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PV HISTORY: LESSONS FOR THE FUTURE

SPECTROLAB, INC.

E.L. Ralph

PV Program Characteristics

- CREDIBILITY AT HIGH LEVEL
- PRACTICALITY HAS BEEN EMPHASIZED.
- LARGE SCALE APPLICATION PROVEN FEASIBLE
- LARGE TECHNOLOGY BASE (INDUSTRY, UNIVERSITY, GOVERNMENT)
- TERRESTRIAL INDUSTRY ESTABLISHED
- PRIDE IN BEING PART OF IT

Early Planning and Goals

• CONVENTIONAL SILICON TECHNOLOGY	~ $2/$W_p$	(1975 $)
• ADVANCED SILICON TECHNOLOGY	~ $0.50/$W_p$	"
• FUTURE POTENTIAL	~ $0.30/$W_p$	"

- MARKETS CHANGE AS PRICES DECREASE

  REMOTE → LDC VILLAGES → RESIDENTIAL → POWER STATIONS

- INDUSTRY MUST BE WELL ESTABLISHED

PLENARY SESSION: E.L. RALPH

PV Program History

- BASED ON STRONG SPACE TECHNOLOGY (60's)
- STRUGGLING SOLAR ENERGY SOCIETY PROVIDED BACKGROUND
- "A PLAN" PRESENTED TO IEEE/PSC (1970)
- NSF/RANN PROGRAM SET GOALS (1971)
- NSF/FEA PROJECT INDEPENDENCE BLUEPRINT REPORT (1974)
- ERDA 10 YEAR PLAN INITIATED (1976)

Major Accomplishments

- FIRM PV REMOTE MARKET ESTABLISHED
- $\$10/W_p$ MODULE IN PRODUCTION
- $\$2.80/W_p$ MODULE TECHNOLOGY READY
- * DICHLOROSILANE SILICON PROCESS DEVELOPED AND BEING APPLIED
  COSTS REDUCED FACTOR OF 3 AND CAPACITY DOUBLED
- * LARGE CZ CRYSTAL GROWTH FURNACES AVAILABLE
  MELT REPLENISHMENT, AUTOMATION, 4-6 INCH DIA.
- SEVERAL SILICON SHEET TECHNOLOGIES DEMONSTRATED
- MODULE DURABILITY IMPROVED - FIELD TEST DATA AVAILABLE
- SYSTEM STUDIES INDICATE PHOTOVOLTAICS CAN COMPETE

* ALSO PROVIDED SIGNIFICANT BENEFITS TO OVERALL SEMICONDUCTOR INDUSTRY

Lessons for the Future

- THE TASK AHEAD IS LARGE (HIGH VOLUME LOW COST)
- TIME SCALE LONGER THAN PREDICTED (> 15 YEARS)
  BUDGET CONSTRAINTS, CAPITAL INVESTMENT, MARKET GROWTH, OIL GLUT
- PLANS MUST BE MODIFIED AND BECOME MORE SELECTIVE
- OLD PROJECTIONS AND GOALS MUST BE REEVALUATED
- MAINTAIN CREDIBILITY AND RELEVANCE (BE PRACTICAL)
- RESEARCH ORIENTATION PROBABLY APPROPRIATE
  ACCELERATED PROGRAM WOULD BE WASTEFUL

Research Objectives

- INCREASE EFFICIENCY
- LOWER MATERIAL COST
- AVOID DUPLICATION (GOVERNMENT AND INDUSTRY)
- EMPHASIZE HIGH RISK/HIGH PAYOFF

Research Needs

- MAJOR ADVANCEMENTS FROM CURRENT TECHNOLOGIES
  (20-25% EFFICIENCY SINGLE OR SEMI-CRYSTAL SI OR GAAS)
  - MODELLING AND DEVICE DESIGN (INC. EFF.)
  - MATERIAL STUDIES
  - DEVICE/MODULE PROCESSES
  - ANALYTICAL METHODS
  - RELIABILITY PHYSICS
- ADVANCEMENTS FROM "NEXT STEP" TECHNOLOGIES
  (12-17% EFFICIENCY THIN FILM POLYCRYSTALLINE MATERIALS)
  - MATERIAL STUDIES SI, CDTE, ZNP, GAAS, INP, $CuInSe_2$
  - EFFICIENCY IMPROVEMENT
  - CRYSTAL BOUNDARY EFFECTS
  - STABILITY PHYSICS
- ADVANCEMENTS FROM "LARGE STEP" TECHNOLOGIES
  (25-50% EFFICIENCY ADVANCED CONCEPT CELL DESIGNS)
  - MULTI-BANDGAP APPROACHES
  - SUPERLATTICE STRUCTURES

