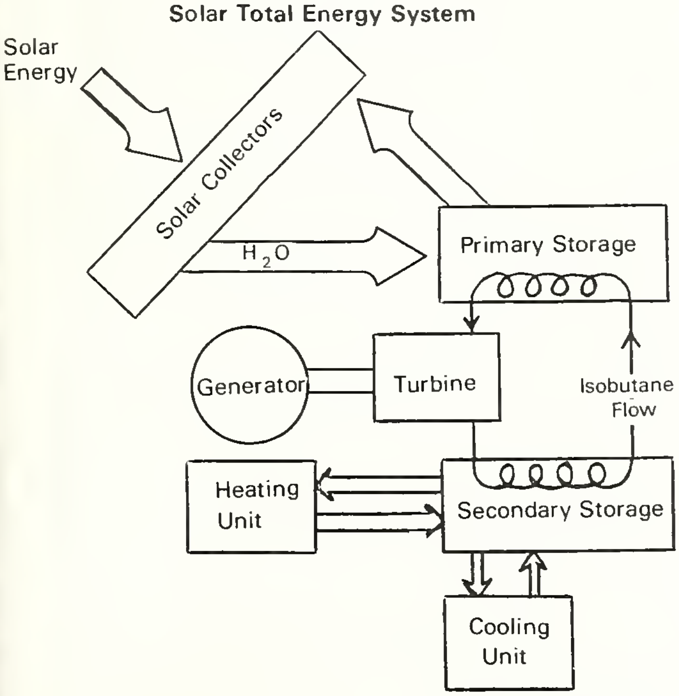
The Feasibility of a Multiple Residence Solar Energy System

The search for new sources of energy to replace dwindling supplies of petroleum and natural gas has become a major national priority. Solar heat is widely discussed as a new source of energy in a variety of settings. Solar space heating appears to be on the horizon, but the economic potential of generating electricity from solar sources is very much an open question.

Large scale, central generation of electricity from solar sources is and will remain unacceptable for some time because extremely large fields of collectors are essential to harness the quantities of solar heat required. On-site solar generation of electricity, however, might prove a more feasible alternative. An on-site system eliminates land acquisition costs because collectors can be built into the rooftops of buildings. In addition, solar heat collected on site can be more efficiently utilized because residual heat unusable for electrical generation is employed for space heating. Single family homes must be ruled out since the high temperatures and complicated equipment involved in on-site generation make it infeasible for operation. Thus, our attention for on-site solar generation of electricity must focus on multiple-unit dwellings, and commercial and industrial applications.

Figure 1

Solar Total Energy System



Drawing by Dan Fleishman

This article attempts to estimate the economic feasibility of an on-site solar energy system which uses presently available technology for this type of development. The Total Solar Energy System (TSES) discussed, would generate electricity and provide space heating and cooling for twenty housing units, totalling 40,000 square feet, on a single site in piedmont North Carolina. The design requirements of the TSES are explained, then an approximation of the economic feasibility is presented.

Design of the TSES

The TSES gathers sunlight in rooftop collectors which use the sunlight to heat pressurized water. The pressurized water, on demand, heats isobutane, a liquid hydrocarbon, which drives an electrical generator. The isobutane loses temperature in the generation process, but retains enough heat to be used for space heating, cooling and hot water heating. A second storage system containing water is then heated by the isobutane, and directly supplies the energy for space conditioning. Figure 1 illustrates the flow of materials through the TSES.

The design of this system was chosen after searching for a generator which could operate at the appropriate temperatures using currently available collector technology. The isobutane generator produced by Solar Sea Power, Inc., and currently in commerical use harnessing geothermal power in the Far West is able to operate using isobutane heated to 300°F.[1] Of the methods currently available to achieve this temperature, flat plate solar collectors with special selective coatings are of the least cost.[2]

Present consumption rates for all electric residential customer in Chapel Hill were used to determine the size of the generation and heating system required.[3] A winter consumption rate of 34,000

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kilowatt hours per month is estimated to be the maximum which would be required by the development. The 100 kilowatt generator necessary to meet this demand was priced at 18,000 dollars; the required ancillary equipment cost 45,000 dollars.[4]

The size of the collector system required was determined by means of Equation 1, where A = the collector

$$(1) \qquad A = \frac{D}{S\, e_c\, e_g}$$

area, D = the daily energy demand during peak seasons, S = the solar constant (180 watts - m ^{2}), e_c = the collector efficiency, and e_g = the generation efficiency.

The daily energy demand during peak seasons was taken as 20/30 of the demand during January, 1975 for the average all electric residence in Chapel Hill.[5]

The collector efficiency is .5.

