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ECONOMIC ASSESSMENT OF CENTRAL RECEIVER SOLAR-THERMAL PLANTS ON THE ENEL SYSTEM

Italy/United States Joint Solar Energy Project "C"

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ABSTRACT

This study was performed to estimate the value and potential economic impact of advanced water/steam stand-alone central receiver solar-thermal plants, in the role of electric generating stations, on the ENEL system in Italy.

The analysis was based on detailed modeling of an advanced water/steam stand-alone plant on the ENEL system. Economic and performance sensitivity to collector area and thermal storage were investigated.

The study indicates that for the projected reference heliostat costs ($\$300/m^2$) the advanced water/steam stand-alone solar plants does not appear to be economically justifiable on the ENEL system in the 1990 time frame.

ACKNOWLEDGMENT

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The Westinghouse study team consisted of: Mr. John T. Day, Study Manager and economics; and Mr. David W. Doar, solar plant and utility system modeling, both from Westinghouse Advanced Systems Technology Division.

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Section 1
INTRODUCTION AND SUMMARY

1.1 Introduction/Background

Annex III-C, "Utility Applications Study of Solar Central Receiver Technology", is one of several Italy/United States Joint Solar Energy Projects included in Annex III of the Memorandum of Understanding between the Government of the United States and the Government of the Italian Republic concerning energy cooperation. The objectives of Annex III-C, referred to as Project "C", which was signed on June 4, 1980, were to assess the cost-effectiveness, both now and in the future, of a large solar central receiver plant in the range of 10 to 100 MWe capacity as it would impact the Italian electric grid; and to gain an understanding of how U.S. developed central receiver technology might be used in the Italian utility grid. To accomplish these objectives, a one-year collaborative project was undertaken by the Department of Energy (DOE) of the United States of America by the Ministry of Industry, Commerce, and Handicraft of Italy (MOI), and by the Ente Nazionale per L'Energia Elettrica of Italy (ENEL). At the request of the Solar Energy Research Institute and with the approval of DOE, Sandia National Laboratories, Livermore is cooperating with ENEL to meet the objectives of Project "C".

1.2 Study Objective

With the concurrence of ENEL, Sandia contracted the Advanced Systems Technology Division of Westinghouse Electric Corporation's Power Systems Company to perform the economic assessment. The study was performed with the assistance of ENEL and Sandia National Laboratories, Livermore. Solar plant performance data was supplied by Sandia. ENEL supplied generation, load, and economic data for their system as well as solar plant cost data. Westinghouse determined solar plant value and the impact on ENEL's system through detailed modeling of the solar plant.

The purpose of the study was to assess the economic impact of a large central receiver solar-thermal plant installed on the Italian utility grid in 1990. The methodology and techniques used to perform the analysis were developed by Westinghouse in EPRI study RP 648[1].

The solar plant examined in this analysis was an advanced water/steam stand-alone plant with thermal storage capabilities.

1.3 Study Assumptions

The results of any study are no better than the assumptions and analytical methods used. However, when dealing with advanced central receiver solar plants of the future and their potential impacts on the ENEL system, it is necessary to make some very specific estimates of the future ENEL system and economic conditions. Through this process one hopes to capture some feel for the potential of the solar plants on the ENEL system, and through sensitivity analysis define the importance of relevant solar plant parameters such as collector area and storage size.

The performance data for the advanced water/steam stand-alone solar plant was provided to Westinghouse by Sandia National Laboratories, Livermore. The performance characteristics for the advanced water/steam stand-alone solar plant were determined to be similar to the performance characteristics for any solar plants planned for construction in Italy. Costs for the solar plant were provided by ENEL and reflect the wide range of estimates for future heliostat costs.

1.4 General Conclusions

The following conclusions were derived from a limited investigation of the potential impact of an advanced water/steam stand-alone central receiver solar-thermal electric plant on the ENEL system. A more detailed explanation for each of these conclusions is provided in Section 5.

- Based on the performance and economics used, the microeconomic value does not quite equal the estimated cost ($C/V \approx 1.35$ with heliostat at $\$300/m^2$).

- Some thermal storage (approximately three hours) appears to be justified.

- The design point collector area($695{,}000 m^2$) seems adequate.

- The principal value of the solar-thermal plant is its ability to displace oil consumption on the ENEL system. This opportunity may disappear if major adjustments are made to the generating mix.

- The solar plant cannot compete with a coal plant based on the assumptions used.

Section 2
METHODOLOGY

2.1 General Methodology

The basic methodology used in this study involved the detailed modeling of the ENEL system with and without a solar plant. The difference in utility operating costs and capacity credit established the value of the solar plant. The results given in this report were obtained through detailed modeling of the solar plant and the ENEL system for a year, and projecting this operation throughout the 30-year life expectancy of the solar plant. It was assumed that the solar plant would begin operation on January 1, 1990. This analysis will be referred to as "static analysis."

The economics applied were based upon life cycle revenue requirements calculations. From the revenue requirements estimates over the solar plant life expectancy, the following were calculated:

- Solar Plant Cost
- Solar Plant Value
- Net Solar Plant Cost
- Cost/Value Ratio

Certain general guidelines were used in establishing the methods described in this report. They were as follows:

- To utilize conventional utility planning methods and tools as much as possible. This serves to enhance the ease of interpretation of results by utility planners and others familiar with these techniques. It provides confidence in the results through the use of established, tested methods, and it allows the use of existing tools or computer programs.

- Utilize existing solar plant static analysis methodology and solar plant model which was developed in EPRI RP 648[1]. In other words, use the tools, procedures and data established under that or other previous solar studies wherever practical.

Two principal analytical tools were used in this study:

- Simulation of the solar plant operation with the ENEL system, using integrated economic dispatch
- Classical loss-of-load probability calculations to achieve a desired level of utility system reliability

2.2 Static Analysis

The solar plant static analysis was used to obtain the results shown in this report. It was used to estimate the value of five advanced water/steam solar-thermal plant configurations through the detailed modeling of their operation on the ENEL system. The five configurations reflect variations in the major plant parameters such as collector area and storage capacity. The economic impact of these variations was obtained from the static analysis.

A detailed methodology was developed by Westinghouse to assess a solar plant's value under EPRI RP 648[1]. This methodology consists of the coordinated use of several computer models as shown in Figure 2-1. The core models are the Solar Plant Model, the Westinghouse Daily Production Cost Program and the Westinghouse Generation Planning Capacity Model.