UTILITIES PERSPECTIVE

OMIT

ELECTRIC POWER RESEARCH INSTITUTE

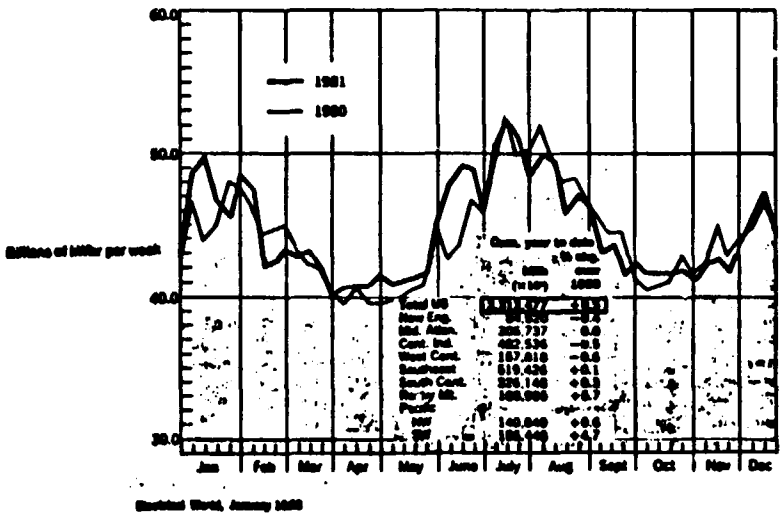
R.W. Taylor

"WOULD YOU TELL ME, PLEASE, WHICH WAY
I OUGHT TO GO FROM HERE?"

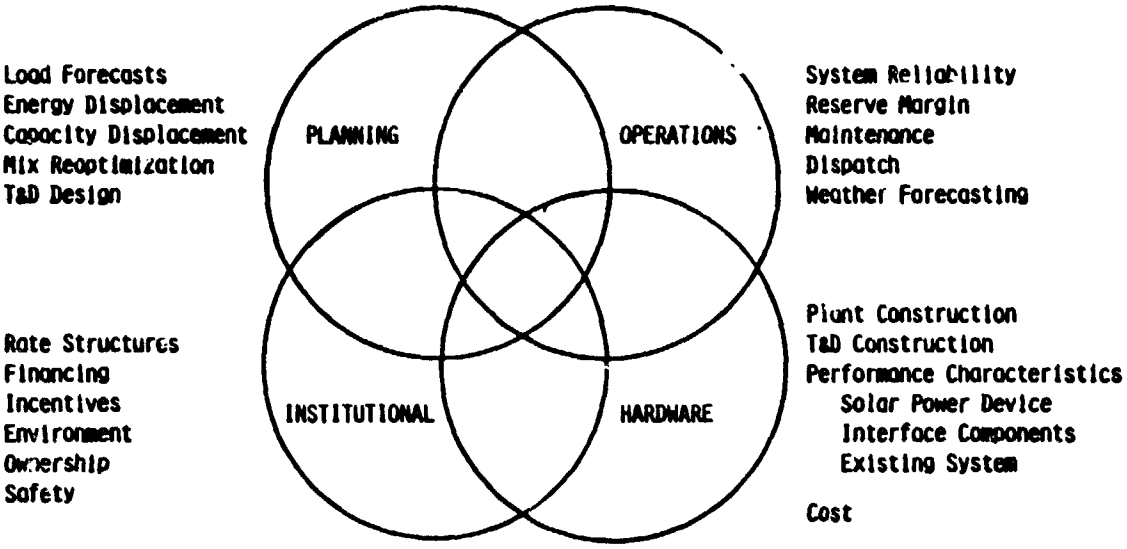
"THAT DEPENDS A GOOD DEAL ON WHERE
YOU WANT TO GET TO."

