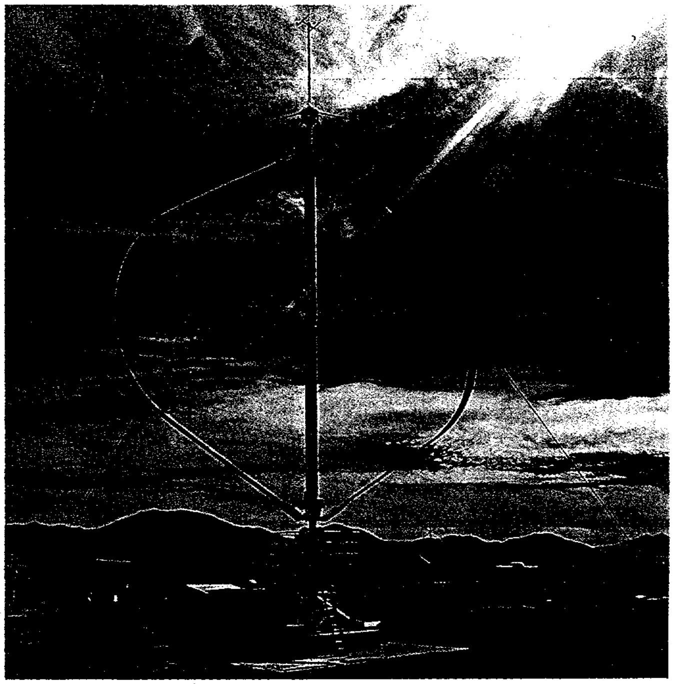
WIND CONVERSION — Winds are ultimately driven by energy that flows from the sun. Large-scale wind turbines (windmills) are being developed to generate electricity for electric utilities. Smaller turbines are being developed for use in remote areas where utility grids do not exist, and where the only alternative often is petroleum-powered generators.

SOLAR-THERMAL CONVERSION — In this method, electric generators powered by heat engines use energy converted from sunlight by various kinds of solar collectors. Utility companies, for example, can generate electricity in central power-generating stations by concentrating and collecting solar heat to make steam for conventional turbogenerators. In solar total-energy systems, solar thermal energy is used for space heating and cooling as well as for generating electricity — a process called cogeneration.

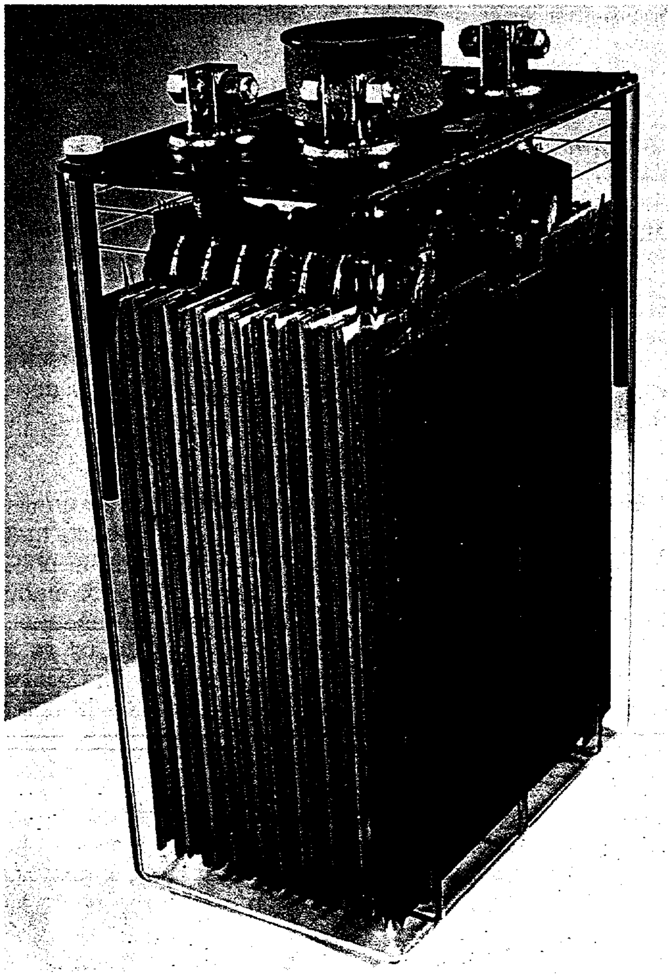
STORAGE OF SOLAR ELECTRICAL ENERGY

We have seen that sunlight can be converted into electricity. But the demand for electricity often occurs at times when electricity cannot be generated from the sun — at night or on cloudy days, for example. Because of this time lag between demand and supply, a solar system is more useful if it can store electricity for later use. Batteries can fill this need.