The general framework of the specific methods employed conforms to the following sequence of analysis:

- Develop hourly load projection for the 1990 ENEL system
- Simulate the operation of conventional units on the PG&E system for 1990, using detailed production costing model, producing incremental operating cost tables
- Use incremental cost tables, hourly system loads, and hourly insolation to dispatch the solar plant, subtracting solar plant electrical output from the load
- Use hourly load reduction to calculate solar plant capacity credit and conventional capacity displacement

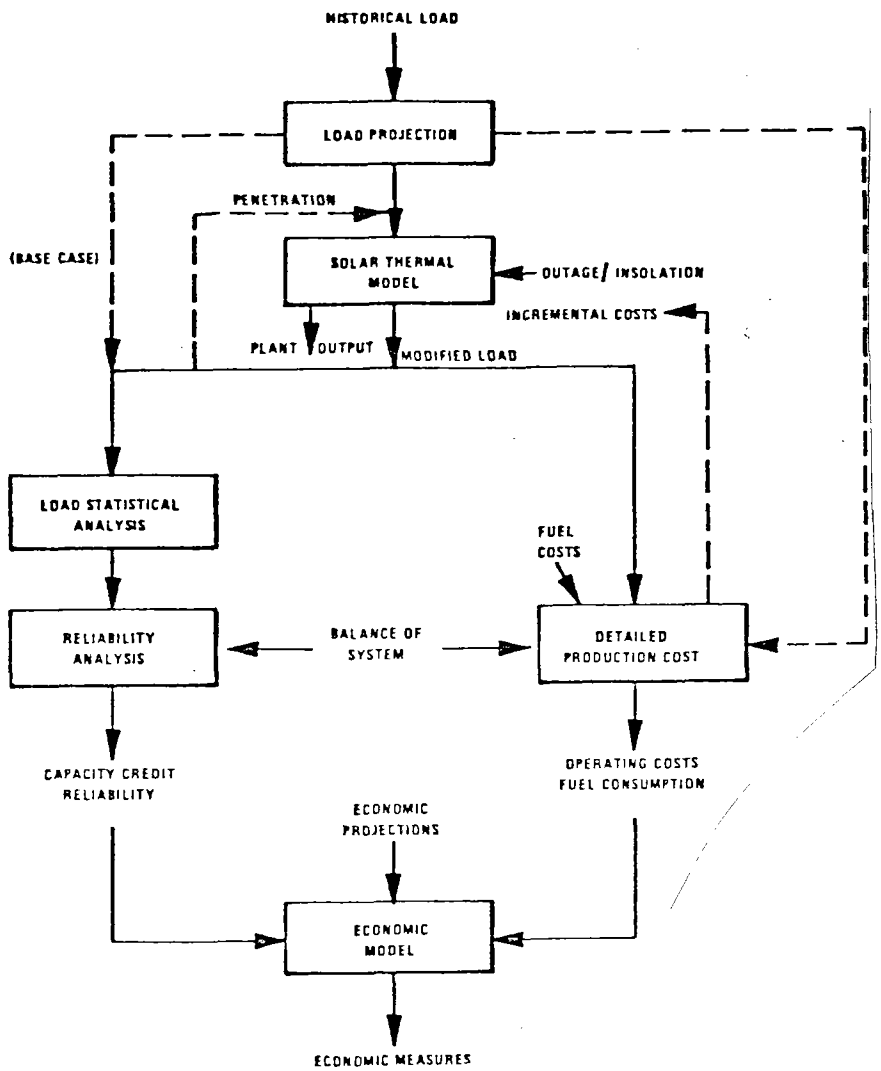

Figure 2-1. Solar-Thermal Plant Static Analysis Sequence

- Resimulate operation of conventional generating units with reduced ENEL system load
- Use economic procedures to calculate resulting solar plant value for solar plant life expectancy

This framework allows the evaluation of a variety of solar plant concepts and configurations in different operating and insolation environments. It also provides a vehicle for assessing the value of a single solar plant independent of its cost projection. From this process not only is the operational economic impact of the solar plant obtained, but also the effects upon fuel consumption and solar plant and conventional plant operational requirements.

This is a general procedure from which an estimate of the lifetime value of a solar plant to the ENEL system may be established. The value is established from the differences in the balance-of-system cost, with and without the presence of the solar plant. Values are established for the following factors:

- Operating credit
  --Fuel costs
  --Other displaced operating and maintenance costs
- Capacity credit
  --Capacity displacement (reduction in installed capacity)

Using the procedures outlined above, the value of the advanced water/steam stand-alone solar plant to the ENEL system was determined. Analysis was performed in this manner to evaluate variations in the solar plant collector area and storage capacity.

In addition, the computer simulations provided base parameters on which an analysis of the sensitivity of the results to the heliostat costs was performed. Operational information was produced on both the solar plant performance and the balance of the ENEL system in the presence of a solar plant.

Section 3
STUDY ASSUMPTIONS

3.1 ENEL System Assumptions

3.1.1 General

In order to determine the value of a solar plant on the ENEL system, it was necessary to specify the ENEL system in detail. Detailed modeling of the ENEL system was essential to the methodology of determining the value of the solar plant collector area and thermal storage capacity variations. The ENEL generating mix, conventional generating unit characteristics, hourly loads, and insolation characteristics were specified in addition to the economic and solar plant performance assumptions.

3.1.2 Load Characteristics

The projected hourly load data for 1990 was supplied by ENEL. The peak load is projected to be 48,000 MW and will occur in the month of December. Two typical daily load curves are shown in Figure 3-1. As can be seen in Figure 3-1, ENEL is a winter peaking utility.

3.1.3 Generation Mix

The generation mix for the 1990 ENEL system is shown in Table 3-1. The total system capacity is projected to be 59,600 MW and will be composed of 134 thermal units, 20 pumped storage units, and 72 hydro units. The total energy produced by these units for one year of operation is approximately 260,000 GW hours.

The characteristics for the units represented in the study are shown in Table 3-2.