LEWIS CARROLL

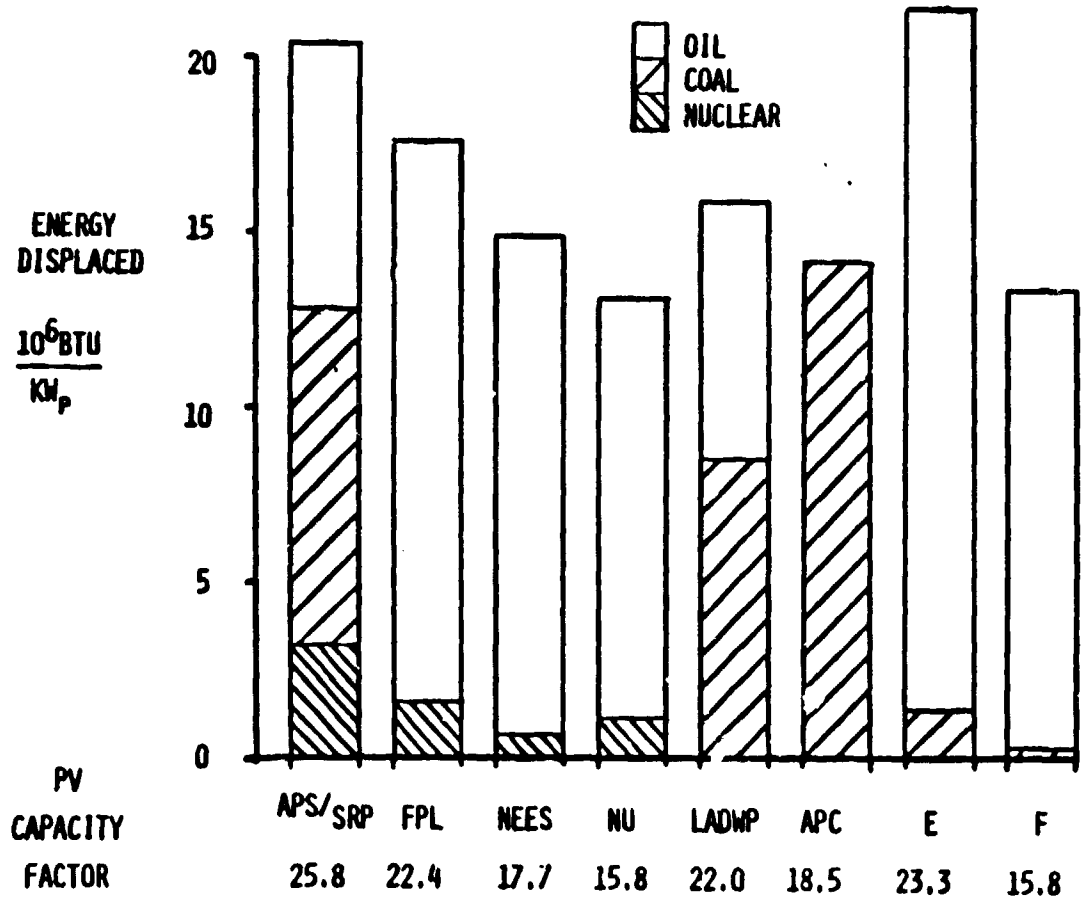
Weekly U.S. Electric Consumption



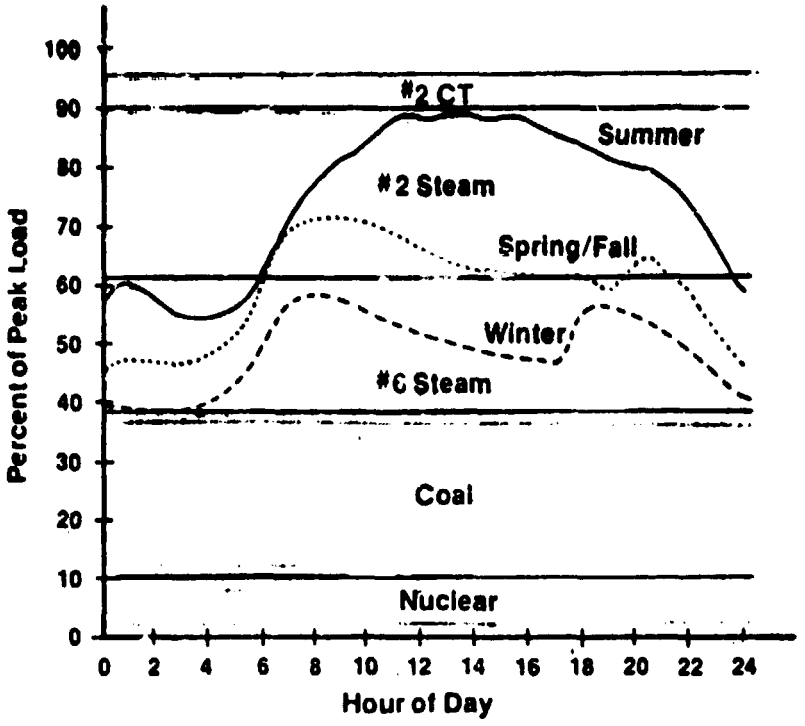
The Solar Equation



