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A Sensitivity Analysis of SPURR

Robert E. Witholder

SERI

Solar Energy Research Institute

A Division of Midwest Research Institute

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A SENSITIVITY ANALYSIS OF SPURR

ROBERT E. WITHOLDER

APRIL 1980

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FOREWORD

This report documents a portion of the research output of Task 5229, "Solar Modeling Forum," in the Economic Analysis Branch of the Analysis Division. For this sensitivity analysis, a critical parameter in the model was identified and its value changed while all other parameters remained constant. Results were evaluated in terms of intuitive expectations.

The author acknowledges the contributions and critical reviews of Mark Wallenrod, a graduate intern from the University of Pennsylvania.

Approved for:

SOLAR ENERGY RESEARCH INSTITUTE

Dennis Costello, Chief
Economic Analysis Branch

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SUMMARY

Sensitivity analysis was performed on the agricultural and industrial process heat and utility market sectors of the SPURR (System for Projecting the Utilization of Renewable Resources developed by the MITRE Corporation) model which utilized the DPR baseline scenario. The objective of this sensitivity analysis is to determine if variations in solar system capital cost, operation and maintenance cost, and fuel cost (for biomass only) correlate with "common sense" and do not offend basic intuition. In general, this effort is part of a much larger issue: validation of SPURR.

Variations of the factors were evaluated for the following output parameters (others are available):

- accumulated installed systems,
- annual energy production,
- accumulated capital cost, and
- accumulated life-cycle cost.

An analysis of the results is presented for three criteria: (1) type of relationship, (2) sense, and (3) sensitivity.

The type of relationship indicates whether the change in penetration is linear or nonlinear with respect to a change in a given variable, while sense attempts to evaluate the direction of change with respect to an intuitive feeling about penetration. Sensitivity is the ratio of percentage change in penetration versus a percentage change in a given factor (e.g., capital cost).

This study has practical applications for engineering improvements in solar technologies and is useful as a planning tool in the R&D allocation process. The results of the analysis for the variables studied indicate that SPURR simulation is consistent with intuitive effects for these variables.

Further research efforts will be conducted after a coding problem encountered in the output report of the SHACOB component is corrected. A similar analysis will be performed in this sector.

SPURR must also be modified so that variations in system lifetime can be included. Presently, sensitivity analysis of system lifetime will produce results that are counter-intuitive and are the result of the economic equations in the model that cannot handle systems with different lifetimes. Comparisons between systems require a common time basis, including a common year for cost comparison and a common operating period.

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SECTION 1.0

INTRODUCTION

The Solar Energy Research Institute (SERI) has conducted a limited sensitivity analysis to determine the variation of projected market penetration by the model entitled A System for Projecting the Utilization of Renewable Resources (SPURR) [1]. SPURR, developed by the MITRE Corporation for the Department of Energy (DOE), is comprised of three computer programs. Each program simulates a different market sector to estimate market penetration. The computer models and the market sectors they cover are:

- SHACOB—solar heating and cooling of buildings market;*
- AIPH—agricultural and industrial process heat market [2]; and
- UTILITY—centralized electricity generation market and the synthetic fuels and products market [3].

Two scenarios have been used for analysis by the model. They contain major economic assumptions describing trends in energy demand, energy price, taxes, and incentives [2,3]. The two scenarios are:

- the Recent Trends Scenario (RTS), and
- the National Energy Plan (NEP).

The MITRE Corporation has performed a limited sensitivity analysis on the National Energy Plan (simulating the National Energy Act) scenario and Recent Trends Scenario (simulating "business-as-usual") [4]. The Domestic Policy Review (DPR) Scenario is a recent update to the NEP scenario and was developed by MITRE to investigate variations in oil prices and their effect on solar penetration. It is the DPR baseline case that was used for the sensitivity analysis done at SERI. MITRE's sensitivity analysis of the NEP and RTS scenarios has included parameters such as energy prices, tax credits and incentives, market shares, market potential, service demand growth rate, and accelerated acceptance of solar. The sensitivity analysis performed at SERI focused on variations of solar system lifetime, solar system capital cost, and operation/maintenance cost that could be related to improvements in design and uncertainty in estimated cost.

The variations of these parameters are summarized in Table 1-1. The results of the sensitivity analysis will have practical application to engineering improvements in solar technologies that can be translated to changes in the three primary variables. Secondly, the results will continue the verification and validation of SPURR by contributing to the dialogue of published results versus intuitive expectations and by highlighting error in the programs or algorithms.

At this point in the analysis, no significant problems were encountered other than a coding problem in the output reports of the SHACOB sector (which limited this sensitivity analysis to the AIPH and utility sectors) and unexpected results when the system lifetime was varied. To facilitate the visual analysis of the sensitivity results, SERI added a

*Sensitivity of this sector was not included in this report because of problems with the program that are being corrected by MITRE.

Table 1-1. SENSITIVITY ANALYSIS (% VARIATIONS)

	Capital Cost								O&M Costs						Fuel Costs			
	+50	+30	+20	-10	-20	-30	-40	-46	+50	+30	+20	-10	-20	-30	+20	-10	-20	-30
Utilities																		
Biomass	X		X		X	X				X		X	X	X	X	X	X	X
OTEC		X		X	X	X	X		X		X		X	X				
Photovoltaics		X		X	X		X		X			X	X	X				
Solar Thermal		X		X	X	X			X		X		X	X				
WECS			X	X	X	X		X	X		X		X	X				
Process Heat	+30	+40	+20	+10	-10	-20	-40	-60	+50		+20		-20	-30				
Solar Thermal	X	X	X	X	X	X	X	X	X		X		X	X				

graphics package for plotting the required outputs. Prior to the sensitivity runs, SERI was able to replicate (on CDC computer) the baseline cases generated by MITRE to verify that there are no code or machine errors in the SERI model. The error in the model output processor of the SHACOB sector prevented SERI from performing an analysis of that sector. This will be performed at a later date when the problem is corrected.

SECTION 2.0

THE SPURR MODEL

SPURR simulates solar technology competition in the marketplace as a tool to evaluate the future of solar energy technologies. The simulation of solar market behavior examines the effects of solar and conventional technology costs, tax incentives, subsidies, and future fuel costs on the market acceptance of solar energy alternatives. Figure 2-1 illustrates the SPURR flow diagram. (For additional detail see Coluzzi and Rebibo, 1978; Drescher and Rebibo, 1978; MITRE, 1977; MITRE, 1978.)

2.1 PROCESS HEAT COMPONENT

The Agricultural and Industrial Process Heat (AIPH) component examines the marketability of solar systems by segmenting the economic market into existing submarkets of three areas:

- nine census regions;
- six competing conventional systems (coal, gas, oil, synfuels, electric resistance, and electric heat pump); and
- temperature ranges (water at 40-60°C, 60-80°C, and 80-100°C; air at 50-100°C, 100-150°C, and 150°C; steam at 100-150°C and 150°C).

