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Solar Central Receiver Systems Comparative Economics

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COMPARATIVE ECONOMICS

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SOLAR CENTRAL RECEIVER SYSTEMS COMPARATIVE ECONOMICS

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Several major conceptual design studies of solar central receiver systems and components have been completed in the last year. The results of these studies are used to compare the projected cost of electric power generation using central receiver systems with that of more conventional power generation.

Cost estimates are discussed throughout much of this paper. Table I is an overview which summarizes a far more detailed estimate. In particular, this shows the cost estimate for a molten salt central receiver system. Heat is collected at the receiver in a molten salt. This molten salt either is used to generate steam (to be fed to the turbine) or is sent to storage for later use. The example is for a 100 MW_e 39% annual capacity factor plant. The cost estimate for such a system is that the plant will cost approximately \$1270 per kilowatt of nameplate capacity. (This is a cost estimate for a so-called *n*th plant as opposed to the first commercial plant). As shown in Figure 1, the system cost is broken down into a number of accounts. For example, there is an account for land, which is assumed to cost approximately \$700 an acre to buy and approximately \$3300 per acre for site preparation or 2.7% of the plant cost. "Structures" here are the standard kind of building associated with power plants-administration buildings and so on. Turbine plant equipment is the turbine generator, condensor, water treatment, etc. Electric plant equipment is the switch yard, and wiring. Collector equipment is the installed heliostat field including field wiring. The receiver and thermal storage accounts are self explanatory. The final account concludes all the distributables, indirects and contingency. Distributables and indirects are, for example, architect-engineer services, spare parts and so on. A ten percent contingency was assumed.

Figure 1 shows levelized busbar energy cost as a function of annual capacity factor indicating the fraction of the cost due to each of the sub-systems. Depending on capacity factor, the cost of energy is estimated to be between 70 and 90 mills per kilowatt hour for capacity factors between 25 and 75%. Figure 1 assumes Barstow insolation which is typical of many southwestern locations. A 25% capacity factor plant has very little energy storage-only enough to buffer the turbine from solar transients. A 75% capacity factory plant would have approximately 13 hours of storage, and will

TABLE I
 INSTALLED CAPITAL COST
 MOLTEN SALT/RANKINE SYSTEM
 (1979 \$)

\$1270/kW _e 39% Annual Capacity Factor Plant		
<u>Account</u>		<u>%</u>
4100 Site, Structures & Misc. Equipment		7.5
4110 Site and Preparation	2.7	
4120 Structures, Etc.	4.8	
4200 Turbine Plant Equipment		12.0
4300 Electric Plant Equipment		2.1
4400 Collector Equipment		39.3
4500 Receiver Equipment		12.3
4510 Receiver Unit	4.2	
4520 Riser, Downcomer, Horizontal Piping	2.4	
4530 Working Media	0.3	
4540 Tower	3.9	
4560 Steam Generator	1.5	
4600 Thermal Storage Equipment		3.3
4610 Media Containment Equipment	1.2	
4620 Media Circulation Equipment	0.2	
4630 Foundation	0.1	
4680 Media	1.8	
4800 Distributables, Indirects, Contingency		<u>23.4</u>
		100

Figure 1. Levelized Busbar Energy Cost

operate around the clock during the summer and approximately 18-19 hours a day during the winter. As can be seen, approximately fifteen percent of the cost of electricity is due to operations and maintenance; about half of that is associated with the heliostat field. Heliostat O&M includes normal kinds of repair and preventive maintenance and also washing of the heliostats several times a year to remove dust. The rest of the plant is assumed to have O&M costs of approximately 1.5% of the capital cost per year escalating at 8% per year throughout the life the plant. Heliostats are seen to be between 30 and 40% of the cost of electricity using the estimated installed capital cost for mass produced heliostats, \$70 per square meter in 1979 dollars. Receiver, tower and storage are a small percentage of the costs of the plant; at higher capacity factors they account for approximately 15% of the cost of energy. Balance of plant includes electric power generation system, switch yard, steam generator, and some other things such as land. Finally, there are the distributables, indirects and contingency. Busbar energy cost decreases as a function of capacity factor for capacity factors up to approximately seventy five percent. This is primarily due to the low "cost" of energy storage. In this context "cost" refers to both dollars and energy availability. Molten salt storage systems, for example, have been estimated to cost less than \$15/kW_{eh} of capacity. Such systems which use the same fluid in storage as in the receiver eliminate availability losses due to intermediate heat exchangers.