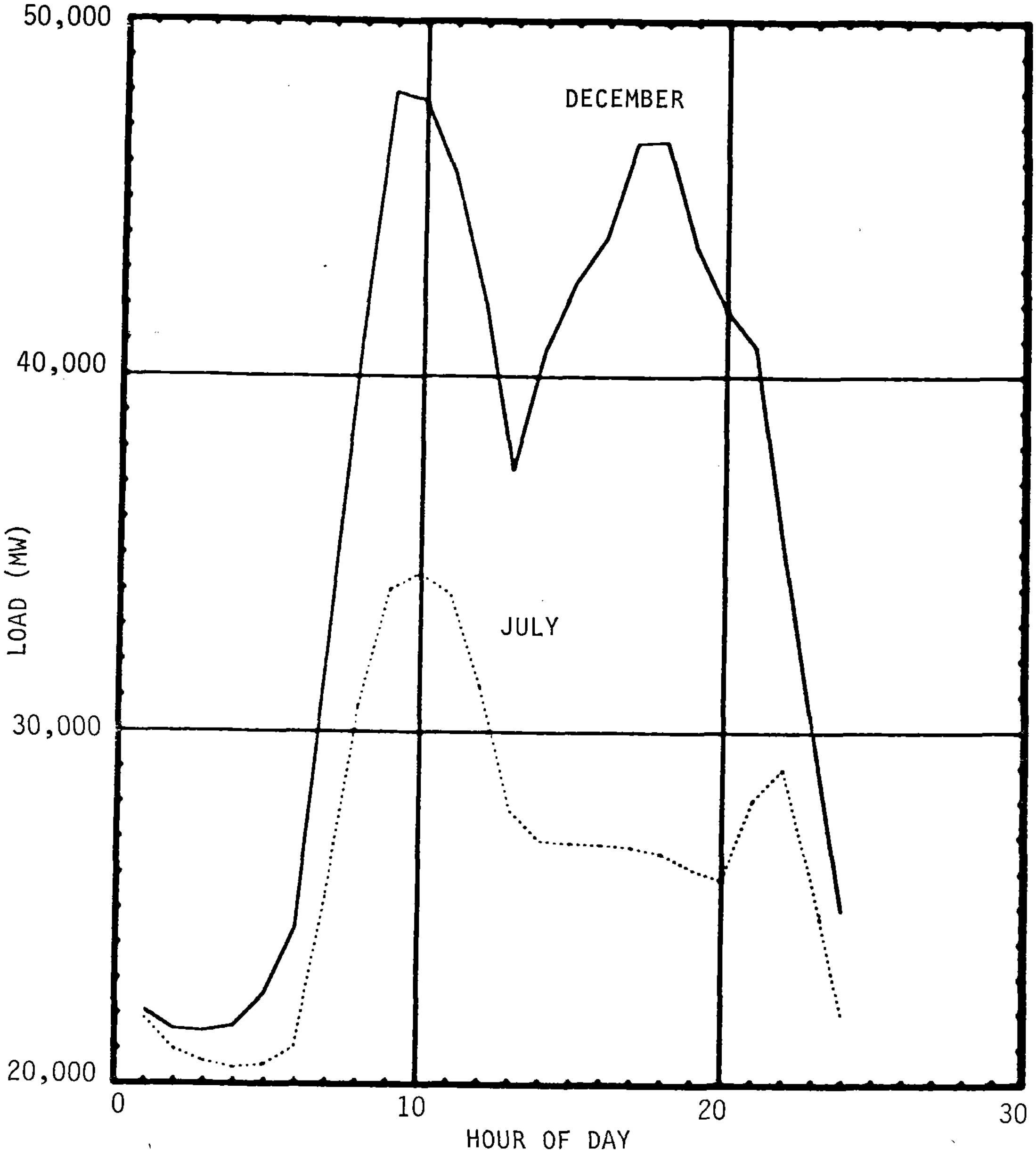

Figure 3-1. Typical 1990 Daily Load Curves (ENEL)

Table 3-1

ENEL 1990 GENERATING MIX

Fuel Type	Percent of Total Capacity
Hydro	15.1
Nuclear	16.8
Coal	25.1
Oil	31.2
Gas	3.4
Pumped Storage	8.4

Table 3-2
GENERATING UNIT CHARACTERISTICS FOR 1990 ENEL SYSTEM
(FUEL COST IN 1980 DOLLARS)

				Unavailability Data	
Plant Type	Unit Capacity MW	Number on System	1990 Fuel Cost $/MBtu	Scheduled Maintenance Wks/yr.	Forced Outage %/yr.
Oil	150	24	5.99	4	10.0
Oil	300	30	5.99	6	14.0
Oil	600	10	5.99	7	14.0
Coal	150	4	2.19	4	10.0
Coal	300	24	2.19	6	14.0
Coal	600	12	2.19	7	16.0
Nuclear	1000	10	.88	7	17.0
Gas Turbine	100	20	8.68	2	5.0
Pumped Storage	250	20	-	6	10.0
Run of River	125	8	-	0	5.0
Pond	125	40	-	0	5.0
Lake	125	24	-	0	5.0

3.2 Insolation Assumptions

3.2.1 Adrano-Fort Worth Comparison

The insolation characteristics are important in determining the value of a solar plant located on any utility system.

Similar studies (2,3) used detailed insolation data which reflected a typical meteorological year for the site of interest. A typical meteorological year is a hypothetical representative year of weather data. In the United States typical meteorological year data has been constructed by the National Climatic Center from SOLMET weather data for selected sites by using specific months in various years.

ENEL supplied raw insolation and weather data for Adrano, Sicily, Italy, which is the site of the Eurelios 1 MWe experimental solar-thermal plant. Difficulty arose in converting this information into a complete year's data in the SOLMET format. The available United States SOLMET typical meteorological year (TMY) data was screened to find a site with direct normal insolation characteristics similar to Adrano, and with approximately the same latitude. Fort Worth, Texas TMY data was selected as being most representative. The monthly average daily insolation for the sites and the totals for the year are shown in Table 3-3.

Table 3-3

AVERAGE DAILY AND YEARLY TOTAL INSOLATION FOR
ADRANO, ITALY AND FORT WORTH, TEXAS
(KW/m^2)

Month	Adrano	Fort Worth
January	2.50	3.38
February	2.94	3.86
March	3.75	4.93
April	4.20	4.20
May	4.03	4.63
June	5.92	5.97
July	6.46	6.39
August	5.47	6.14
September	4.52	5.45
October	3.25	4.99
November	2.94	4.31
December	2.83	3.58
TOTAL FOR YEAR	1487	1761

3.3 Economic Assumptions

3.3.1 General

The economic principles applied in the methodology used for the economic impact analysis of a solar-thermal power plant on the ENEL system were based upon revenue requirements analysis. This required the application of escalation rates, present worth discounting, and capital carrying charge rates. ENEL chose to have the analysis done in constant 1980 dollars, thus all escalations are relative to inflation. The discount rate is zero as was specified by ENEL. Assumptions for solar and conventional plant capital cost, operation and maintenance costs, fuel costs, and the escalation of these costs for 30 years into the future were also necessary assumptions. All costs are given in 1980 dollars except where noted otherwise.

3.3.2 ENEL Economic Scenario

The economic data was supplied by ENEL and is representative of its data for economic analysis. ENEL removes the effects of inflation in its economic analysis. This means that all escalation rates and capital carrying charge rates are specified relative to inflation. The present worth discount rate was also assumed to be zero. The ENEL economic assumptions are shown in Table 3-4.

Table 3-4
ENEL ECONOMIC ASSUMPTIONS (1980 $)

Present Worth Discount Rate	0%
Fixed Charge Rate (%) (G-T, Pumped Storage, Coal, Nuclear)	7/7/7/7
Fuel Cost ($/MBTU, 1990, in 1980 $) (Gas, Oil, Coal, Nuclear)	8.69/5.99/2.19/.88
Fuel Escalation Rate (%) (Gas, Oil, Coal, Nuclear)	2/2/0/0
Capital Cost ($/KWe, 1980 $) (G-T, Pumped Storage, Coal, Nuclear)*	250/400/550/950
Capital Escalation Rate	0%
O+M Escalation Rate	0%
Inflation Rate	15%

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*100 MW Gas Turbine
250 MW Pumped Storage
600 MW Coal
1000 MW Nuclear

3.4 Solar Plant Characteristics

3.4.1 General

The basic solar plant concept used in this study, was the advanced water/steam stand-alone plant with a thermal storage system to supplement direct solar energy generation.

3.4.2 Solar Plant Performance

Table 3-5 summarizes the performance characteristics of the advanced water/steam stand-alone plant analyzed in this study. The unit is rated at 100MWe.

The baseline total collector area was 695,000 m^2, representing a solar multiple of 1.5, based on 950 watts/m^2. The overall receiver efficiency, taking into account absorptivity, radiation and convention losses, was 82.8%.

Thermal storage was capable of operating the turbine generator at a level of 70 MWe for three hours. The maximum output of the turbine generator was limited to 70 MWe when operated from storage due to the thermodynamic characteristics of the storage steam. The thermal heat loss rate was 0.12 %/hour.

The operating limits of the turbine generator were 30 MWe minimum and 100 MWe maximum when operated directly from the receiver and 70 MWe maximum through storage. The maximum net efficiency was 38.4% direct receiver and 33.2% through storage. The daily solar system startup energy was 15 MWh(th).

The average annual efficiency train for the advanced water/steam stand-alone solar plant is shown in Figure 3-2. This efficiency train was obtained from the solar model output for the baseline configuration described in this section (3.4.2). The overall efficiency was 14.4%.

The distinguishing feature of the advanced water/steam stand-alone solar plant schematic, shown in Figure 3-3 is the solar reheat system. A fraction of the heliostat field is focused on an additional receiver unit which supplies the high-temperature steam in the reheat cycle. Figure 3-3 also depicts a parallel storage system which when drawn upon ultimately directs its steam to the intermediate pressure turbine. The maximum output of the unit is then restricted to 70 MWe.