The annualized life-cycle solar cost is computed from a prototype-system capital cost for each application and region. The prototype capital cost is based on a generic solar design that includes storage, and it is appropriate to each temperature range. The annualized life-cycle conventional cost is computed from the fuel cost, fuel escalation rates, and capital cost. The ratio of solar cost to conventional cost is used as a figure-of-merit in the MITRE market share function (Fig. 2-2). Some of the key assumptions for process heat are shown in Table 2-1.

2.2 UTILITY COMPONENT

The centralized electric and synthetic fuels and products markets are handled by the utility module of SPURR. This market is segmented into nine census regions: five electric and four synthetic demand types.

Tables 2-2 and 2-3 list the technologies in this sector. Table 2-2 identifies the type of load that the technology will satisfy: base, intermediate, semipeaking, peaking, and fuel-saver. Those technologies that qualify as fuel savers—if the lifetime fuel savings plus capacity credit is greater than the lifetime revenue requirements of the fuel saver—are allocated to satisfy demand for that year. The remaining demand for electricity and synthetic fuels is allocated among solar and conventional technologies using a probability-of-least-cost approach, a Monte Carlo simulation. In this allocation, the technology's annualized cost, present value over the lifetime of the plant, is used and constrained by building rate and rate of penetration. Experience factors are then applied to appropriate technologies at the end of the year for computing market penetration for the following year. Some of the key assumptions for utility and synthetic products are shown in Table 2-4.

Figure 2-1. SPURR Flow Diagram

The METREK market share function is represented by the following equation:

$$Y = \frac{1}{1 + 1/[F \tanh(\hat{T}) e^{(1-1/F)\hat{T}}]}$$

$$\text{where } T = \left(\frac{T - T_0}{r} \right)^2$$

Y = solar share

F = figure of merit

T = time

T_0 = year in which technology first became generally available

r = time scale factor representing number of years required for the technology to mature

In this analysis, T_0 is assumed to be 1973, and r is assumed to be 25 years.

Figure 2-2. MITRE Market Share Function

Table 2-1. PROCESS HEAT BASELINE ASSUMPTIONS IN SPURR

System	Capital Cost (\$/ft ²)	O&M (% of capital)	Lifetime ^a (years)	Market Entry (year)
1. Air 50-100° C aluminum flat plate, black, single glazing rock storage	23.1	0.4	20	1975
2. Air 100-150° C evacuated tube, rock storage	23.1	1.6	20	1978
3. Air 150° C line concentrator	40.5	2.4	20	1983
4. Water 40-60° C solar pond	17.4	12.2	20	1975
5. Water 60-80° C aluminum flat plate, simple glaze, water storage	23.7	4.5	20	1975
6. Water 60-100° C aluminum flat plate, selective single glaze, water storage	26.1	4.6	20	1976
7. Steam 100-150° C parabolic dish, oil/rock storage	37.5	2.5	20	1981
8. Steam 150° C parabolic dish, salt-rock topping, oil/rock storage	38.7	4.4	20	1983

^aAll must have the same lifetime.

Table 2-2. ELECTRIC TECHNOLOGIES

Type of Technology	Name	Description	System ^a Type
Biomass	BIOLOG	Wood-fired steam plant/logging residues	I
	BIOMILL	Wood-fired steam plant/mill residues	B, I
	BIOSLP	Wood-fired steam plant/silvicultural products	B, I
Coal	COALAFB	Steam/atmospheric fluidized bed combustion	B
	COALSTM	Steam/flue gas desulfurization	B, I
	COALTS	Steam/thermal storage	I, SP, P
	COSTMPH	Steam/pumped hydro or compressed air	SP, P
Nuclear	NUC-ADV	Nuclear heavywater reactor—CANDU type	B
	NUCLWR	Nuclear light water reactor	B
Oil	OILCOCY	Combined cycle oil plant	I, SP
	OILOCGT	Open cycle gas turbine	P
OTEC	OTEC	Ocean thermal energy conversion	B
Photovoltaic	PHOFLM	Collector/reflector system—10% efficient	I, SP
		Thin film cells	FS
	PHOSIL	Collector/reflector system—16% efficient, silicon cells	I, SP
	PHOSILFS	Fuel-saver silicon cells	FS
Solar Thermal	SOTHCRC	Central receiver/combined cycle hybrid	I
	SOTHCDFS	Central receiver fuel saver	FS
	SOTHCRTS	Central receiver/thermal storage	I, SP
	SOTHREP	Central receiver repowering	I
	SOTHCST	Central receiver/thermal storage	SP
Wind Energy Conversion Systems (WECS)	WECS2CC	Advanced design/combined cycle hybrid	B
	WECS2FS	Fuel saver	FS
	WECS2GT	Gas turbine hybrid	I
	WECS2WS	Water saver with pumped hydro	I
	WECSIGT	MODI gas turbine	I
	SECSIFS	MODI fuel saver	P, FS

^aB-Base, I-Intermediate, SP-Semipeak, P-Peak, FS-Fuel Saver.

A fuel saver is a system without back-up or storage.

Table 2-3. SYNTHETIC FUELS AND PRODUCTS TECHNOLOGY

Type of Technology	Name	Description
Ammonia	AMHSCG	Production from high sulfur coal
	AMMLGRS	Production from logging residues
	AMMSIL	Production from silvicultural products
	AMMOTEC	Production from OTEC
	AMHSCO	Production from coal
Gas	GSDMDRED	Gas Demand Reduction: a dummy technology producing gas at the price of natural gas and competing in the synthetic natural gas market to simulate a quasinnatural gas technology
Methanol	MEHSCO	Production from high sulfur coal
	METLGRS	Production from logging residues
	METMLRS	Production from mill residues
	METSIL	Production from silvicultural products
Synthetic Crude Oil	SNCDSCO	Production from high sulfur coal
	SNCDSEL	Production from silvicultural products
	SNCISSH	Production from in situ shale oil
	SNCLGRS	Production from logging residues
	SNCMLRES	Production from mill residues
	SNCRETSH	Production from mill shale oil
Synthetic Natural Gas	SNGCRRES	Production from crop residues
	SNGHSCO	Production from high sulfur coal
	SNGLGRS	Production from logging residues
	SNGMLRES	Production from mill residues
	SNGSIL	Production from silvicultural products