For capacity factors above approximately 75%, the cost of energy will begin to increase which is due partly to the length of day change over the year. For example, a plant which would run 100% of the time would require many hours of storage - more than 15 hours to get only through the longest winter night (and even then would have no storm protection). A significant fraction of that storage capacity (and the mirrors to charge it) would be idle

during the long days of the summer and, therefore, the busbar energy cost would be greater. Thus it appears that a plant with a capacity factor of around 75% will provide the lowest busbar energy cost. Whether or not a utility would want to install a solar plant with such a high capacity factor would depend on the other plants which could be or are already installed in the utility network.

Figure 2 compares the estimated levelized busbar energy cost from a central receiver (70 to 90 mills per kilowatt hour as in Figure 4) with the levelized busbar energy cost for a new coal fired Rankine cycle plant. The capital cost of this coal plant was assumed to be \$780 per kilowatt per the Electric Power Research Institute (EPRI) Technical Assessment Guide. The plant will meet 1985 EPA emission standards and has full flue gas desulfurization capabilities. The coal plant is assumed to have a heat rate of 10,000 BTU's per kilowatt hour. The coal which it uses is assumed to have a 1979 price of 65¢ per million BTU's-the ton average cost of coal delivered in the Southwest U.S. in December of 1978. It is seen that at the lower capacity factors (in what might be called the intermediate capacity factor range) the central receiver will compete very well; while in the higher capacity factor regions, (what might be called base load capacity factors) the central receiver appears to provide power at about 30% more than the coal fired plant. There are two things to note from this curve. First, is that if a utility desires to build a new intermediate load plant, that is a plant with a capacity factor in the range 25-40%, today it has little choice other than to build a new coal plant because the National Energy Act prohibits any new oil fired plant which has a capacity factor higher than 17%. Central receivers appear to compete very well with new coal plants in intermediate capacity factors.

Figure 2. Levelized Busbar Electric Cost

The second and most important fact about Figure 2 is not so much that there is a region in which central receivers appear to compete and a region in which they do not, but that the central receiver costs can be placed on the same scale as the coal plant costs. This may be surprising to many people and indeed there are many assumptions which go into such curves; the critical ones being, of course, the capital cost associated with each of the plants and the fuel cost associated with the coal plant. Believability of the costs of the central receiver plant will be addressed later in this paper. As has been mentioned, the capital cost of the coal plant was taken from the EPRI Technical Assessment Guide. The ton average cost of coal used in deriving Figure 2 came from the issues of Electrical Week listing late 1978 fuel prices. Data from the Energy Information Administration indicates that over the past 8 years the cost of coal has escalated at an annual average of at least 6% above general inflation. The curve in Figure 2 for the coal plant assumes that this average rate of escalation for coal will continue for another 6 years - that is, through 1985. From 1985 to 1995 the cost of coal is assumed to decline linearly to general inflation by the year 1995 and then to escalate only at general inflation for the remainder of the life of the plant. This rather complicated assumption on the escalation rate of coal is equivalent to assuming that the cost of coal escalates at approximately 2% from now until the end of the life of the plant (assumed to be the year 2020). Other critical parameters which have been assumed in the calculations are that general inflation and capital escalation are the same and equal to 8%. The effective cost of money (discount rate) is assumed to be 10%. The fixed charge rate is 17 3/4%. O&M costs for the two plants are assumed to escalate at 8% per year.

The curves in Figure 2 depend on many assumptions. Figure 3 shows some of the sensitivities. A 50% capacity factor for the two plants was picked to show sensitivities to the initial cost of coal and the delta fuel escalation, that is the escalation of the cost of the coal above general inflation. The ratio of the levelized busbar energy cost of the solar plant to the levelized busbar energy cost of the coal plant is plotted. Three different curves are shown for the initial costs of coal - \$0.65, \$0.35 and \$1.50 per million BTU's-reflecting the real range of delivered coal prices in the southwest in late 1978. 65¢ per million BTU's was the ton average cost of coal in December of 1978 and was used in Figure 2. The arrow on Figure 3 points to the ratio as obtained from Figure 2 - that is, coal costs assumed to be \$0.65 per million BTU's with approximately a 2% delta fuel escalation above inflation. As indicated, the busbar energy cost of solar would be about 10% more than for coal with those assumptions.

As mentioned in the southwest at the end of 1978, delivered coal prices ranged from 35¢ per million BTU to \$1.50 per million BTU. The curve shows that for solar plants to be competitive with \$1.50 per million BTU coal, no escalation for the fuel costs above inflation is required for the solar plants to be competitive. For the ton average cost of coal about a 3% escalation above inflation is required for the solar plant to be economically competitive in the strict sense with coal. It should be pointed out that data recently obtained by the Energy Systems Group of Rockwell International, show that many new long-term coal contracts average \$1.50 per million BTU's.

Figure 3. Solar to Coal Busbar Energy Cost Ratio