Table 3-5

ADVANCED WATER/STEAM STAND-ALONE SOLAR PLANT
PERFORMANCE DATA

General

- Size: 100 MWe
- Solar Multiple: 1.5 (950 watts/m^2)
- Simulation Period; 1 Year
- Simulation Stepsize: 1 Hour

Collector

- Total Collector Area: 695,000 m^2
- Annual Field Efficiency (Shading/Blocking/Cosing Losses): 77%
- Primary Reflectivity: 90%
- Atmospheric Attenuation Factor: 93%
- Wind Defocus Speed: 15.6 m/sec

Receiver

- Absorptivity: 92%
- Efficiency: 90%

Storage

- Usable Energy: 3 Hours at 70 MWe Turbine Generator Output
- I/O Efficiency: 100%
- Heat Loss Rate: 0.12 %/Hour

Turbine Generator

- Net Efficiency (Including Auxiliaries):
  38.4% Maximum Direct Receiver;
  33.2% Maximum Through Storage
- Operation Limits:
  100 MWe Maximum, 30 MWe Minimum Direct Receiver;
  70 MWe Maximum, 30 MWe minimum - Storage
- Efficiency Correction: Wet Cooling Part-Load Efficiency Correction

Miscellaneous

- Solar System Startup Energy: 15 MWh(th)
- Transport Line Efficiency: 99.3%
- Forced Outage (Equipment): 15%
- Scheduled Outage: 5 Weeks per Year - Outage Weeks: 31-35