Table 2-4. UTILITY AND SYNTHETIC PRODUCTS BASELINE ASSUMPTIONS IN SPURR AND GROUPING PER TECHNOLOGY CATEGORY

	Type of Load Satisfied	Capital Cost (\$/kW)	O & M Cost (\$/kW)	Lifetime (years)	Size (MW)	Market Entry
A. Photovoltaics						
1. PHOSIL	Inter.	\$ 4,081	\$ 64.0	30	100	1991
					0.2	1980-85
2. PHOFLM	Inter.	49,016	82.0	30	100	1991
					1.0	1981-86
3. PHOCON	Inter.	8,200	23.5	30	5.0	2030
					100	2030
					1.0	2030
4. PHOFLM	Semi PK	\$ 30,686	\$ 39.0	30	10	1983
					100	1991
5. PHOSIL	Semi PK	25,551	29.0	30	10	1976-91
					100	1991
6. PHOSILFS	FS	19,047	14.3	30	100	2030
7. PHOFLMFS	FS	21,313	19.4	30	100	1991
B. Solar Thermal						
1. SOTHCRC	Inter.	\$ 1,416	\$ 10.0	30	100	2030
					100	1989
2. SOTHCRTS	Inter.	4,130	20.0	30	5	1980-85
3. SOTHCRTS	Semi PK	2,687	14.0	30	100	1991
4. SOTHREP	Inter.	2,157	8.0	30	50	1986
5. SOTH CRFS	FS	2,328	12.0	30	100	1991
C. WECS						
1. WECS 2 CC	Base	\$ 1,614	\$ 28.5	30	100	1989
2. WECS 1 GT	Inter.	925	17.4	30	10	2030
					100	1989
3. WECS 2 GT	Inter.	1,495	21.3	30	1.5	1980-85
4. WECS 2 WS	Inter.	1,670	17.0	30	100	1986
5. WECS 1 FS	FS	805	21.9	30	100	2030
6. WECS 2 FS	FS	1,379	27.8	30	100	1989
D. Biomass						
1. BIOMILL	Base	\$ 1,190	\$ 78.0	30	46	1980
2. BIOSLP	Base	1,190	78.0	30	46	1995
3. BIOSLP	Inter.	1,190	48.7	30	46	1995
4. BIOMILL	Inter.	1,190	48.7	30	46	1991
5. BIOLOG	Inter.	1,190	48.7	30	46	1991
6. METSIL	Methanol	13.4	2.03 ^a	30	0.47X10 ^{7c}	1995
7. METLGRS	Methanol	13.4	2.03	30		1991
8. METMLRS	Methanol	13.4	2.03	30		1991
9. SYNMLRES	Syncrude	3.7	0.73	25	0.64X10 ⁷	1991
10. SNCDLRS	Syncrude	3.7	0.73	30	0.64X10 ⁷	2000
11. SNCLGRS	Syncrude	3.7	0.73	30	0.64X10 ⁷	1991
12. AMMSIL	Ammonia	173.0	28.0	30	0.35X10 ⁶	2000
13. AMMLGRS	Ammonia	173.0	28.0	30	0.35X10 ⁶	1991
14. SNGSIL	SNG	5.4	1.18	30	0.69X10 ⁷	2000
15. SNGLGRS	SNG	5.4	1.18	30	0.69X10 ⁷	1990
16. SNGRRRES	SNG	9.1	2.07	30	0.19X10 ⁷	2030
17. SNGMLRES	SNG	5.4	1.18	30	0.69X10 ⁷	1990
E. OTEC						
1. OTEC	Base	\$ 2,751	\$ 35.0	30	400	1993
					25	1983-86
2. AMNOTECH	Ammonia	992 ^b	50.0	20	0.62X10 ⁶	1992

^a\$/MBtu.

^b\$/ton-yr.

^cBtu/day.

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SECTION 3.0

CAPITAL COST SENSITIVITY ANALYSIS

Capital cost was varied in each SPURR sector* to evaluate the effects on the following SPURR output parameters:

- accumulated installed systems (million ft² or GW),
- annual energy production (TWh or quads/yr),
- accumulated capital cost (\$), and
- accumulated life-cycle cost (\$).

Accumulated installed systems measure the number of systems installed. Annual energy production measures the total energy production of all plants in a specific year. Accumulated capital cost is the total capital cost of all plants built up to a specific year and accumulated federal expense is the amount of federal money lost due to tax credits. Annual fuel utilization measures the amount of fuel burned. (Annual fuel utilized is provided for wind energy conversion systems (WECS) only to show the effect of saving fuel.) Accumulated life-cycle cost is total life-cycle cost of systems installed at that time; it includes capital cost, O&M, and fuel cost over the lifetime of the plant. Annual fuel utilized and accumulated federal expense also were calculated as functions of variation in capital cost. Annual fuel utilized is shown for WECS only; however, the remaining data are available upon request.

The data in this section are presented in two ways: variation of penetration in real units from 1980 to 2000 as a function of time; and penetration, percentage change from baseline versus percentage change in capital cost. The technologies showing a high ratio of the percentage change in penetration versus the percentage change in capital cost were: process heat (solar thermal), solar thermal (utilities), photovoltaics, and OTEC. OTEC showed extreme sensitivity on a percentage basis, but this may be due to the small number of plants that were built (i.e., a change of one plant when two were built causes a 50% change in installed systems). WECS and biomass showed the lowest sensitivity to changes in capital cost. See Tables 2-1 and 2-4 for a range of baseline capital cost in the SPURR data base and the grouping of technologies in each category.

In addition to displaying the data, an analysis of the results was provided in a qualitative and quantitative fashion according to three criteria: type of relationship, sense, and sensitivity. The type of relationship indicates whether the change in capital cost penetration was linear or nonlinear. Sense attempts to evaluate the direction of change in penetration with respect to intuitive feel about penetration; i.e., if capital cost increases, one feels that fewer systems should be built or vice versa. This analysis of sense is looking for obvious errors in the SPURR methodology. The final evaluation uses sensitivity in a qualitative (high, low, moderate, none) and quantitative sense (if change was linear) by reporting the proportionality of the change in penetration with the change in capital cost. Some sensitivities were as high as 10:1 (OTEC) and as low as 0.3:1 (biomass).

*A later revision of this report will include the SHACOB data.

3.1 PROCESS HEAT SYSTEM PENETRATION VS. CAPITAL COST VARIATION

The sensitivity of the process heat systems up to $\pm 60\%$ variations in capital cost of all solar thermal technologies in this sector (see Table 2-1) as a function of time is shown in Figs. 3-1 through 3-8. Figures 3-9 and 3-10 show the percentage variations in penetration of the SPURR output parameters for the year 2000.

The changes in the process heat systems were done for all the technologies in that group simultaneously, provided that technology had entered the market (see market entry dates in Table 2-1). Individual technologies (i.e., solar ponds) can be treated separately but were not in this analysis. The following is a summary of the results:

	<u>Acc.* Installed Systems</u>	<u>Annual Energy Produced</u>	<u>Acc. Capital Cost</u>	<u>Acc. LCC** Cost</u>
Type of relationship	Linear,	Linear, inverse	Nonlinear inverse	Nonlinear
Sense	Proper	Proper	Proper	Proper
Sensitivity	High	High	Moderate 1.33:1	Moderate 1.33:1

The inverse linear variation effect, observed in accumulated installed systems and annual energy produced with variation in solar capital cost, is to be expected and is in the proper direction. Installed systems and annual energy production are primarily functions of market share (which, in turn, is inversely a function of solar capital cost). Thus, as capital cost decreases, the number of solar units built would increase, increasing the number of systems installed and the annual energy production.