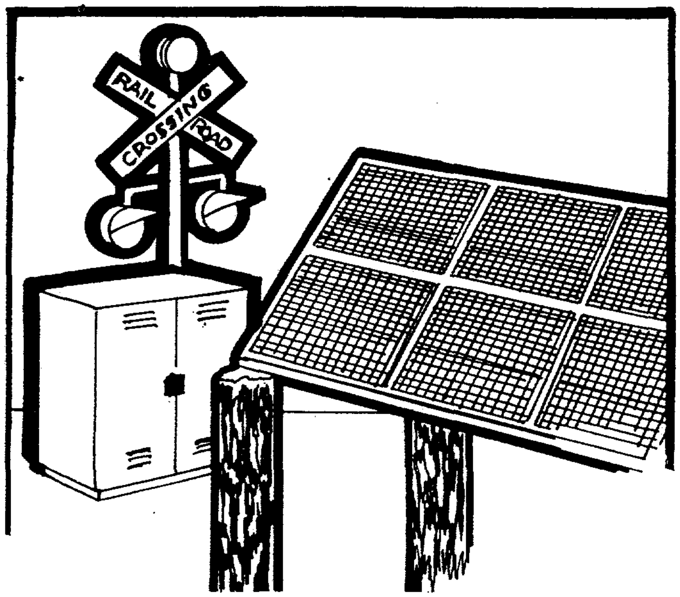
Batteries convert electrical energy, store it chemically, and redeliver it on demand as electrical energy through electrochemical processes called charging and discharging. Solar-energy storage batteries now in use include lead-acid and nickel-cadmium batteries.



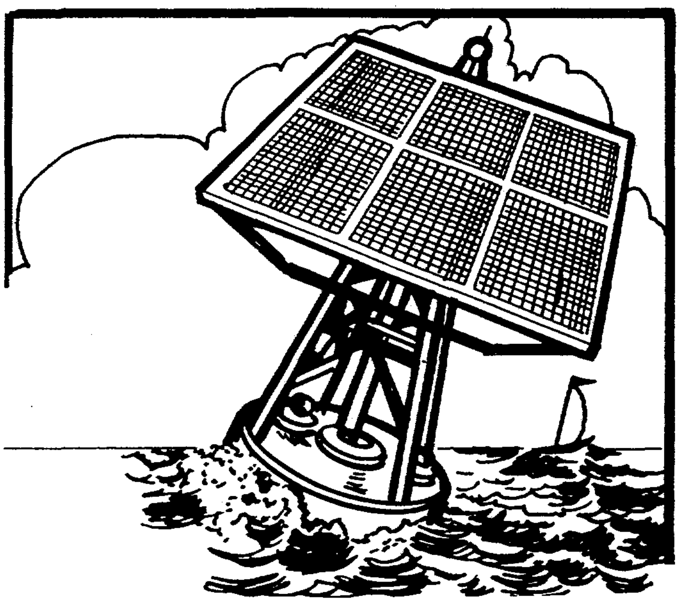
Vertical-axis wind turbine 17 metres in diameter. This research turbine shows a two-bladed design made of extruded aluminum



A lead-acid battery



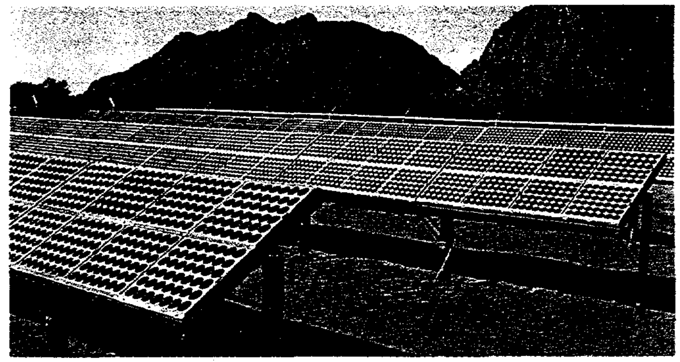
A railroad-signaling photovoltaic application that uses energy storage batteries



An offshore buoy with solar energy storage batteries

Photovoltaic systems with battery storage are being used today to supply power to remote stand-alone installations where power lines don't exist. These applications include railroad signaling and grade-crossing equipment, offshore navigational aids, unmanned microwave radio relay stations, and residential power for small villages like Schuchuli in Arizona.

