Gould and Vrba suggest that their origin might simply be the result of the high levels of circulating androgens associated with the growth of the unusually large female body. The clitoris and labia majora, being homologs of the penis and scrotum, simply enlarge in response to the high levels of the hormone. Once present, the pseudogenitalia may then have been co-opted in the meeting ceremony, as exaptations. They arose initially with no function, and then assumed a role.

Molecular biology of recent years has revealed many new and intriguing categories of DNA, some of which appear to have no role. One explanation of this has been that the nonaptive sequences provide raw material for future evolution. But the logic of natural selection does not allow for selection for future use. More likely is that the accumulation of nonaptive DNA is a consequence of the innate property of repeated sequences of nucleic acid to replicate and move around the genome. Later it may be recruited to perform some role, in which case it becomes an exaptation.

"The ultimate decision about whether we have written a trivial essay on terminology or made a potentially interesting statement about evolution must hinge upon the importance of exaptation, both in frequency and in role," write Gould and Vrba. Evolution depends on the raw material presented to selection, and this typically has been thought of in terms of genetic variation. Gould and Vrba say that phenotypic variation, in contrast to genotypic variation, has not adequately been considered. "Flexibility lies in the pool of features available for exaptation," they state. "The paths of evolution—both the constraints and the opportunities—must be largely set by the size and nature of this pool of potential exaptations."

In addition to placing the phenomenon of genetic redundancy in the realm of exaptation, Gould and Vrba suggest that most of what the human brain now does is unrelated to its original adaptation, and are there for exaptations. With examples like these, they assert, the subject cannot be deemed unimportant.

"The codification of exaptation not only identifies a common flaw in much evolutionary reasoning—the inference of historical genesis from current utility. It also focuses attention upon the neglected but paramount role of nonaptive features in both constraining and facilitating the path of evolution."—ROGER LEWIN

Solar with a Grain of Salt

Salt gradient solar ponds are the simplest, cheapest way to collect large amounts of solar energy and should be the first to find wide use

Modern solar energy technology often seems to deviate sharply from the age-old engineering dictum that simpler is better. High-tech photovoltaic cells, computer-controlled arrays of heliostats focusing sunlight on high-temperature boilers, and even solar power stations in space are all contenders for shares of the solar energy pie. In the midst of this technological clutter, it seems somehow refreshing that the technique most likely to find the first wide use for collecting solar energy for industry and electrical generation is also the simplest.

Salt gradient solar ponds, which carry the uneuphonious acronym SGSP's, are already in operation in the United States, Israel, and Australia. Several others are already under construction, and at least three much larger projects are on the drawing board. These developments were reviewed at the recent American Chemical Society meeting in Las Vegas and at an April workshop on salt gradient ponds sponsored by the U.S. Department of Energy.

The immediate precursor of the SGSP, the shallow solar pond, has been viewed as a potential energy source since at least the turn of the century. The theory behind it is simple. A shallow bed of water is exposed to sunlight, which heats it to a temperature as high as 60°C. The heated water can then be used directly or the heat energy can be extracted. Small shallow solar ponds are in use at several sites around the world, but they have important limitations, the most crucial being that heated water is brought to the surface by convection. At the surface, a significant proportion of the stored energy is lost through evaporation and radiation, particularly at night. Investigators at several laboratories are exploring ways to retain heat. New ways include pumping the warm water into insulated chambers at night, covering the pond at night with foam, covering the pond with plastic to retard evaporation, and enclosing the water in plastic bags.

As long ago as 1960 Harry Zvi Tabor and his colleagues at the National Physical Laboratory in Israel found that heat loss could be limited by establishing a salt gradient. Their SGSP has three distinct zones: a convective upper layer, a nonconvective middle zone, and a bottom storage zone. The upper zone, says Robert L. French of the Jet Propulsion Laboratory, "is not a designed component but something that is formed naturally as a result of rain, runoff, and other natural occurrences."

The middle zone is the most important, says French, because it traps the heat. It is generally about 1 meter thick, with a density ranging from 1.0 at the top to about 1.2 at the bottom. The density gradient is produced by dissolved salts such as sodium carbonate, sodium chloride, magnesium chloride, or sodium sulfate. This layer is relatively transparent to incident solar radiation, but is opaque to the infrared radiation from the hot water below. Most important, the gradient prevents hot water in the bottom zone from circulating to the surface.

The bottom zone is generally 1 to 4 meters thick and has a high, uniform density produced by concentrations of salt as high as 20 percent. The amount of salt required can be as much as 900 kilograms per square meter. This zone absorbs most of the incident sunlight and stores heat. Because the heat is trapped, the bottom zone can easily boil if heat is not removed.

The work in Israel was abandoned in the early 1960's because petroleum was so cheap then. It did not resume until after oil prices skyrocketed in 1973. The second wave of work was spearheaded by Tabor, the Israeli Ministry of Energy and Infrastructure, and Ormat Turbines, Ltd., one of the largest manufacturers of Rankine cycle turbines for generation of electricity. Rankine cycle turbines are similar to conventional steam generators, but operate with organic fluids whose boiling points are lower than that of water. They can thus be used with low temperature heat sources.

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Ormat and the government have produced several SGSP's, two of which are still producing electricity. The first of these, built at Yavne in the early 1970's, has an area of 1250 square meters and produces 6 kilowatts of electricity. Hot water is pumped out of the bottom zone, through heat exchangers in the Rankine turbine, and back to the bottom. Relatively cool water from the surface layer is used for cooling.