The small variation, nonlinear effects in accumulated capital cost and accumulated life-cycle cost until year 2000 are the result of two opposing functions: (1) market share, inversely a function of solar capital cost; and (2) capital cost, a direct function of solar capital cost. Accumulated capital cost would increase due to higher market shares (when solar capital costs are reduced) but would decrease due to reduced capital cost of each solar unit built. Over the range of -60% to 0% variation in capital cost in process heat, the predominant factor is capital cost of individual units (thus, the curve shows a direct variation with respect to changes in capital cost), but the market share function begins to dominate when capital costs have increased to $+60\%$ (and the penetration varies inversely) as shown in Figs. 3-9 and 3-10.

From this analysis it can be seen that any change in capital cost over the range shown reduced only the accumulated capital cost and accumulated life-cycle cost (and federal expenditure) by year 2000. This can best be seen in Figs. 3-9 and 3-10.

*Accumulated (Acc).

**Life-cycle cost (LCC).

Figure 3-1. Process Heat, % Capital Costs Change vs. Cumulative Installed System

Figure 3-2. Process Heat, % Capital Costs Change vs. Annual Energy Production

Figure 3-3. Process Heat, % Capital Costs Change vs. Accumulated Capital Cost

Figure 3-4. Process Heat, % Capital Costs Change vs. Accumulated Life-Cycle Cost

Figure 3-5. Process Heat, % Capital Costs Change vs. Cumulative Installed Systems

Figure 3-6. Process Heat, % Capital Costs Change vs. Annual Energy Production

Figure 3-7. Process Heat, % Capital Costs Change vs. Accumulative Capital Costs

LEGEND

□ - RUN 16
 ○ - RUN 17
 △ - RUN 42
 + - RUN 43
 x - RUN 0

Run
 16
 17
 42
 43
 0

Change in Capital Costs
 +10
 +20
 +40
 +60
 Baseline

Figure 3-8. Process Heat, % Capital Costs Change vs. Accumulated Life-Cycle Costs

Figure 3-9. % Change in Process Heat Variables vs. % Change in Capital Cost for Year 2000

Figure 3-10. % Change in Process Heat Variables vs. % Change in Capital Cost for Year 2000

3.2 SOLAR THERMAL UTILITY PENETRATION VS. CAPITAL COST VARIATION

The sensitivity of solar thermal utility technologies (see Table 2-4) penetration is a function of time to variations in capital cost of -30% to +30% as shown in Figs. 3-11 through 3-14. Figure 3-15 shows the percentage of variation in penetration of the SPURR output parameters for year 2000. The changes in the solar thermal technologies were done as a group in this analysis but could have been done individually; i.e., the changes were the same for each technology in this group as the technology entered the market (see market entry dates in Table 2-4). The following is a summary of the results:

	<u>Acc. Installed Systems</u>	<u>Annual Energy Produced</u>	<u>Acc. Capital Cost</u>	<u>Acc. LCC Cost</u>
Type of relationship	Linear, inverse	Linear, inverse	Linear	Nonlinear
Sense	Proper	Proper	Proper	Proper
Sensitivity	High 2.5:1	High 2.5:1	Moderate 1:1	Moderate 1:1

In viewing the change in penetration for accumulated life-cycle cost in Fig. 3-14 (see run 33, -30% change in capital cost) and in Fig. 3-15, it is felt that the sense and nonlinearity are proper due to the inclusion of fuel-saver technologies in the group (which amounted to 45% to 50% of installed systems in year 2000). The life-cycle cost of fuel savers is negative (if they are built); i.e., they save more fuel than it costs to build them; while the life-cycle cost of base, intermediate, and peaking load solar thermal systems is positive. This effect is seen in those technology groups that include fuel savers (WECS, photovoltaics), but it is not seen in those that do not include fuel-saver technologies (biomass, OTEC). Additional runs using SPURR could isolate fuel savers from this group to verify this effect.

3.3 PHOTOVOLTAICS UTILITY PENETRATION VS. CAPITAL COST

The sensitivity of photovoltaics utility technologies (see Table 2-4) penetration as a function of time to variation of capital cost of -40% to +30% is shown in Figs. 3-16 through 3-19. Figure 3-20 shows the percentage variation in penetration of the SPURR output parameters for year 2000. The changes in the photovoltaics utility technologies were done as a group in this analysis but could have been done individually; i.e., the changes were the same for each technology in this group as the technology entered the marketplace (see market entry dates in Table 2-4). The following is a summary of the results:

Figure 3-11. Solar Thermal, % Capital Costs Change vs. Cumulative Installed System

Figure 3-12. Solar Thermal, % Capital Costs Change vs. Annual Energy Production

Figure 3-13. Solar Thermal, % Capital Costs Change vs. Accumulated Capital Cost

Figure 3-14. Solar Thermal, % Capital Costs Change vs. Accumulated Life-Cycle Cost

Figure 3-15. % Change in Solar Thermal Penetration Variables vs. % Change in System Capital Cost for Year 2000

Figure 3-16. Photovoltaics, % Capital Costs Change vs. Cumulative Installed Systems

Figure 3-17. Photovoltaics, % Capital Costs Change vs. Annual Energy Production

Figure 3-18. Photovoltaics, % Capital Costs Change vs. Accumulated Capital Cost

Figure 3-19. Photovoltaics, % Capital Costs Change vs. Accumulated Life-Cycle Cost

Figure 3-20. % Change in Photovoltaic Utility Penetration Variables vs. % Change in System Capital Cost for Year 2000

	<u>Acc. Installed Systems</u>	<u>Annual Energy Produced</u>	<u>Acc. Capital Cost</u>	<u>Acc. LCC Cost</u>
Type of relationship	Linear	Linear	Linear	Nonlinear
Sense	Proper	Proper	Proper	Proper
Sensitivity	High 6:1	High 7:1	High 3:1	Variable

The penetration of photovoltaics utilities begins in year 1990 due to input assumption of market entry date (see Table 2-4). The nonlinearity of photovoltaics utilities in accumulated life-cycle cost is due to fuel-saver technologies in this group, similar to that discussed under the solar thermal utilities section.

In summary, the photovoltaics-utility technologies exhibit a high, inversely proportional sensitivity to changes in capital cost.