Solar electricity will become a widely used form of alternate energy only when it is economically feasible for larger grid-connected power applications. Potential applications range from single or multiple residential dwellings to shopping centers, office buildings, manufacturing plants, and small central power generating stations. Such uses will be attractive for photovoltaic systems when technology advances reduce the cost of solar cells below DOE's goal of $1 per peak watt of output power.

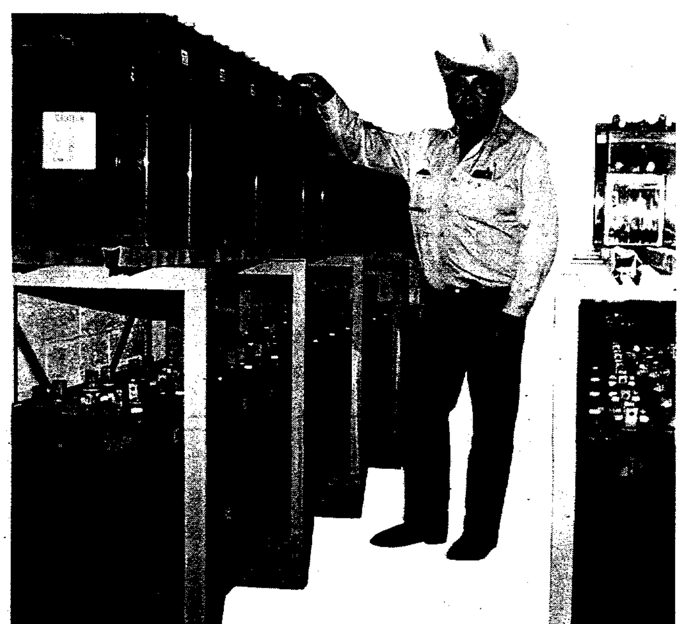


A photovoltaic power system that provides electricity for the Papago Indian Village of Schuchuli in Arizona

Recent studies have shown that batteries, if their cost could be reduced to less than $100 per kilowatt hour of stored energy, and life increased to 20 years, would enhance the desirability of photovoltaic systems and further reduce the amount of oil used for generating electricity in many potential residential applications. Current life-cycle costs for lead-acid batteries for this type of service are about $500 per kilowatt hour.

Batteries require abundant, inexpensive chemical materials for large-scale solar energy storage. They must have long lives and must be able to cycle daily, yet withstand rapid shifts between charging and discharging. They must also accept large variations in input and output currents and be able to discharge to their rated limits. Maintenance must be minimal, with safe operation assured.

Promising battery candidates may evolve from batteries now being developed for other applications like electric vehicles and utility load leveling (a term that means spreading the effects of peak electrical use evenly over a given time). However, the requirements for solar electrical storage differ widely from those for the applications just mentioned, with corresponding advantages and disadvan-



Lead-acid battery storage system for the Schuchuli photovoltaic application tages. For example, the charging and discharging of batteries in load-leveling applications is much more predictable than for batteries in solar applications. Also, it may not be economic to scale down the large batteries used in load leveling to the small sizes needed for many solar uses. Acceptable life-cycle costs are higher for electric-vehicle batteries than for solar-storage batteries, but solar batteries can be larger and heavier.

Some batteries now in development that use flowing electrolytes may have characteristics better suited for solar uses than for electric vehicles. Candidates are NASA/Lewis Research Center's iron-chromium REDOX system, and the zinc-bromine system of Gould, Inc. and of Exxon Enterprises.

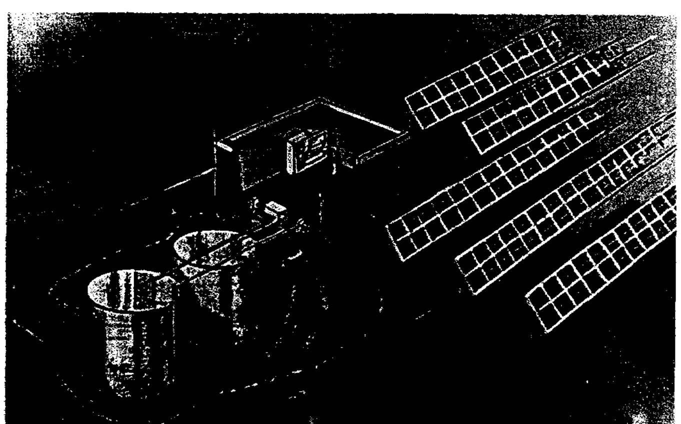
Tests of candidate batteries will begin in the next 1 to 5 years. By then, better-defined application requirements and new battery capabilities should make photovoltaics a significant part of the DOE's long-range goal of finding alternative national energy resources.