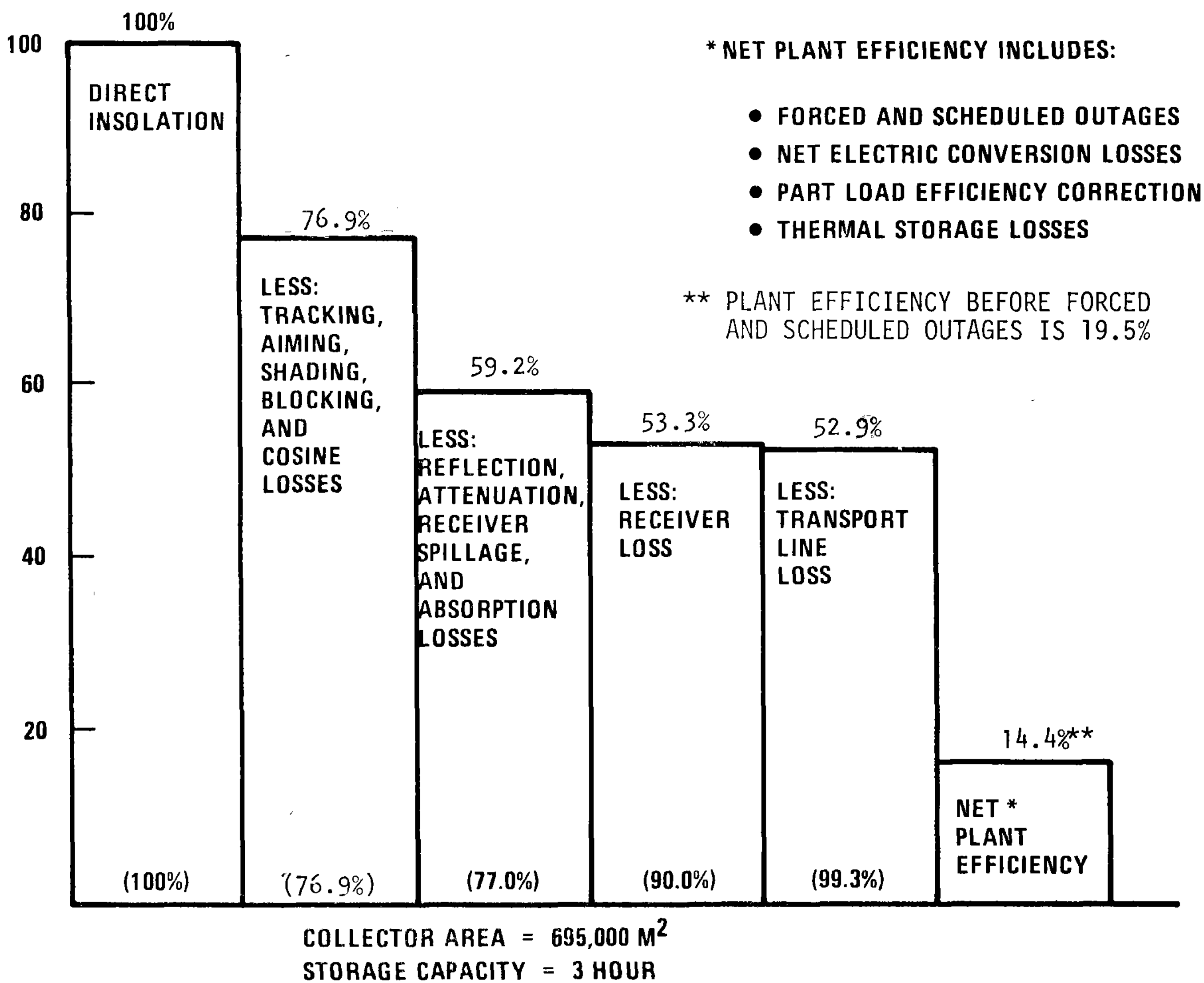

Figure 3-2. Advanced Water/Steam Stand-Alone Annual Average Efficiency Train

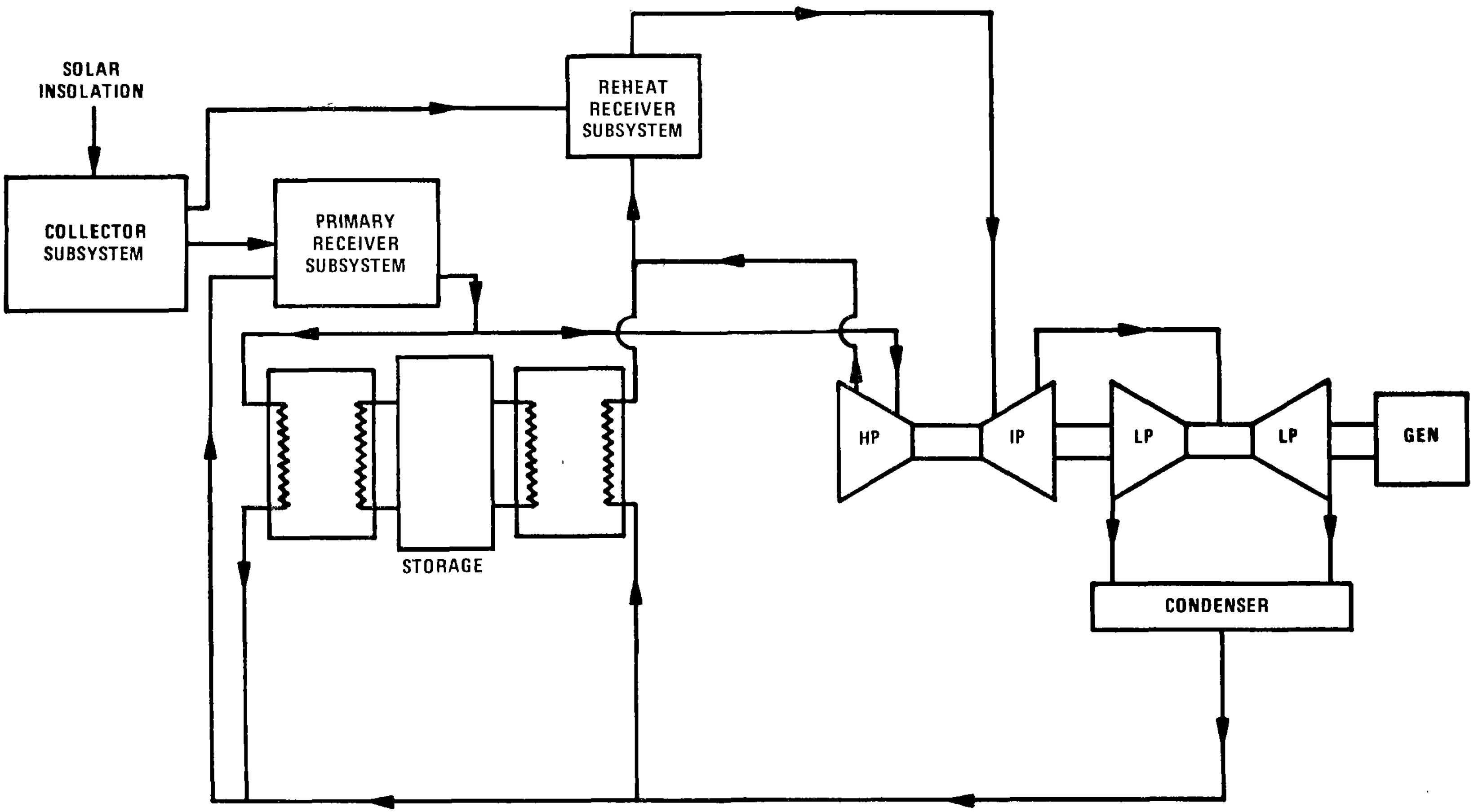

Figure 3-3. Advanced Water/Steam Stand-Alone Plant Schematic

The solar plant characteristics were based on data supplied by Sandia, National Laboratories, Livermore and are representative of the advanced central receiver system design studies. These characteristics are assumed to reasonable approximations of the characteristics of any future Italian solar plants.

The operation of the solar plant was simulated for a period of one year. This one-year period was divided into one-hour increments for the simulation of the solar plant operation.

3.4.3 Solar Plant Operation

The operating strategy used in the solar plant model was an economic dispatch routine designed to take the best advantage of the solar plant's characteristics including storage capabilities. The dispatch was oriented to displace the operation of those units on the balance of the utility system which had the highest incremental operating costs. Solar plant subsystem capacities and efficiencies were recognized.

3.4.4 Solar Plant Availability

The solar plant investigated in this study had an equipment forced outage rate of 15% and a scheduled maintenance period of five contiguous weeks per year. The scheduled maintenance was taken during weeks 31, 32, 33, 34 and 35. These weeks were picked because the system peak loads were low and the system reliability was high. From a system reliability viewpoint, the solar plant would have a minimal impact on the system if it were on maintenance during these weeks.

3.4.5 Solar Plant Cost

By utilizing the methodology described in Section 2 of this report, the value of the solar-thermal plant to the ENEL system was determined independent of its projected costs. This value, influenced by ENEL system characteristics as well as the solar plant design, was of principal interest. However, in order to determine solar's net impact, some estimate of plant cost had to be made.

The assumed costs for the solar plant are shown in Table 3-6. These costs were supplied by ENEL, except for the cost of six hours of storage. This cost was determined by using the ENEL cost for three hours storage and the ratio of Sandia's cost for 3 hour and 6 hour storage used in Reference 2. The solar plant costs were given in 1979 dollars but were used as 1980 dollars. A ground coverage fraction of 33% was used to determine the amount of land necessary for the heliostat fields.

The total cost of the solar plant is very sensitive to the cost of the heliostats. Three different heliostat costs were used in this study. Table 3-7 shows a breakdown of the costs for the baseline solar plant configuration (695,000 m^2, 3 hour storage).

O+M costs for the solar plant were assumed to be 1.5% of the total first year installed cpaital cost. A 30-year life was assumed for the solar plant.

Table 3-6
ENEL SOLAR PLANT COST ASSUMPTIONS (1980 DOLLARS)

Heliostats	$100/M^2$	$300/M^2$	$500/M^2$
Receiver/Tower		20.0M	
EPG Systems		40.0M	
Storage		0 Hours - 0.0	
		3 Hours - 30.0M	
		6 Hours - 56.1M*	
Land		$10.0/(M^2 of land)	
Administrative		4.0M	
Master Control		3.0M	

*Cost estimated from Sandia cost of 6 hours of storage

Table 3-7
ENEL SOLAR PLANT COST ASSUMPTIONS
3 HOURS STORAGE - 695,000 M^2 (1980 M$)

	Low Heliostat Costs	Nominal Heliostat Costs	High Heliostat Costs
Heliostats	69.5	208.5	347.5
Receiver/Tower	20.0	20.0	20.0
EPG Systems	40.0	40.0	40.0
Storage	30.0	30.0	30.0
Land	21.1	21.1	21.1
Administrative	4.0	4.0	4.0
Master Control	3.0	3.0	3.0
TOTAL	187.6	326.6	465.6

Section 4
STUDY RESULTS

4.1 General

The results of this study are based upon the data assumptions and the analytical methods used. A great many assumptions were required to make an economic evaluation of the operation of a solar plant on the ENEL system. These include assumptions as to solar plant costs and performance, fuel costs and real escalation rates, and other economic conditions. These assumptions are discussed in Section 3 of this report.

4.1.1 Costs and Value

The basis of the economic assessment has been to determine the lifetime costs and value through detailed modeling of the ENEL system with and without the solar plant configuration of interest. The economics are based on the impact upon the life cycle revenue requirements needed to support the solar plant and the balance of the ENEL system. Table 4-1 shows the cost and value breakdowns for a representative case.

The solar plant costs include the capital costs of the heliostat field, receiver tower, electric generation plant, land, administrative areas, master control system, and the capital costs of thermal storage where applicable. O&M costs are the operating and maintenance costs associated with the operation of the solar-thermal plant.

The total value is comprised of two credits or savings. One is the net fuel value saved by the ENEL system. The variable O&M savings were not obtained as all O&M costs for conventional plants were assumed to be fixed. The other is the capacity credit which is the capital value of the solar-thermal plant due to displaced or deferred conventional plant installation on the ENEL system.

Table 4-1

EXAMPLE ADVANCED WATER/STEAM STAND-ALONE CENTRAL RECEIVER SOLAR PLANT COST AND VALUE TABLE (3-Hour Storage, 695,000 m^2 Collector Area)

Solar Plant Cost (LCRR*, 1990, in 1980 M$)	
To Support Capital Investment	685.8
Lifetime Fixed O&M	147.0
Total Lifetime Cost	832.7
Solar Plant Value (LCRR, 1990, in 1980 M$)	
Value of Fuel Displaced	594.3
Variable O&M Saved	0
Conventional Capital Investment	24.4
Total Lifetime Value	618.7
Net Value (LCRR, 1990, in 1980 M$)	-214.0
Cost/Value Ratio	1.35
Solar Plant Cost ($/kW, 1990)	2246.5
Break-even Plant Cost ($/kW, 1990)	3265.6
Annual Energy Output (GWhe/yr)	175.6
Levelized Energy Cost (Mills/kWh)	158.1

*Life Cycle Revenue Requirements

As shown in the table, the majority of the total value of the solar plant is net fuel value.