3.4 BIOMASS SYSTEMS* PENETRATION VS. CAPITAL COST

The sensitivity of biomass systems* technology (see Table 2-3) penetration as a function of time to variation of capital cost of -30% to +50% is shown in Figs. 3-21 through 3-24. Figure 3-25 shows the percentage of variation in penetration of the SPURR output parameters for year 2000. The changes in the biomass systems* technologies were done as a group in this analysis but could have been done individually; i.e., the changes were the same for each technology in this group as the technology entered the marketplace (see market entry dates in Table 2-4). The following is a summary of the results:

	<u>Acc. Installed Systems</u>	<u>Annual Energy Produced</u>	<u>Acc. Capital Cost</u>	<u>Acc. LCC Cost</u>
Type of relationship	Linear, inverse	Linear, inverse	Linear, inverse	Linear, inverse
Sense	Proper	Proper	Proper	Proper
Sensitivity	Low 0.3:1	Low 0.3:1	Low 0.3:1	Low 0.3:1

Biomass systems technologies exhibit consistent behavior across all penetration variables (linear, inverse proportionality). Penetration of biomass is relatively insensitive to change in capital cost in SPURR.

*Group includes biomass utilities and synthetic products technologies.

Figure 3-21. Biomass, % Capital Costs Change vs. Cumulative Installed Systems

Figure 3-22. Biomass, % Capital Costs Change vs. Annual Energy Production

Figure 3-23. Biomass, % Capital Costs Change vs. Accumulated Capital Costs

Figure 3-24. Biomass, % Capital Costs Change vs. Accumulated Life-Cycle Cost

Figure 3-25. % Change Biomass System Penetration Variables vs. % Change in System Capital Cost for Year 2000

3.5 WECS UTILITY PENETRATION CAPITAL COST

The sensitivity of WECS utility technology (see Table 2-4) penetration as a function of time to variation of capital cost of -46% to +20% is shown in Figs. 3-26 through 3-30. An additional curve was added to show annual fuel utilization versus change in capital cost (see Fig. 3-28). Figure 3-31 shows the percentage of variation in penetration of the SPURR output parameters for year 2000. The changes in the WECS utility technologies were done as a group in this analysis but could have been done individually; i.e., the changes were the same for each technology in this group as the technology entered the marketplace (see market entry dates in Table 2-4). The following is a summary of the results:

	<u>Acc. Installed Systems</u>	<u>Annual Energy Produced</u>	<u>Acc. Capital Cost</u>	<u>Acc. LCC Cost</u>
Type of relationship	Linear, inverse	Linear, inverse	Nonlinear	Nonlinear
Sense	Proper	Proper	Proper	Proper
Sensitivity	Low 0.5:1	Low 1:1	Variable	Variable

The numbers of installed WECS systems exhibit relatively low sensitivity to changes in capital cost, but they show a predominant effect of fuel savers in the group in accumulated capital and life-cycle cost (see Section 3.2 for a detailed discussion of this effect). This is expected since the capital cost is a major cost in this system, compared to O&M and fuel cost (zero).

3.6 OTEC SYSTEMS* PENETRATION VS. CAPITAL COST

The sensitivity of OTEC systems* technology (see Table 2-4) penetration as a function of time to variation of capital cost of -40% to +30% is shown in Figs. 3-32 through 3-35. Figure 3-36 shows the percentage of variation in penetration of the SPURR output parameters for year 2000. The changes in the OTEC technologies were done as a group in this analysis but could have been done individually; i.e., the changes were the same for each technology in this group as the technology entered the marketplace (see market entry dates in Table 2-4). The following is a summary of the results:

*OTEC systems include utility capability and ammonia synthetic products.

Figure 3-26. WECS, % Capital Costs Change vs. Cumulative Installed Systems

Figure 3-27. WECS, % Capital Costs Change vs. Annual Energy Production

Figure 3-28. WECS, % Capital Costs Change vs. Annual Fuel Utilization

Figure3-29. WECS, % Capital Costs Change vs. Accumulated Capital Costs

Figure 3-30. WECS, % Capital Costs Change vs. Accumulated Life-Cycle Costs

Figure 3-31. % Change in WECS Systems Penetration Variables vs. % Change in System Capital Cost for Year 2000

Figure 3-32. OTEC, % System Capital Costs Change vs. Cumulative Installed System

Figure 3-33. OTEC, % System Capital Cost Change vs. Annual Energy Production

Figure 3-34. OTEC, % System Capital Cost Change vs. Accumulated Capital Costs

Figure 3-35. OTEC, % System Capital Cost Change vs. Accumulated Life-Cycle Costs

Figure 3-36. % Change in OTEC System Penetration Variables vs. % Change in System Capital Cost for Year 2000

	<u>Acc. Installed Systems</u>	<u>Annual Energy Produced</u>	<u>Acc. Capital Cost</u>	<u>Acc. LCC Cost</u>
Type of relationship	Linear,* inverse	Linear,* inverse	Linear,* inverse	Linear,* inverse
Sense	Proper	Proper	Proper	Proper
Sensitivity	High 10:1	High 9:1	High 4:1	High 4:1

In SPURR, OTEC technologies have a late market entry date (1995), and the penetration percentages do not exhibit a visibly linear relationship to capital cost changes. However, this is due to the SPURR methodology's deciding not to build (or to build) another plant or plants in a given year due to a change in capital cost and the small number of total plants built. The curves exhibit the discrete nature of new OTEC plants relative to the total plants built by that year (e.g., a new plant built in a given year exhibits a 100% change in installed systems if the baseline penetration was one plant in that year). Thus, if the penetration were run out to more future years (2025), the curves would have shown a more linear relationship (straight line).

*See explanation in text.

SECTION 4.0

ANNUAL O&M COST SENSITIVITY ANALYSIS

Annual O&M cost was varied in each SPURR sector* to evaluate the effects on the following SPURR variables:

- accumulated installed systems (million ft² or GW),
- annual energy production (TWh or quads/yr),
- accumulated capital cost (\$), and
- accumulated life-cycle cost (\$).

Two other penetration variables also were calculated as a function of variation in O&M cost. Annual fuel utilized is shown for WECS only (the data for both variables are available upon request). Accumulated installed systems are a measure of the number of systems installed.

Annual energy production measures the total energy production of all plants in a specific year. Accumulated capital cost is the total capital cost of all plants built up to a specific year. Accumulated federal expense is the amount of federal money lost due to tax credits. Annual fuel utilization measures the amount of fuel burned. (Annual fuel utilized is given only for WECS systems to show the effect of saving fuel.) Accumulated life-cycle cost is the total life-cycle cost of systems installed at that time; it includes capital cost, O&M, and fuel cost over the lifetime of the plant.

The data in this section are presented in two ways: (1) variation of penetration in real units as a function of time (1980 to 2000) and (2) percentage change from baseline scenario (penetration) versus percentage change in annual O&M cost. The only technology showing high sensitivity (ratio of percentage in penetration versus percentage change in O&M cost) was OTEC. OTEC showed extreme sensitivity on a percentage basis, but this may be due to the small number of plants built (i.e., a change of one plant when two were built causes a 50% change in installed systems). All other technologies showed low sensitivity to changes in O&M cost. (See Tables 2-1 and 2-4 for a range of baseline O&M costs in the SPURR data base and the grouping of technologies in each category.)