THE BATTERIES FOR SPECIFIC SOLAR APPLICATIONS PROGRAM (BSSAP) AT SANDIA

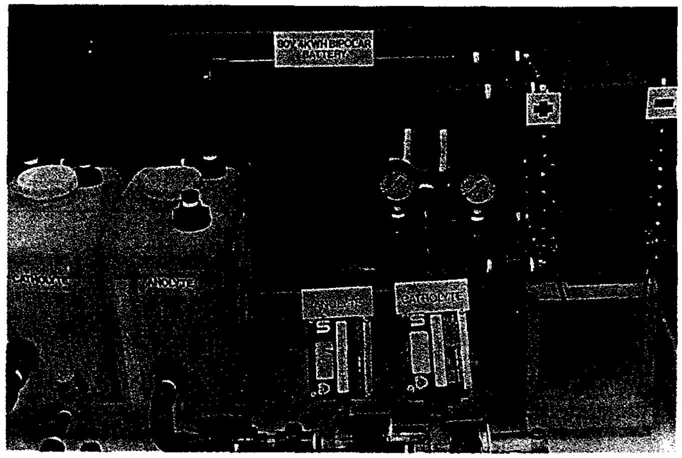
DOE has selected Sandia National Laboratories as its lead laboratory to direct a program to develop and test batteries for electrical storage in a variety of solar applications. Initial emphasis is on storage in photovoltaic systems, but wind-energy and solar-thermal systems will be considered later.

The BSSAP program is divided functionally into five tasks:

Task I	Battery Requirements Analysis
Task II	Laboratory Evaluation
Task III	PV Advanced Systems Tests
Task IV	Applied Experiments
Task V	Battery Research and Development



Artist's concept of a PV system that uses NASA/Lewis Research Center's iron-chromium REDOX battery system

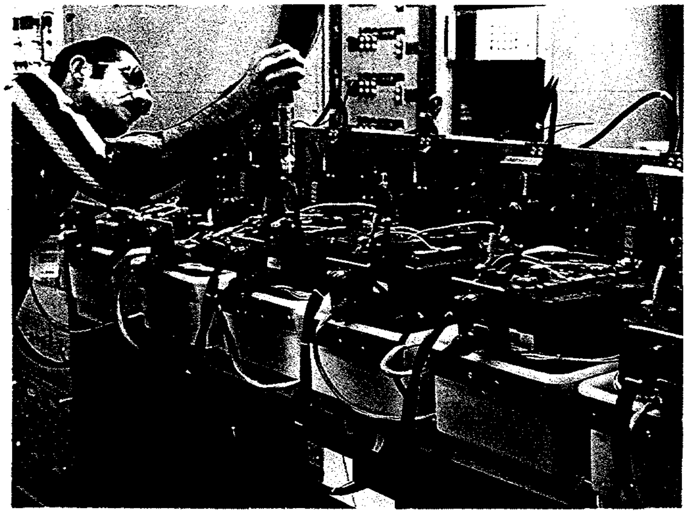


The zinc-bromine laboratory battery of Exxon Enterprises

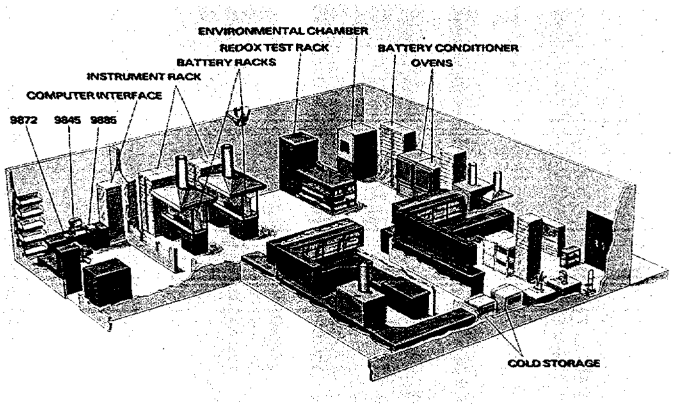
TASK I — BATTERY REQUIREMENTS ANALYSIS — In Task I, computer simulation techniques are used to model complete solar systems under different assumptions about geographical location, type of application, battery cost and performance, and costs of competing energy sources. In this way, the program can target applications where battery storage promises to be cost-effective. The simulations also indicate the type of duty cycle a battery will undergo in each application. For example, in stand-alone applications with no other source of energy but the solar system, the battery storage capacity will have to be quite large. Thus the daily discharge cycle will require only a small percentage of the capacity. But the battery will experience an annual cycle, because the average state of charge slowly declines in winter, recovering in summer. In contrast, for applications where utility lines can provide backup power, the battery could be sized to provide only a single day's electricity. Here the battery would undergo a deep discharge cycle daily. Two such diverse applications impose very different technical requirements on the batteries. Information like this is essential in a battery development program.