A larger, 7000-square-meter pond began operation at Ein Bokek in December 1979. It can produce 35 kilowatts continuously or a peak of 150 kilowatts. Ormat and the government are now finishing a 250,000-square-meter demonstration pond at Beit Arava that is scheduled to begin producing 5 megawatts of electricity in September 1983. This is the first of a series of SGSP's around the Dead Sea that the Israelis hope will be producing some 2000 megawatts of electricity by the year 2000. This will be a significant amount in a country that now has only 2700 megawatts of capacity.

The generation of electricity via an SGSP is a relatively inefficient process. The pond itself has an efficiency of about 20 percent—that is, it captures about 20 percent of the incident radiation. The Rankine cycle turbine has an efficiency of about 8.5 percent, so that the overall efficiency of electrical generation is about 1.5 percent. Nonetheless, the estimated installation cost for the Dead Sea project is only about $2000 per kilowatt, roughly equivalent to the cost of hydroelectric installations.

There is now one "commercial" SGSP operating in the United States, a 2000-square-meter (0.5-acre) pond that provides heat to the municipal swimming pool and a recreational facility in Miamisburg, Ohio. There are four other ponds now operating and five others that are being brought up to temperature or that will be constructed this year. Most are for research purposes, since there are still several questions that must be answered. Foremost among the problems is the fact that operation is highly site-specific, so that experience at many different locations is necessary before generalizations can be made.

Maintenance is also a problem. This includes both normal maintenance, which is not altogether different from maintenance of a swimming pool, and maintenance of the gradient, which will probably require periodic injections of brine at the bottom and fresh water at the top. "There is no question," says French, "that the Israelis are way ahead of us on techniques for maintaining the gradient." New ways to create the gradient are also being explored. Typically, this is done by layering solutions of decreasing density sequentially on the top of the storage zone. Howard C. Bryant and his colleagues at the University of New Mexico are exploring the use of salts, such as potassium nitrate, whose solubility increases strongly with temperature. A warm, saturated solution of such salts will automatically drop to the bottom of the pond, creating a gradient naturally.

"There is no question that the Israelis are way ahead of us on techniques for maintaining the gradient."

Another important factor is the liner and its integrity. Concentrated saline solution can percolate through most types of soil, killing plants and contaminating nearby water supplies. Plastic and rubber liners have been used in most of the existing ponds, but there is a potential for leaks at the seams—as occurred, in fact, at the Miamisburg pond.

One way to avoid the need for liners is to use dried lake beds. Nevada, alone, has some 2000 square miles of dried lake beds that could be used for SGSP's, says Christo Stojanoff of the Desert Research Institute. Unfortunately, he adds, the concentrated salt solution leaches metals and salts from the playas. These turn the gradient dark, preventing sunlight from reaching the bottom of the pond.

It is thus necessary to find some way to confine the leached salts to the storage zone. One way to do this would be to float a nonpolar organic fluid between the bottom and middle layers. Stojanoff and his colleagues have examined many possible fluids, and have found some fluorosilicons that seem to have the right combination of densities and refractive indices for this use. Salt flats around the Salton Sea in Imperial County, California, do not have this leaching problem, says French, but the seawater itself is turbid and colored, which also interferes with energy absorption. Conventional filtering and sedimentation do not remove the problem, and French is studying other approaches, including treatment with activated carbon.

It might even be possible to do away with both salt and liner. Moshe Levy and David Vofsi of the Weizmann Institute of Science in Israel reported at the American Chemical Society meeting that it might be possible to stop convection by using aqueous gels of polyacrylamide, polyvinyl alcohol, and other polymers. Field tests with small quantities have shown that temperatures as high as 95°C can be obtained and maintained for days, but the polymers are not stable to ultraviolet radiation from the sun.

Most scientists are confident that all the salt gradient solar problems can be solved, and several larger projects are on the drawing board. The U.S. Department of Energy, the California Energy Commission, and Southern California Edison Company are collaborating on a study of installing 46 square miles of solar ponds to generate 600 megawatts of electricity at the Salton Sea. A decision on a 5-megawatt demonstration plant is expected by June 1983.

Another large project will be associated with a salinity control project on the Red River in Texas. The U.S. Army Corps of Engineers is diverting saline tributaries of the Red River and pumping them into a 1200-hectare brine lake at Truscott, Texas. Cecile Leboeuf and her colleagues at the Solar Energy Research Institute in Boulder, Colorado, have designed an SGSP project that would use the brine to provide all the electricity required for the project. An initial 100,000-square-meter pond should be completed in 1984, and the entire 5-megawatt system could be finished by 1995.

There are many other potential applications that are less dramatic. Many mining operations in the western United States produce significant quantities of brine that must be impounded anyway, says James L. Giulianelli of the Colorado School of Mines. These impoundments could be upgraded to produce process heat and, perhaps, electricity for the mining operations at minimal cost. Solar-generated electricity can be economically competitive right now at locations such as the Australian outback and the Caribbean Sea, adds Michael Edesess of Flow Research Company.

Industry and government officials already seem impressed by the potentialities of salt gradient solar ponds. If the demonstration plants now planned are successful, there will undoubtedly be many more installations. Such ponds may never supply more than a small percentage of total U.S. energy needs, but at many locations they can provide a relatively inexpensive source of energy.

—THOMAS H. MAUGH II