In addition to displaying the data, the results were analyzed in a qualitative and quantitative fashion according to three criteria: type of relationship, sense, and sensitivity. Type of relationship indicates whether the change in penetration was linear or nonlinear with respect to change in O&M cost. Sense attempts to evaluate the direction of change in penetration with respect to intuitive feel about penetration; i.e., if O&M cost increases, then one feels that fewer systems should be built, or vice versa. This analysis of sense involves looking for obvious errors in the SPURR methodology. The final evaluation uses sensitivity in a qualitative (high, low, moderate, none) and a quantitative sense (if change was linear) by reporting the proportionality of the change in penetration with the change in O&M cost. Some sensitivities were as high as 3:1 (see OTEC) and some as low as 0.2:1 (see WECS).

*A later revision of this report will include the SHACOB data.

Even though OTEC market penetration is sensitive to O&M cost, the other solar technologies are relatively insensitive to changes in O&M cost. Estimates of O&M cost in future technologies have been known to have the greatest uncertainty in the SPURR data base; yet by doing the analysis, the penetration of these technologies does not vary more than 10% by year 2000.

4.1 PROCESS HEAT SYSTEMS PENETRATION VS. ANNUAL O&M COST

The sensitivity of process heat systems (all are solar thermal technologies, see Table 2-1) penetration as a function of time to variation in annual O&M cost of -30% to +50% is shown in Figs. 4-1 through 4-4. Figure 4-5 shows the percentage variation in penetration of the SPURR output parameters for the year 2000. The changes in the process heat technologies were done as a group, but they could have been treated individually; i.e., the changes were the same for each technology in this group as the technology entered the marketplace (see market entry dates in Table 2-1). The following is a summary of the results:

	<u>Acc.* Installed Systems</u>	<u>Annual Energy Produced</u>	<u>Acc. Capital Cost</u>	<u>Acc. LCC Cost</u>
Type of relationship	Linear, inverse	Linear, inverse	Linear, inverse	Linear
Sense	Proper	Proper	Proper	Proper
Sensitivity	Low 0.2:1	Low 0.2:1	Low 0.2:1	None

In summary, the penetration of process heat systems is relatively insensitive to changes in O&M cost and does not affect accumulated life-cycle cost (see Fig. 4-5).

4.2 SOLAR THERMAL UTILITIES PENETRATION VS. ANNUAL O&M COST

The sensitivity of solar thermal utilities technologies (see Table 2.2) penetration as a function of time to variation in annual O&M cost of -30% to +50% is shown in Figs. 4-6 through 4-9. Figure 4-10 shows the percentage variation in penetration of the SPURR output parameters for the year 2000. The changes in the solar thermal utility technologies were done as a group in this analysis but could have been done individually; i.e., the changes were the same for each technology in this group as the technology entered the marketplace (see market entry dates in Table 2-1). The following is a summary of the results:

*Accumulated (Acc.).

Figure 4-1. Process Heat, % O&M Costs Change vs. Cumulative Installed Systems

Figure 4-2. Process Heat, % O&M Costs Change vs. Annual Energy Production

Figure 4-3. Process Heat, % O&M Costs Change vs. Accumulated Capital Costs

Figure 4-4. Process Heat, % O&M Costs Change vs. Accumulated Life-Cycle Costs

Figure 4-5. % Change in Process Heat Variables vs. Change in System O&M Costs for Year 2000

Figure 4-6. Solar Thermal, % O&M Costs Change vs. Cumulative Installed Systems

Figure 4-7. Solar Thermal, % O&M Costs Change vs. Annual Energy Production

Figure 4-8. Solar Thermal, % O&M Costs Change vs. Accumulated Capital Costs

Figure 4-9. Solar Thermal, % O&M Costs Change vs. Accumulated Life-Cycle Costs

Figure 4-10. % Change in Solar Thermal Utility Variables vs. % Change in System Annual O&M for Year 2000

	<u>Acc. Installed Systems</u>	<u>Annual Energy Produced</u>	<u>Acc. Capital Cost</u>	<u>Acc. LCC Cost</u>
Type of relationship	Linear, inverse	Linear, inverse	Linear, inverse	Linear, inverse
Sense	Proper	Proper	Proper	Proper
Sensitivity	Low 0.3:1	Low 0.3:1	Low 0.3:1	—

In summary, the penetration of solar thermal utilities was relatively insensitive to changes in O&M cost.

4.3 PHOTOVOLTAIC UTILITIES PENETRATION VS. ANNUAL O&M COST

The sensitivity of photovoltaic utility technologies (see Table 2-2) penetration as a function of time to variation in annual O&M cost of -30% to +50% is shown in Figs. 4-11 through 4-14. Figure 4-15 shows the percentage variation in penetration of the SPURR output parameters for the year 2000. The changes in the photovoltaic utility technologies were done as a group in this analysis but could have been done individually; i.e., the changes were the same for each technology in this group as the technology entered the marketplace (see market entry dates in Table 2-1). The following is a summary of the results:

	<u>Acc. Installed Systems</u>	<u>Annual Energy Produced</u>	<u>Acc. Capital Cost</u>	<u>Acc. LCC Cost</u>
Type of relationship	Linear, inverse	Linear, inverse	Linear, inverse	Nonlinear
Sense	Proper	Proper	Proper	Proper
Sensitivity	Moderate 1:1	Moderate 1.3:1	Moderate 1:1	Moderate 2:1

The penetration of photovoltaic utilities is sensitive to O&M cost and the effect is linear. In the penetration variables plotted, the effect is inverse (see Fig. 4-15) with the exception of accumulated life-cycle cost. In this case, the sensitivity to O&M is enough to reduce the accumulated life-cycle cost when O&M is reduced. In solar thermal utilities the sensitivity to O&M was not enough to show a reduction in accumulated life-cycle cost with reduced O&M cost. The nonlinear relationship (see Fig. 4-14) of accumulated life-cycle cost is due to the inclusion of photovoltaic fuel-saver systems in this group (as discussed in Section 3.0).