4.1.2 Capacity Credit

One component of the value determination for solar plants is the capital investment savings due to the displacement or deferral of new conventional generating plant additions. It was assumed for this study that any capacity credit was taken in the form of displaced combustion turbine installations. This strategy maximizes the operating credit and the displacement of premium fossil fuels (oil and natural gas).

Taking any capacity credit at all, beginning in the first year of solar plant operation, may be optimistic. The ENEL system, like many utilities in the United States[2], is currently heavily dependent upon gas and oil. Current economics call for plant additions over the next few years for these utilities to be primarily coal or nuclear fueled plants. If only new baseload plants (coal and nuclear) are in the utility plans during the period of solar plant introduction, then only this new baseload can be deferred to give the solar plant capacity credit. It has been shown (4,5) to be advantageous for systems in need of new baseload capacity to defer taking capacity credit until the system generating mix is better balanced, and to take only operating savings during the initial years of the solar plant's life.

4.1.3. Cost/Value Ratio Perspective

The cost/value parameter is the ratio of lifetime costs and lifetime value. The cost/value ratio which is used as an economic indicator for much of the results should be used with some caution. First, it is a microeconomic quantity, viewed from a strict electric utility economics sense, and does not reflect any major sociological, ecological, or national balance-of-payments benefits. Please see Reference 2.

Caution should be used in treating the cost/value threshold of 1.0 as a absolute determination of microeconomic viability. A cost/value of less than 1.0 can be achieved with an incremental coal plant (1990 installation). If the conventional generation capacity and plant type mix provided by ENEL for the 1990 time frame are used with the ENEL economics (see Table 3-4 and Figure 4-1), incremental (in addition to those planned) coal plants have a cost/value of less than one. Estimates indicate a cost/value of .5 or less for a baseloaded coal plant becoming operational in the 1990 time frame on the ENEL system. If incremental capital is available for solar plants that is not available for conventional fossil plants, then the solar plants can be assessed directly on their cost/value ratio. However, if there is an alternative use for the same capital, then the coal plants appear preferable based on this simple microeconomic analysis.

4.1.4 Other Factors

The solar-thermal energy is the total gigawatt-hours of electricity produced annually by the solar-thermal plant. The capacity factor is a ratio of the actual annual solar plant electric energy output to the plant electric energy output if it is performed at full capacity throughout the year. The capacity credit in megawatts is the estimated conventional capacity displaced by the solar-thermal plant.

4.2 Solar-Thermal Plant Concept

The purpose of this study was to evaluate the impact of the stand-alone solar plant concept on the ENEL system and determine the relative cost/value ratios between variations in collector area and thermal storage. The stand-alone concept used was an advanced water/steam plant with thermal storage.

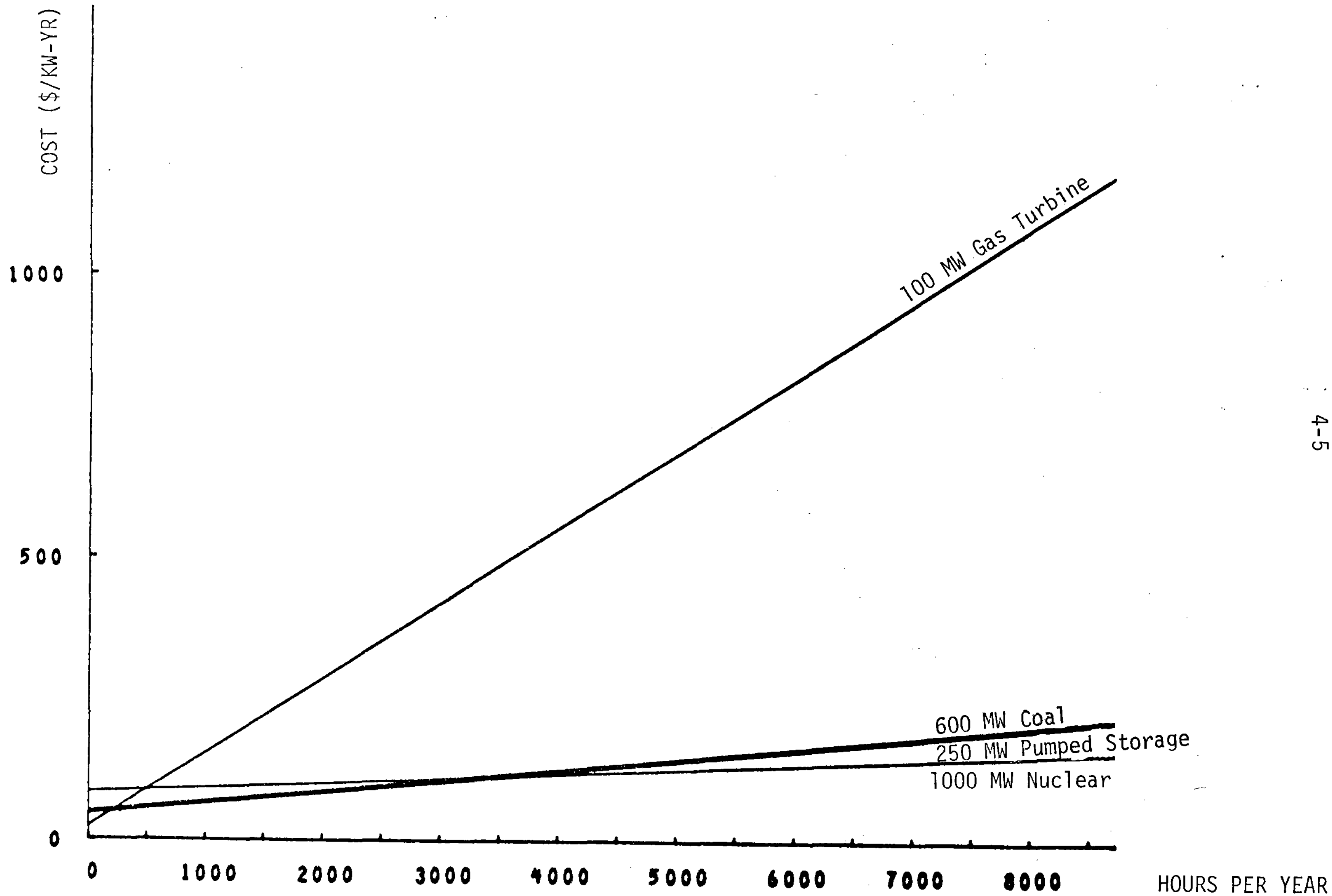

Figure 4-1. Lifetime Levelized Cost Versus Plant Utilization (1990 Installation 1980$)

4.3 Solar Plant Subsystem Sizing Experiments

4.3.1 General

The purpose of the following analyses was to check the sensitivity of the C/V ratios to variations in the amount of thermal storage capacity and the plant's total collector area. Since three different heliostat costs were used, the three corresponding C/V ratios are shown for each case.

4.3.2 Thermal Storage Experiment

The purpose of the experiment was to determine the sensitivity of the C/V ratios to a change in thermal storage. The collector areas used at each of the storage levels were the baseline values obtained from the Economic Assessment of Advanced Central Receiver Solar-Thermal Power Systems(1) for an advanced water/steam stand-alone plant. The results of a limited experiment are shown in Table 4-2.

Table 4-2
THERMAL STORAGE EXPERIMENT

Collector Area ($10^3 m^2$)	Thermal Storage (Hours)	Cost/Value $100/m^2	$300/m^2	$500/m^2
494	0	.78	1.37	1.96
695	3	.77	1.35	1.92
756	6	.84	1.41	1.99

Based on the cost/value ratio criterion, the results of this experiment show that three hours of storage is most attractive for all three heliostat costs.