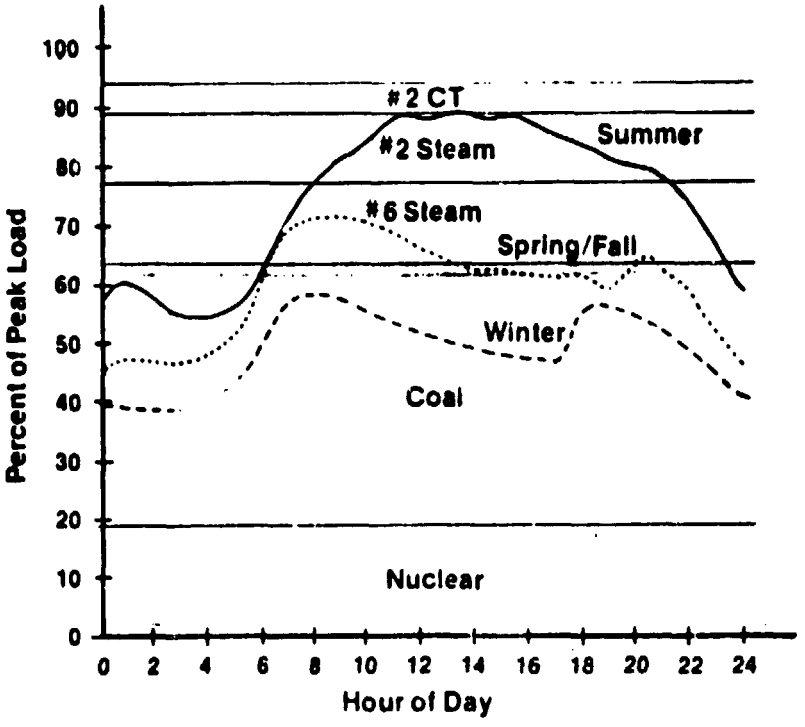
PV Value Analysis Comparison



1985 Load Profile and Fuel Mix: Reference Case

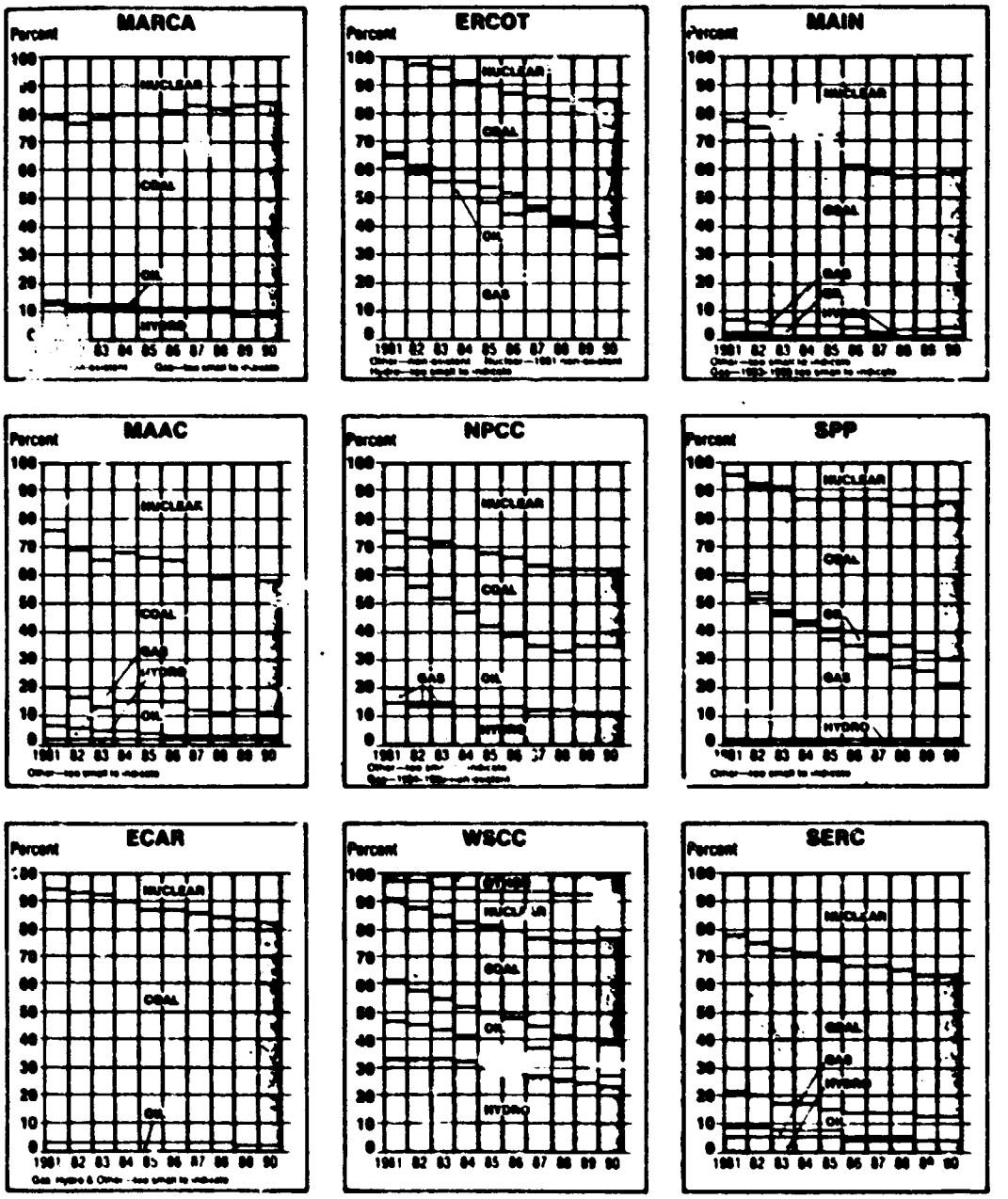


1998 Load Profile and Fuel Mix: Reference Case



Regional Electric Generation by Principal Energy Sources (by Percentage of Total)

(Contiguous U.S.)