Figure 4-11. Photovoltaics, % O&M Costs Change vs. Cumulative Installed Systems

Figure 4-12. Photovoltaics, % O&M Costs Change vs. Annual Energy Production

Figure 4-13. Photovoltaics, % O&M Costs Change vs. Accumulated Capital Costs

Figure 4-14. Photovoltaics, % O&M Costs Change vs. Accumulated Life-Cycle Costs

Figure 4-15. % Change in Photovoltaic Utility Penetration Variables vs. % Change in Annual O&M Cost for Year 2000

4.4 BIOMASS SYSTEMS* PENETRATION VS. ANNUAL O&M COST

The sensitivity of biomass systems* technologies (see Table 2-2) penetration as a function of time to variation in annual O&M cost of -30% to +30% is shown in Figs. 4-16 through 4-19. Figure 4-20 shows the percentage variation in penetration of the SPURR output parameters for the year 2000. The changes in the biomass system technologies were done as a group, but they could have been done individually; i.e., the changes were the same for each technology in this group as the technology entered the marketplace (see market entry dates in Table 2-1). The following is a summary of the results:

	<u>Acc. Installed Systems</u>	<u>Annual Energy Produced</u>	<u>Acc. Capital Cost</u>	<u>Acc. LCC Cost</u>
Type of relationship	Linear, inverse	Linear, inverse	Linear, inverse	Linear, inverse
Sense	Proper	Proper	Proper	Proper
Sensitivity	Low 0.3:1	Low 0.3:1	Low 0.3:1	Low 0.3:1

The biomass system technologies are relatively insensitive to changes in O&M. The dominant factor in biomass cost are capital and fuel costs.

4.5 WECS UTILITY PENETRATION VS. ANNUAL O&M COST

The sensitivity of WECS utility technology (see Table 2-2) penetration as a function of time to variation in annual O&M cost of -30% to +50% is shown in Figs. 4-21 through 4-25. Figure 4-26 shows the percentage variation in penetration of the SPURR output parameters for the year 2000. In addition to the standard four variables plotted as a function of time, annual fuel utilization was plotted also to show the fuel savings by WECS. The changes in the WECS utility technologies were done as a group in this analysis but could have been done individually; i.e., the changes were the same for each technology in this group as the technology entered the marketplace (see market entry dates in Table 2-1). The following is a summary of the results:

	<u>Acc. Installed Systems</u>	<u>Annual Energy Produced</u>	<u>Acc. Capital Cost</u>	<u>Acc. LCC Cost</u>
Type of relationship	Linear, inverse	Linear, inverse	Linear, inverse	Nonlinear
Sense	Proper	Proper	Proper	Proper
Sensitivity	Low 0.4:1	Low 0.5:1	Low 0.4:1	Low 0.2:1

*Includes utility and synthetic products technologies (see Table 2-2).

Figure 4-16. Biomass, % O&M Costs Change vs. Cumulative Installed Systems

Figure 4-17. Biomass, % O&M Costs Change vs. Annual Energy Production

Figure 4-18. Biomass, % O&M Costs Change vs. Accumulated Capital Costs

Figure 4-19. Biomass, % O&M Costs Change vs. Accumulated Life-Cycle Costs

Figure 4-20. % Change in Biomass System Penetration Variables vs. % Change in Annual O&M Cost for Year 2000

Figure 4-21. WECS, % O&M Costs Change vs. Cumulative Installed Systems

Figure 4-22. WECS, % O&M Costs Change vs. Annual Energy Production

Figure 4-23. WECS, % O&M Costs Change vs. Annual Fuel Utilization

Figure 4-24. WECS, % O&M Costs Change vs. Accumulated Capital Costs

Figure 4-25. WECS, % O&M Costs Change vs. Accumulated Life-Cycle Cost

Figure 4-26. % Change in WECS Utility Penetration Variables vs. % Change in Annual O&M Cost for Year 2000

The WECS utility sensitivity to O&M cost was relatively low; however, the nonlinear effect of including fuel savers in this group (see additional discussion of this effect in Section 3.5) are observable in Figs. 4-25 and 4-26.

4.6 OTEC SYSTEM* PENETRATION VS. ANNUAL O&M COST

The sensitivity of OTEC system* technologies (see Table 2-2) penetration as a function of time to variation in annual O&M cost of -30% to +50% is shown in Figs. 4-27 through 4-30. Figure 4-31 shows the percentage variation in penetration of the SPURR output parameters for the year 2000. The changes in the OTEC system technologies were done as a group in this analysis but could have been done individually; i.e., the changes were the same for each technology in this group as the technology entered the marketplace (see market entry dates in Table 2-1). The following is a summary of the results:

	<u>Acc. Installed Systems</u>	<u>Annual Energy Produced</u>	<u>Acc. Capital Cost</u>	<u>Acc. LCC Cost</u>
Type of relationship	Nonlinear	Nonlinear	Nonlinear	Nonlinear
Sense	Proper	Proper	Proper	Proper
Sensitivity	High 3:1	High 3:1	High 3:1	High 3:1

As shown by the variation in capital cost, the discrete (discontinuous) behavior of penetration variables is observed (see Fig. 4-31). It is due to the small number of large plants (400 MW) that were built since the market entry of OTEC (1995). In this case, a 20% decrease in annual O&M cost was sufficient to have additional plants built but a change to -30% did not alter the number of plants built by year 2000. The same was true over the range from 0 to +20%; however, the life-cycle cost did reduce somewhat over this same range (see Fig. 4-31). Thus, the sensitivity to O&M seems high (when viewed as a percentage change from baseline) due to the small number of large plants that have been built.

*Includes OTEC electric generation and ammonia plants (see Table 2-2).

Figure 4-27. OTEC, % Annual O&M Costs Change vs. Cumulative Installed Cost

Figure 4-28. OTEC, % Annual O&M Costs Change vs. Annual Energy Production

Figure 4-29. OTEC, % Annual O&M Costs Change vs. Accumulated Capital Costs

Figure 4-30. OTEC, % Annual O&M Costs Change vs. Accumulated Life-Cycle Costs

Figure 4-31. % Change in OTEC System Penetration Variables vs. % Change in Annual O&M Cost for Year 2000

SECTION 5.0

BIOMASS FUEL COST SENSITIVITY ANALYSIS

Biomass fuel cost was varied in each SPURR utility sector to evaluate the effects on the following SPURR output parameters:

- accumulated installed systems (million ft² or GW),
- annual energy production (TWh or quads/yr),
- accumulated capital cost (\$), and
- accumulated life-cycle cost (\$).

Accumulated installed systems is a measure of the number of systems installed. Annual energy production measures the total energy production of all plants in a specific year. Accumulated capital cost is the total capital cost of all plants built by a specific year. Accumulated federal expense is the amount of federal money lost due to tax credits. Annual fuel utilization measures the amount of fuel burned. Accumulated life-cycle cost is the total life-cycle cost of systems installed at that time and includes capital cost, O&M, and fuel cost over the lifetime of the plant.

The data in this section are presented in two ways: (1) variation of penetration (in real units) as a function of time (1980 to 2000) and (2) percentage change from baseline scenario (penetration) versus percentage change in capital cost. Biomass systems showed low sensitivity (ratio of percentage change in penetration versus percentage change in capital cost) to changes in fuel cost.