The generation efficiency is .15.

Using this method, the required collector area was determined to be 20,000 square feet.

One day's storage capacity is all that is used because of the high capital cost of providing a system capable of storing the high temperature, high pressure liquids for longer than one day. During periods of successive cloudy days, the development will rely on electricity supplied by the local utility company. The conventional equipment required to perform the heating and cooling during these periods which would be present both with and without the TSES, and the electrical wiring to each unit of the development are not included in the cost of the TSES.

The TSES is expected to last twenty years. Thomason solar homes equipped with similar collectors have been in operation this length of time[6] and extending this period would not significantly alter the system's feasibility.

Economic Feasibility of the System

The TSES would be considered economically viable if the capital and operating costs of the system were less than the savings resulting from lower electricity purchases from the utility. In order to make this comparison, all costs and benefits must be expressed at a common time. This comparison is made in Equation 2:

$$(2) \qquad PV = \sum_{i=1}^{20} (E_i / (1+r)^i) - K - \sum_{i=1}^{20} (M_i / (1+r))$$

where PV = the present value of net benefits from the solar system, E_i = the savings resulting from lowered electricity consumption in year i, K = the incremental capital costs of the TSES over a conventional system, M_i = the maintenance, and replacement costs in year i, and r = the rate of discount.

Maintenance and replacement costs (M_i) for the system were approximated at $400 per year from data for a similar type of installation made available by Sandia Laboratories.[7]

Figure 2

Capital Costs for the Total Solar Energy System

100 KW Generator and Boiler Cost*	$18,000
Fluid Transmission**	7,000
Fluid Processing and Distribution**	20,000
Pump**	6,000
Other Equipment**	12,000
Collectors at $10/ft^2 +	200,000
Collectors at $6/ft^2 +	120,000
Savings in Conventional System Components	(40,000)
Incremental Capital Costs at $10/ft^2	223,000
Incremental Capital Cost at $6/ft^2	143,000

* from Hilbert Anderson, Solar Sea Power, Inc., 1975.

**R. B. Pope and W. P. Schimmel, *The Solar Community and the Cascaded Energy Concept Applied to a Single Home and a Small Subdivision,* Sandia Laboratories, Alburqerque, 1973.

\+ see text for explanation of collector costs

The incremental capital costs of the TSES over a conventional system (K) are summarized in Figure 2. The TSES allows the removal of certain conventional elements from the development. These items (totalling $40,000) are subtracted from the total capital cost of the TSES to arrive at the incremental capital cost. Calculations were performed using both the present collector cost of $10 per square foot and a projection of $6 per square foot which might result from the use of mass production techniques. The total capital cost of the TSES is $223,000 at $10/ft^2, and $143,000 at $6/ft^2.

The calculations are performed at three rates of discount (r): 12 percent, 9 percent, and 6 percent. 12 percent is close to what a private investor would require as a return on his money in order to invest in a TSES. 9 percent and 6 percent are rates which might be artificially created by government intervention in solar energy construction. The environmental and economic consequences of energy supply and demand problems make this a possibility. One of the principle conclusions of the Ford Foundation Energy Policy Project, for instance, was that on-site total energy systems be encouraged as a means of saving substantial amounts of energy.[8]

The savings resulting from lowered electricity consumption in the TSES in each year (E_i), were calculated using Equation 3:

$$(3) \qquad E_i = P(Q_{ae} - Q_{tses})$$

where Q_{ae} = the quantity of electricity which would be required to meet all of the heating, cooling, and miscellaneous needs of the development if the TSES were not installed; Q_{tses} = the quantity of electricity which will be required to supplement the TSES during periods of cloudy weather; and P = the price of electrical energy purchased from the utility.

Q_{ae} is set at 20 times the average yearly consumption of electricity for all electric residential customers in Chapel Hill in 1975.[9] Q_{ae} = 262,000 kwh.

Q_{tses} is set at the average daily consumption of electricity for all electric residential customers in

Chapel Hill (718 kwh) times the average number of fully overcast days per year in piedmont North Carolina (96.73)[10]. Q_{tses} = 69,449 kwh.

The analysis is performed for three electricity price projections. In a *stagnant case,* P is fixed at the 1976 cost per kilowatt hour to all electric, residential custmers in the Duke Power System who use as much energy as would be used by the units served by the TSES[11] (P^s = 3.33 cents per kilowatt hour). In a *low dymanic case,* P is taken as 3.33 cents per kwh in 1976 and then is increased at a rate of 5 percent per year (P^l_1 = 3.33 cents per kwh. $P^l_{n+1} = 1.05\ P^l_n$). In a *high dynamic case,* P is increased from the same base at a rate of 10 percent per year (P^h_1 = 3.33¢/kwh. $P^h_{n+1} = 1.1\ P^h_n$).