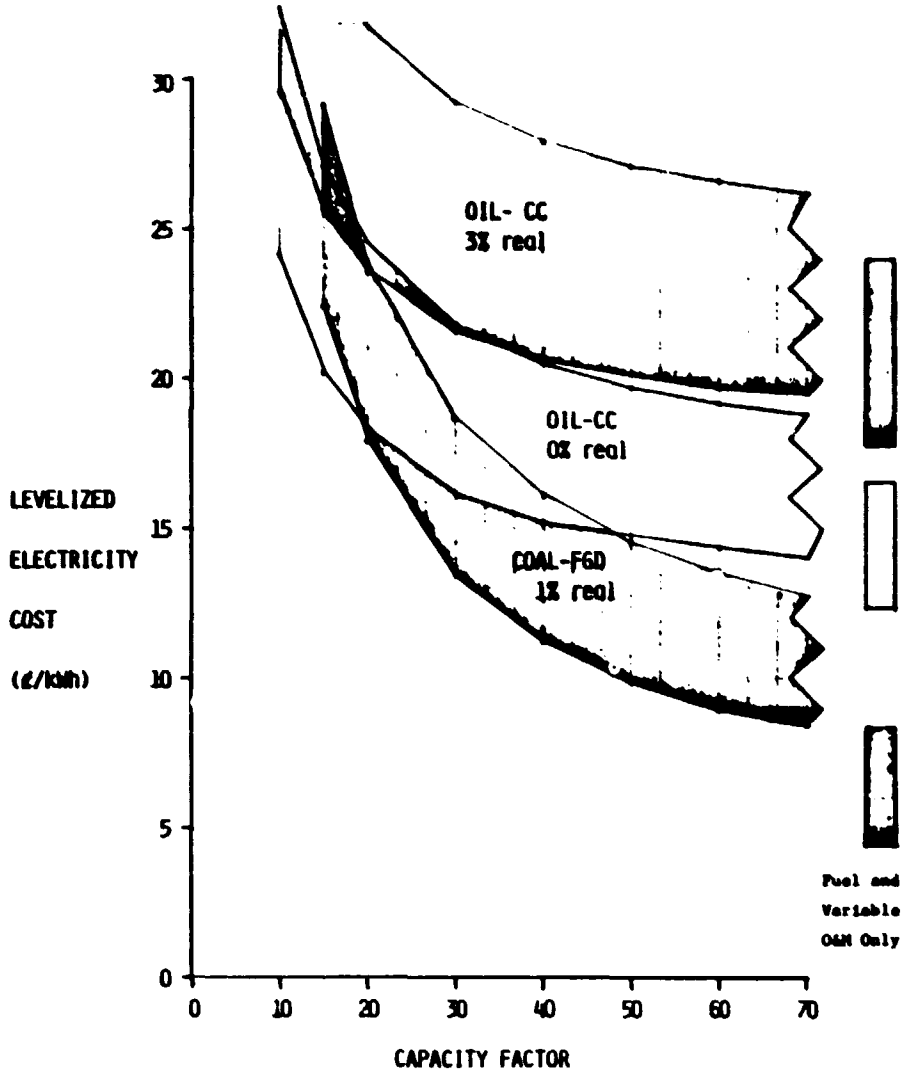


FROM: Electric Power Supply and Demand 1981-1990
July 1981, National Electric Reliability Council

Conventional Plant Characteristics (1982 $)

	COAL (Subcritical 500MW)	OIL (Combined Cycle 250MW)
TOTAL CAPITAL REQUIREMENT	$1113-1246/kW	$496-653/kW
FIXED O&M	$14.9-19.5/kW-yr	$6.2-8.7/kW-yr
VARIABLE O&M	$0.0024-0.0054/kWh	$0.0014-0.0021/kWh
HEAT RATE	9970-10410	8600-8685
FUEL COST	$1.50-2.60/$10^6$ BTU	$6.00-8.00/$10^6$ BTU
REAL ESCALATION	1%/yr	0-3%-yr
INFLATION 8.5%/yr	DISCOUNT RATE 12.5%/yr	FCR = 0.18

Range of Costs for Two New Generation Sources



Additional Sources of Competition

- New Baseload Capacity
- Increased Regional Power Pooling
- Conservation and Load Management
- Storage

Critical PV System Parameters

System Efficiency	=	? Modules X ? BOS
System Cost	=	[$ Modules + $BOS][1+Indirect] + $O&M
System Value	=	F (Utility, Performance)

Project Cost by Cost-Account Categories of Current Experiments

Project	UPS		Light Mfg.		Radar Sta.		Shop. Ctr.		High Sch.		Sci. & Art	
Cost Category	$/m^2	$/W$_p$	$/m^2	$/W$_p$	$/m^2	$/W$_p$	$/m^2	$/W$_p$	$/m^2	$/W$_p$	$/m^2	$/W$_p$
Engineering	593	10.56	329	3.09	76	1.25	560	8.41	495	7.42	373	3.06
PV Modules	576	10.23	1454	13.63	1114	18.33	753	11.32	725	10.85	1435	11.77
Structure	90	1.60	305	2.86	41	0.67	44	0.66	46	0.69	277	2.27
Foundation	18	0.32	122	1.14	30	0.50	70	1.05	121	1.81	84	0.69
Civil Work	54	0.96	(1)	(1)	85	1.40	137	2.05	178	2.67	195	1.60
Electrical	219	3.91	76	0.71	86	1.42	173	2.59	231	3.46	104	0.85
Pwr. Cond. & Ctrl.	108	1.91	183	1.71	76	1.25	180	2.70	159	2.38	56	0.46
Buildings	54	0.96	(2)	(2)	18	0.47	38	0.57	20	0.29	(2)	(2)
TOTAL	1712	30.45	2469	23.14	1536	25.28	1955	29.35	1975	29.58	2524	20.70

Notes: (1) Roof-Mounted. (2) Control Located In Application Building. (3) Roof-Mounted, Reroof Cost.