In addition to displaying the data, a qualitative and quantitative analysis of the results is provided for three criteria: type of relationship, sense, and sensitivity. The type of relationship indicates whether the change in penetration was linear or nonlinear with respect to fuel cost. For biomass the change was linear. Sense attempts to evaluate the direction of change in penetration with respect to intuitive feel about penetration; i.e., if fuel cost increases, one feels that fewer systems should be built, or vice versa. This analysis of sense is looking for obvious errors in the SPURR methodology. For biomass the sense was "proper." The final evaluation uses sensitivity in a qualitative (high, low, moderate, none) and a quantitative sense (if change was linear) by reporting the approximate proportionality of the change in penetration with the change in fuel cost. The sensitivities range from a high of 0.7:1 to a low of 0.2:1.

BIOMASS UTILITY AND SYNTHETIC FUELS PENETRATION VS. FUEL COST

The sensitivity of biomass utility and synthetic fuels technology penetration as function of time to variation in feedstock cost of -10% to +20% is shown in Figs. 5-1 through 5-4. Figure 5-5 shows the percentage variation in penetration of the SPURR output parameters for the year 2000. The changes in the biomass technologies were done as a group in this analysis but could have been done individually; i.e., the changes were the same for each technology in this group as the technology entered the marketplace (see market entry dates in Table 2-1). The following is a summary of the results:

Figure 5-1. Biomass, % Fuel Costs Change vs. Cumulative Installed Systems

Figure 5-2. Biomass, % Fuel Costs Change vs. Annual Energy Production

Figure 5-3. Biomass, % Fuel Costs Change vs. Accumulated Capital Cost

Figure 5-4. Biomass, % Fuel Costs Change vs. Accumulated Life-Cycle Cost

Figure 5-5. % Change in Biomass System Penetration Variables vs. % Change in Annual Fuel Cost for Year 2000

	<u>Acc. Installed Systems</u>	<u>Annual Energy Produced</u>	<u>Acc. Capital Cost</u>	<u>Acc. LCC Cost</u>
Type of relationship	Linear, inverse	Linear, inverse	Linear, inverse	Linear
Sense	Proper	Proper	Proper	Proper
Sensitivity	Low 0.3:1	Low 0.1:1	Low 0.6:1	Low 0.1:1

Biomass sensitivity to fuel cost was relatively low.

SECTION 6.0

CONCLUSIONS

Sensitivity analysis was performed on the agricultural and industrial process heat and utility market sectors of the SPURR model which utilized the DPR baseline scenario. The objective of this sensitivity analysis is to determine if variations in solar system capital cost, operation and maintenance cost, and fuel cost (for biomass only) correlate with "common sense" and do not offend basic intuition. In general, this effort is part of a much larger issue: validation of SPURR.

Variations of the factors were evaluated for the following output parameters (others are available):

- accumulated installed systems,
- annual energy production,
- accumulated capital cost, and
- accumulated life-cycle cost.

An analysis of the results is presented for three criteria: (1) type of relationship, (2) sense, and (3) sensitivity.

The type of relationship indicates whether the change in penetration is linear or nonlinear with respect to a change in a given variable, while sense attempts to evaluate the direction of change with respect to an intuitive feeling about penetration. Sensitivity is the ratio of percentage change in penetration versus a percentage change in a given factor (e.g., capital cost).

6.1 CAPITAL COST

Capital cost was varied while all other parameters remained constant. The technologies showing high ($>1:1$) sensitivity were process heat (solar thermal), solar thermal (utilities), photovoltaics, and OTEC.

An inverse linear variation affecting the accumulated installed systems and annual energy production was observed in process heat systems. As capital cost decreases, the number of solar units built increases. Consequently, the number of "installed systems" and "annual energy production" increase.

The nonlinear effect in accumulated capital cost and accumulated life-cycle cost is a result of two opposing functions: market share and capital cost. Accumulated capital cost increases due to higher market shares (when solar costs are reduced) but decreases due to the reduced capital cost of each solar unit.

Any change in capital costs over the study range (± 60) reduces accumulated capital and accumulated life-cycle costs by the year 2000.

A nonlinearity is observed in accumulated life-cycle cost of solar thermal utility technologies. This is due to the inclusion of fuel-saver systems. The life-cycle cost of a fuel-saver system is negative; i.e., it saves more fuel cost than the cost to build it.

This effect is also predominant in photovoltaic utility technologies. Photovoltaic systems show a high, inverse proportional sensitivity to changes in capital cost.

Wind energy conversion systems (WECS) exhibit a low sensitivity to changes in capital cost but show significant effects of fuel savers in accumulated capital costs and accumulated life-cycle costs. Capital costs are the major cost in these systems. Fuel costs are zero and operating and maintenance costs are negligible.

The penetration of biomass systems is relatively insensitive to changes in capital costs. Consistent behavior (linear-inverse proportionality) is observed across all penetration variables.

Ocean Thermal Energy Conversion (OTEC) systems are extremely sensitive on a percentage basis. This is due to the small number of plants built (a change of one plant when two are built results in a 50% change in capital costs). SPURR OTEC plants also have late market entry dates.

6.2 OPERATING AND MAINTENANCE COSTS

Annual operating and maintenance costs were varied in each SPURR sector to evaluate the effects on the stated parameters. The only technology exhibiting a high sensitivity was OTEC. This was attributed to the relatively small number of large plants that had been built in the simulation.

Overall, the analysis of penetration of solar technologies shows a variation of less than 10% by the year 2000. These results should be qualified in light of the uncertainty surrounding estimates of O&M cost for future technologies in the SPURR data base.

Process heat systems and solar thermal utility technologies are insensitive to changes in O&M costs and do not affect accumulated life-cycle costs.

Photovoltaic utility technologies are moderately sensitive to O&M cost and the effect is linear. The nonlinear nature of accumulated life-cycle costs is due to the inclusion of fuel savers.

O&M costs are large enough to significantly reduce accumulated life-cycle costs when O&M costs are reduced in photovoltaic systems.

WECS systems exhibit low sensitivity and nonlinear effects associated with fuel savers.

Biomass technologies are insensitive to changes in O&M costs. The critical parameters in this case are capital and fuel costs.

6.3 FUEL COST: BIOMASS

The effects on penetration of varying biomass fuel cost are linear. Sensitivity ratios are low, ranging from 0.7:1 to 0.2:1.

6.4 SUMMARY

This study has practical applications for engineering improvements in solar technologies and is useful as a planning tool in the R&D allocation process. The results of the analysis for the variables studied indicate that SPURR simulation is consistent with intuitive effects for these variables.

Further research efforts will be conducted after a coding problem encountered in the output reports of the SHACOB component is corrected. A similar analysis will be performed in this sector.

SPURR must also be modified so that variations in system lifetime can be included. Presently, sensitivity analysis of system lifetime will produce results that are counter-intuitive and are the result of the economic equations in the model that cannot handle systems with different lifetimes. Comparisons between systems require a common time basis, including a common year for cost comparison and a common operating period. "This is a consequence of the annualization of the energy cost into a stream of payments that is constant throughout the lifetime"[5].

SERIO

SECTION 7.0**REFERENCES**

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