The results of the calculations for the *stagnant* case ($P = P^s$), are presented in Figure 3. 175,124 dollars, for example, is the present value of an investment in the TSES computed at a discount rate of 12 percent, using present collector costs (10 dollars/ft²) and holding electricity prices constant at 3.33 cents/kwh. Figure 3 shows that if electricity rates were to remain constant over the next twenty years, the TSES would be uneconomical even at the government induced discount rate of 6 percent.

Figure 4 shows the results of the calculations under the *low dynamic case* ($P = P^l$). For example, 156,621 dollars is the present value of an investment in the TSES built in 1976 at a discount rate of 12 percent using present collector costs (10 dollars/ft²), and allowing electricity prices to rise 5 percent per year from a start of 3.33 cents/kwh. The values in Figure 4 indicate that the TSES is not economical when compared with a 5 percent increase in electricity rates.

Figure 5 gives the values for the present value of the TSES under the *high dynamic case* where electricity rates are seen to rise 10 percent per year. In all but one case the system fails to recover its capital costs in energy cost savings. In one case, with an assumed collector cost of 6 dollars and a discount rate of 6 percent, the system shows a positive present value.

Figure 3

Present Value of Total Energy System with Stagnant Electricity Prices (parentheses indicate negative values)

Collector Cost	$6/ft²	$10/ft²
Rate of Discount		
6%	($69,478)	(149,478)
9%	(82,302)	(162,302)
12%	(95,124)	(175,124)

Figure 4

Present Value of the Total Energy System at 5% Annual Increase in Electricity Prices (Low Dynamic Case)
(parentheses indicate negative values)

Collector Cost	16/ft²	$10/ft²
Rate of Discount		
6%	($32,342)	(112,342)
9%	(58,632)	(138,632)
12%	(76,621)	(156,621)

Figure 5

Present Value of the Total Energy System at a 10% Annual Increase in Electricity Prices (High Dynamic Case)
(parentheses indicate negative values)

Collector Costs	$6/ft²	$10/ft²
Rate of Discount		
6%	$35,586	(46,414)
9%	(6,116)	(86,116)
12%	(45,817)	(125,817)

Conclusions

The calculations presented show that with present technology and with reasonably expected growth in the cost of electricity, a TSES on the scale presented here is not economical. This is true even when the cost of the collector units are reduced by almost half from the present cost, and even at rates of discount substantially below those commonly used by private investors. Only in one case examined, where all inputs are assumed most favorable toward the TSES, does the system show a slight positive net present value.

It should be emphasised that these estimates compare the TSES to an all electric home, which is more expensive to operate than a fuel oil heated home. Had the comparison been made with a fuel oil heated home, the TSES would have fared even more poorly.

Predicted skyrocketing costs of energy produced by conventional means may change the competitive position of solar electrical energy production, as may advances in solar energy technology. For today, however, solar electrical prōduction on an intermediate scale is uneconomical in North Carolina.

Footnotes

1. Hilbert Anderson, Solar Sea Power, Inc., 1975.
2. Aden B. Meinel et al., *Solar Application Study: Status, Economics, and Priorities,* Recommendations for White House Energy Task Force, unpublished 1973. These collectors are available through numerous contractors in the state.
3. Gray Culbreth, University of North Carolina Service Plants, Chapel Hill, 1976.
4. The generator is available through Solar Sea Power, Inc. Estimates for the ancillary equipment come from R. B. Pope and W. P. Schimmel, *The Solar Community and the Cascaded Energy Concept Applied to a Single Home and a Small Subdivision,* Sandia Laboratories, Albuqerque, 1973.
5. Culbreth, supra note 3.
6. Pope and Schimmel, p. 8.
7. Pope and Schimmel, supra note 4.
8. Freeman, S. David et. al., *A Time to Choose, America's Energy Future, The Ford Foundation Energy Policy Project,* Ballinger, Cambridge, Mass., 1974, p. 326.
9. Culbreth, supra note 3.
10. Charles Carney, *Climates of the States, North Carolina,* Agricultural Experiment Station, North Carolina State University, Raleigh, p. 12.
11. Duke Power Company, *Schedule RA (NC): Residential Service, All Electric,* North Carolina Utilities Commission Docket No. E-7, Sub 197, Feb. 1976.