Central-Station Balance-of-System Cost Summary (December 1982 $)

Item	Flat Plate		Concentrator	
	$/M^2	$/KW	$/M^2	$/KW
Array Structure	28.6		•	
Module Installation	7.1		13	
Foundation	5.3		17	
Land	1.0		2.6	
Site Preparation	8		15	
Roads, Fences, Other Civil	1.7		2.9	
DC Subsystem		24		73
Power Conditioning		93		93
AC Subsystem		12		15
Switchyard		14		14
Station Power	0.3		0.8	
Instrumentation	1		3.5	
Grounding	0.9		1.3	
Surge Protection	4		4	
Total BOS Field Cost	58	143	60	195

•Array Structure & Tracking Included with Module Cost

Balance-of-System Efficiencies (%)

Item	Flatplate	Concentrator
Module Degradation	95	95
Dirt Accumulation	95	95
Module Mismatch	97	97
Interarray Shadowing	98.5	99.9
DC Subsystem	99.4	98.9
Power Conditioning	95	95
AC Subsystem	99.5	99
Switchyard	99	99
[illegible]tion Power	99.9	99.9
TOTAL	80	80

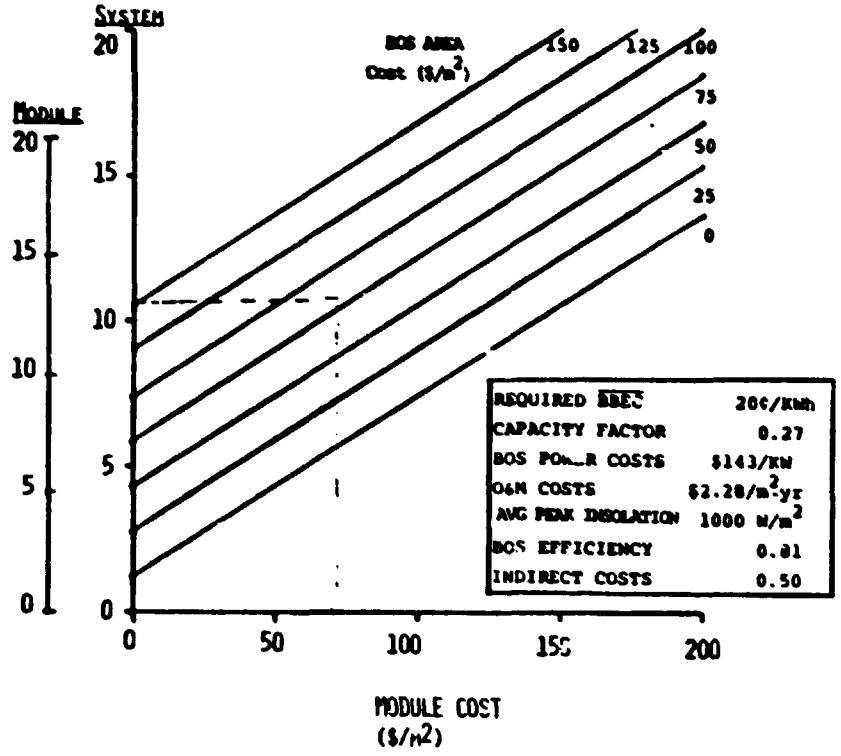
Operating and Maintenance ($/m^2-yr)

ITEM	FLATPLATE	CONCENTRATOR
OPERATORS	0.54	0.54
PLANT MAINTENANCE	0.96	1.36
ARRAY CLEANING (~1/MO)	0.51	0.51
MODULE REPLACEMENT (0.2%/YR)	0.27	0.28
	2.28	2.69