4.3.3 Collector Area Experiment

The purpose of this experiment was to determine the sensitivity of the C/V ratios to a change in collector area. A 25% increase and decrease in the baseline collector area for three hours storage was used. The results are shown in Table 4-3.

Table 4-3
COLLECTOR AREA EXPERIMENT

Collector Area ($10^3 m^2$)	Thermal Storage (Hours)	Cost/Value $100/m^2	$300/m^2	$500/m^2
521	3	.87	1.41	1.96
695	3	.77	1.35	1.92
829	3	.74	1.35	1.96

The results of this experiment show a preference for the 829,000 M^2 collector area at \$100/m^2 and a preference for the baseline collector area at \$500/m^2. The 521,000 M^2 collector area did not appear attractive for any of the assumed heliostat costs. As the cost of heliostats is reduced, a larger collector field can usually be justified. Using a different criteria such as net value will usually favor the smaller collector field as long as the cost/value ratio is above one, and the larger field if the ratio is less than one.

Section 5
CONCLUSIONS AND OBSERVATIONS

5.1 Conclusions

The general conclusions from this investigation are contained in Section 1.4. The following is a more detailed explanation of these conclusions. It should be noted that the analysis performed was limited; therefore, the conclusions should be treated in that context.

- Based on the performance data and economics used, the microeconomic value does not quite equal the estimated cost (C/V = 1.35 with heliostat cost of $\$300/m^2$).

The heliostat costs have a large impact on the total cost for the solar plant. There are currently only two European suppliers of heliostats and the cost of the heliostats is very quantity sensitive. The European suppliers currently estimate a cost of $\$1000/m^2$ for heliostats with a cost of $\$500/m^2$ attainable. A cost of $\$300/m^2$ is comparable to the costs for the Barstow installation in the U.S. Commercial production costs of $\$100/m^2$ are predicted for the U.S. Based on this data, $\$300/m^2$ was used as a reference cost for the heliostats. However, a wide range of heliostat costs were investigated in order to show the sensitivity of the results to the heliostat costs.

- Some thermal storage (approximately three hours) appears to be justified.

The daily loads for the ENEL system exhibit an evening peak, especially in the winter (Figure 3-1). Adding thermal storage to the solar plant allows the solar plant to operate during part of the evening peak. This operating strategy which was made available by the thermal storage should be of benefit to ENEL. The cost effectiveness of such storage will depend both upon the cost and performance of the storage and the costs of the heliostats required to charge it.

- The design point collector area (695,000 M^2) seemed adequate.

A 695,000 M^2 collector area was used for the baseline configuration. This collector area seemed adequate for the insolation characteristics and the three hours of thermal storage. This conclusion is based on the fact that very little waste heat or thermal energy spillage was observed during the simulated operation of the solar plant.

- The principal value of the solar-thermal plant is its ability to displace oil consumption on the ENEL system. This opportunity may disappear if major adjustments are made in the generating mix.

The 1990 ENEL system has a generating mix that is heavily reliant on oil-fined capacity (Table 3-1). This situation will most likely change in the years beyond 1990 when more coal and nuclear units are brought on-line. This means that the total energy from the oil-fired units will be reduced. This will decrease the amount of oil available for displacement by the output of a solar plant. Therefore, the value of the solar plant will be reduced.

- The solar plant cannot compete with a coal plant for the economic assumptions used.

If an additonal 100 MWe in coal capacity is assumed to exist on the ENEL system, using the ENEL capital costs per kilowatt for a coal plant, a better cost/value ratio will result for the coal plant than for a solar-thermal plant, even with 100 $/$M^2$ collectors. This is due to the lower capital cost for a coal plant and the significantly larger amount of oil displaced by the coal plant's output. The higher yearly energy available from the coal plant is the result of the coal plant's ability to operate 24 hours a day, although restrictions in the coal plant's availability were considered.

5.2 Observations

There are several observations concerning the ENEL system and the effects of operating a solar plant on this system. If a solar plant installation occurs during an all coal and/or nuclear expansion period on the ENEL system, the capacity credit should be deferred until a greater portion of the ENEL capacity is coal and/or nuclear based. Since the ENEL system in the 1990 time frame is representative of this condition, the capacity credits used in this study may be optimistic.

The land available for building a large solar plant in Italy is limited because of the terrain. The area of land suitable for the heliostat field of a 100 MW solar plant may not be available. Most likely there will only be enough suitable land for a plant no larger than 50 MWe.

Any serious consideration of a large central receiver solar-thermal plant for the ENEL system should be preceded by a more detailed system impact analysis involving multiyear modeling. Because of the anticipated changes in the post 1990 generation mix, evaluation of solar installations in other than the 1990 time frame should be investigated. An optimal expansion planning computer program would be useful in capturing the dynamics of any solar program involving successive installations.

Section 6
REFERENCES

1. A Methodology for Solar-Thermal Power Plant Evalution, EPRI ER-869, prepared by Westinghouse Electric Corporation for the Electric Power Research Institute under Contract RP 648, August 1978.

2. Economic Assessment of Advanced Central Receiver Solar-Thermal Power Systems, Final Report No. DOE/SF 10601-1, prepared by Westinghouse Electric Corporation for the U.S. Department of Energy as part of DE-AC03-79SF10601, October 1980.

3. Economic Assessment of Advanced Central Receiver Solar-Thermal Power Systems, Report of PG&E Assessment, Report No. DOE/SF-10601-2, prepared by Westinghouse Electric Corporation for the U.S. Department of Energy as part of DE-AC03-79SF10601, January 1981.

4. Solar-Thermal Repowering Utility Value Analysis, SERI/TR-8016-1, prepared by Westinghouse Electric Corporation for the Solar Energy Research Institute under Contract XH-9-8016-1, September 1979.

5. J. T. Day, "Economic Criteria for Assessing New Generating Technologies", Vol. 41, pp. 495-499, Proceedings of the American Power Conference, Chicago, Illinois, April 1979.

Appendix A
LISTING OF CASE RESULTS

This appendix contains the results of the five cases analyzed. For details of the assumptions and procedures, please refer to the appropriate sections of the report.

All dollars shown are in 1980 dollars and reflect life cycle revenue requirements.

Table A-1

521,000 m^2, 3 Hours Storage

*** ALL PEAKING CREDIT ***
ENEL DOE/SAN 1990 ADVANCED WATER/STEAM 3 521
3 HOURS STORAGE 521000 COLLECTOR AREA
SOLAR PLANT VALUE AND COST TABLE ENEL ECONOMICS 1
LIFE CYCLE REVENUE REQUIREMENTS 1980 MILLIONS

SOLAR PLANT COST	$100/M2	$300/M2	$500/M2
STC PLANT COST	346.3	565.1	783.9
STC PLANT O+M	74.2	121.1	168.0
STC TOTAL COST	420.5	686.2	951.9
SOLAR PLANT VALUE			
FUEL VALUE	466.2	466.2	466.2
VARIABLE O+M	0.0	0.0	0.0
STC FUEL COST	0.0	0.0	0.0
CAPACITY CREDIT	19.2	19.2	19.2
TOTAL VALUE	485.4	485.4	485.4
NET VALUE	64.9	-200.8	-466.5
COST/VALUE	.87	1.41	1.96
BREAKEVEN $/KW 1980	1958.1	1734.8	1511.6
PLANTCOST $/KW 1980	1648.9	2690.9	3732.9
STC ENERGY GWH/YR	132.1	132.1	132.1
CAPACITY FACTOR	.151	.151	.151
ENERGY COST MILLS/KWHR	106.1	173.1	240.2