TASK II — LABORATORY EVALUATION — Here the object is to evaluate small battery systems in *simulated* solar applications. In this way, both commercially existing and development batteries can be thoroughly tested in carefully controlled, repeatable conditions. A variety of lead-acid batteries are under test at Sandia's Battery Test Lab, where application charge-discharge profiles are expected to be developed. Results of these tests will be compared to manufacturers' charge-discharge profiles. Combining manufacturers' data with our data may make it possible to predict battery performance in solar applications. Advanced battery prototypes will be tested in this lab to confirm the developer's data. Zinc-bromine and iron-chromium REDOX flow batteries are early candidates for testing.

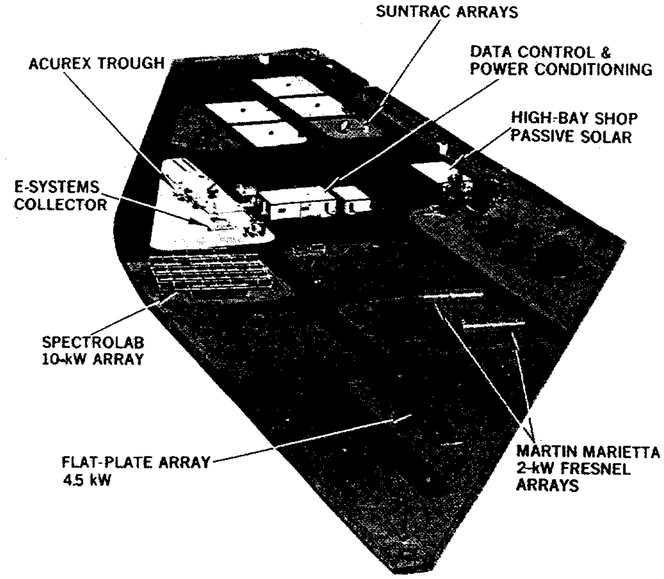
TASK III — PV ADVANCED SYSTEMS TESTS — In Task III, batteries that look promising in laboratory testing are scaled up to full size and tested in a full-scale PV system at Sandia's Photovoltaic Advanced Systems Test Facility. This intermediate step is essential to obtain high-quality test data under real but controlled conditions.



Batteries under test at Sandia's current Battery Test Lab



New Battery Test Lab to be constructed at Sandia in 1981



Sandia's Photovoltaic Advanced Systems Test Facility

TASK IV — APPLIED EXPERIMENTS — In this task, the logical follow-on for batteries that successfully negotiate the tests of Task III, battery storage systems are installed in demonstration solar projects (PV, wind, or thermal-electric). System output goes to loads that are controlled by the system users, although the experiments will be instrumented and monitored. Maintenance is by the users. Systems that pass the technical requirements of these experiments and show promise for competitive mass production are ready for commercialization. If the developer is a private business, commercialization may mean nothing more than a company decision to go into production. But if the developer is a governmental laboratory, DOE help may be needed to bring an interested company "up to speed" on the technology; then the company would proceed into production on its own.

TASK V — BATTERY RESEARCH AND DEVELOPMENT — This task is the heart of the battery program. Early results from Task I showed that *no* existing battery technology meets both the performance and cost requirements needed for solar applications; Task V is charged with developing batteries that meet both requirements. From the large number of electrochemical systems now in research, two were chosen for initial funding. Both have promise for solar applications, and they were not receiving substantial support. They are the zinc-bromine system under development by Exxon Research and Engineering Company, and NASA-Lewis Research Center's iron-chromium REDOX system. Both are flow batteries, so-called because the electrolytes and reactants are pumped from storage tanks through the power-producing stack of cells. A key element in most flow batteries is the membrane separating the two electrolytes in each half of the cell. Sandia is doing basic research on the properties of membranes that can be beneficial to many types of flow batteries.

Besides these advanced batteries, Sandia also supports work to improve the performance of the lead-acid batteries now used in most solar applications; improvements in these batteries will pay off immediately. The major issue is that of maintenance. Gould and Eagle-Picher are developing completely sealed lead-acid batteries that are totally maintenance-free and are also capable of deep discharges.

The BSSAP at Sandia is following a logical program development schedule that should result in long-lived, low-maintenance, and inexpensive battery storage systems available for public use by 1990.

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