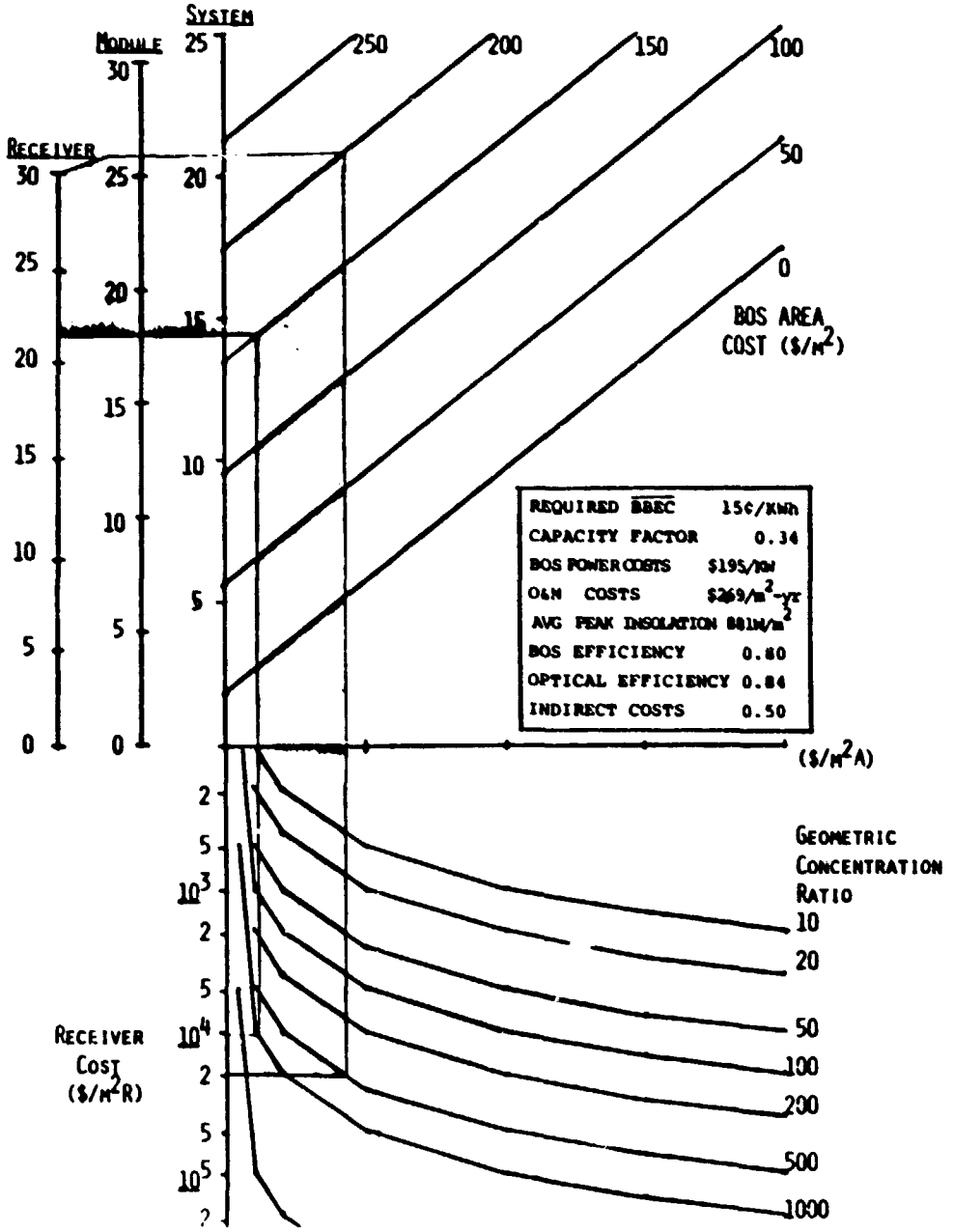
Indirect Costs

OWNER'S COSTS (EXCLUDING LAND)	6%
A & E FEE (MINIMAL MODULE CHECKOUT)	6%
CONTINGENCY	20%
INTEREST DURING CONSTRUCTION (3 YR CONSTRUCTION PERIOD)	12%
	50%

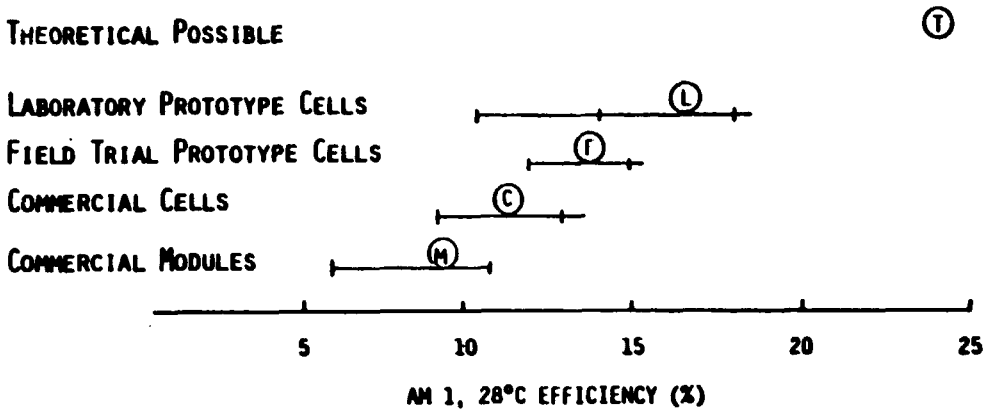
Flat-Plate Cost-Efficiency Tradeoff



Concentrator Cost-Efficiency Tradeoff



Comparison of Typical Efficiency Ranges



Daily Performance of Lovington Array During 1981