CAPACITY DISPLACEMENT TABLES

	MEGAWATTS	VALUE RR
PEAKING	36.7	19.2
INTERMEDIATE	0.0	0.0
BASE LOADED	0.0	0.0
TOTAL	36.7	19.2

CAPACITY CREDIT TAKEN IN YEAR 1990

Table A-2

695,000 m^2, 3 Hours Storage

*** ALL PEAKING CREDIT ***
ENEL DOE/SAN 1990 ADVANCED WATER/STEAM 3 695
3 HOURS STORAGE - 695000 COLLECTOR AREA
SOLAR PLANT VALUE AND COST TABLE ENEL ECONOMICS 1
LIFE CYCLE REVENUE REQUIREMENTS 1980 MILLIONS

	$100/M2	$300/M2	$500/M2
SOLAR PLANT COST			
STC PLANT COST	393.9	685.8	977.7
STC PLANT O+M	84.4	147.0	209.5
STC TOTAL COST	478.3	832.7	1187.2
SOLAR PLANT VALUE			
FUEL VALUE	594.3	594.3	594.3
VARIABLE O+M	0.0	0.0	0.0
STC FUEL COST	0.0	0.0	0.0
CAPACITY CREDIT	24.4	24.4	24.4
TOTAL VALUE	618.7	618.7	618.7
NET VALUE	140.4	-214.0	-568.5
COST/VALUE	.77	1.35	1.92
BREAKEVEN $/KW 1980	2544.4	2246.5	1948.7
PLANTCOST $/KW 1980	1875.6	3265.6	4655.6
STC ENERGY GWH/YR	175.6	175.6	175.6
CAPACITY FACTOR	.200	.200	.200
ENERGY COST MILLS/KWHR	90.8	158.1	225.4

CAPACITY DISPLACEMENT TABLES

	MEGAWATTS	VALUE RR
PEAKING	46.4	24.4
INTERMEDIATE	0.0	0.0
BASE LOADED	0.0	0.0
TOTAL	46.4	24.4

CAPACITY CREDIT TAKEN IN YEAR 1990

Table A-3

$869{,}000\ m^2$, 3 Hours Storage

*** ALL PEAKING CREDIT ***
ENEL DOE/SAN 1990 ADVANCED WATER/STEAM 3 869
3 HOURS STORAGE 869000 COLLECTOR AREA
SOLAR PLANT VALUE AND COST TABLE ENEL ECONOMICS 1
LIFE CYCLE REVENUE REQUIREMENTS 1980 MILLIONS

	$100/M2	$300/M2	$500/M2
SOLAR PLANT COST			
STC PLANT COST	441.5	806.5	1171.4
STC PLANT O+M	94.6	172.8	251.0
STC TOTAL COST	536.1	979.3	1422.5
SOLAR PLANT VALUE			
FUEL VALUE	699.4	699.4	699.4
VARIABLE O+M	0.0	0.0	0.0
STC FUEL COST	0.0	0.0	0.0
CAPACITY CREDIT	27.6	27.6	27.6
TOTAL VALUE	727.0	727.0	727.0
NET VALUE	190.9	-252.2	-695.4
COST/VALUE	.74	1.35	1.96
BREAKEVEN $/KW 1980	3011.6	2639.2	2266.8
PLANTCOST $/KW 1980	2102.3	3840.3	5578.3
STC ENERGY GWH/YR	205.3	205.3	205.3
CAPACITY FACTOR	.234	.234	.234
ENERGY COST MILLS/KWHR	87.0	159.0	231.0

CAPACITY DISPLACEMENT TABLES

	MEGAWATTS	VALUE RR
PEAKING	52.7	27.6
INTERMEDIATE	0.0	0.0
BASE LOADED	0.0	0.0
TOTAL	52.7	27.6

CAPACITY CREDIT TAKEN IN YEAR 1990

Table A-4

494,000 m^2, No Storage

*** ALL PEAKING CREDIT ***
ENEL DOE/SAN 1990 ADVANCED WATER/STEAM 0 494
0 HOURS STORAGE 494000 COLLECTOR AREA
SOLAR PLANT VALUE AND COST TABLE ENEL ECONOMICS 1
LIFE CYCLE REVENUE REQUIREMENTS 1980 MILLIONS

SOLAR PLANT COST	$100/M2	$300/M2	$500/M2
STC PLANT COST	275.9	483.4	690.8
STC PLANT O+M	59.1	103.6	148.0
STC TOTAL COST	335.0	586.9	838.9
SOLAR PLANT VALUE			
FUEL VALUE	412.4	412.4	412.4
VARIABLE O+M	0.0	0.0	0.0
STC FUEL COST	0.0	0.0	0.0
CAPACITY CREDIT	16.2	16.2	16.2
TOTAL VALUE	428.6	428.6	428.6
NET VALUE	93.6	-158.4	-410.3
COST/VALUE	.78	1.37	1.96
BREAKEVEN $/KW 1980	1759.3	1547.6	1335.9
PLANTCOST $/KW 1980	1313.7	2301.7	3289.7
STC ENERGY GWH/YR	116.9	116.9	116.9
CAPACITY FACTOR	.133	.133	.133
ENERGY COST MILLS/KWHR	95.5	167.4	239.2

CAPACITY DISPLACEMENT TABLES

	MEGAWATTS	VALUE RR
PEAKING	30.8	16.2
INTERMEDIATE	0.0	0.0
BASE LOADED	0.0	0.0
TOTAL	30.8	16.2

CAPACITY CREDIT TAKEN IN YEAR 1990

Table A-5

756,000 m^2, 6 Hours Storage

*** ALL PEAKING CREDIT ***
ENEL DOE/SAN 1990 ADVANCED WATER/STEAM 6 756
6 HOURS STORAGE 756000 COLLECTOR AREA
SOLAR PLANT VALUE AND COST TABLE ENEL ECONOMICS 1
LIFE CYCLE REVENUE REQUIREMENTS 1980 MILLIONS

SOLAR PLANT COST	$100/M2	$300/M2	$500/M2
STC PLANT COST	465.4	782.9	1100.4
STC PLANT O+M	99.7	167.8	235.8
STC TOTAL COST	565.1	950.7	1336.2
SOLAR PLANT VALUE			
FUEL VALUE	647.2	647.2	647.2
VARIABLE O+M	0.0	0.0	0.0
STC FUEL COST	0.0	0.0	0.0
CAPACITY CREDIT	25.8	25.8	25.8
TOTAL VALUE	673.0	673.0	673.0
NET VALUE	107.9	-277.7	-663.2
COST/VALUE	.84	1.41	1.99
BREAKEVEN $/KW 1980	2729.8	2405.8	2081.8
PLANTCOST $/KW 1980	2216.1	3728.1	5240.1
STC ENERGY GWH/YR	190.5	190.5	190.5
CAPACITY FACTOR	.217	.217	.217
ENERGY COST MILLS/KWHR	98.9	166.3	233.8

CAPACITY DISPLACEMENT TABLES

	MEGAWATTS	VALUE RR
PEAKING	49.1	25.8
INTERMEDIATE	0.0	0.0
BASE LOADED	0.0	0.0
TOTAL	49.1	25.8

CAPACITY CREDIT TAKEN IN YEAR 1990