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PROCEEDINGS OF THE USDOE PHOTOVOLTAICS TECHNOLOGY DEVELOPMENT AND APPLICATIONS PROGRAM REVIEW

November 7-9, 1978
Arlington, Virginia

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OAO Corporation
Beltsville, Maryland

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U.S. DOE PHOTOVOLTAICS TECHNOLOGY
DEVELOPMENT AND APPLICATIONS PROGRAM REVIEW

Arlington, Virginia
November 7-9, 1978

Prepared for

Department of Energy Photovoltaic Branch
Division of Distributed Solar Technology

In Response to
Contract #JPL-BB-689-604

Prepared by

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PREFACE

This report of the Proceedings of the DOE Photovoltaic Technology Development and Application Program Review has been assembled to provide the participants and attendees with a compilation of abstracts of the presentations. Copies of visual aids used have been printed in the best available form.

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SECTION I. OVERVIEW AND PROJECT STATUS REPORTS

N79-25486

PHOTOVOLTAIC MISSION ANALYSIS

S. L. Leonard

The Aerospace Corporation

El Segundo, California

Presented at

U.S. Department of Energy

PHOTOVOLTAICS TECHNOLOGY DEVELOPMENT AND APPLICATIONS PROGRAM REVIEW

Arlington, Virginia

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Photovoltaic Mission Analysis

OBJECTIVE

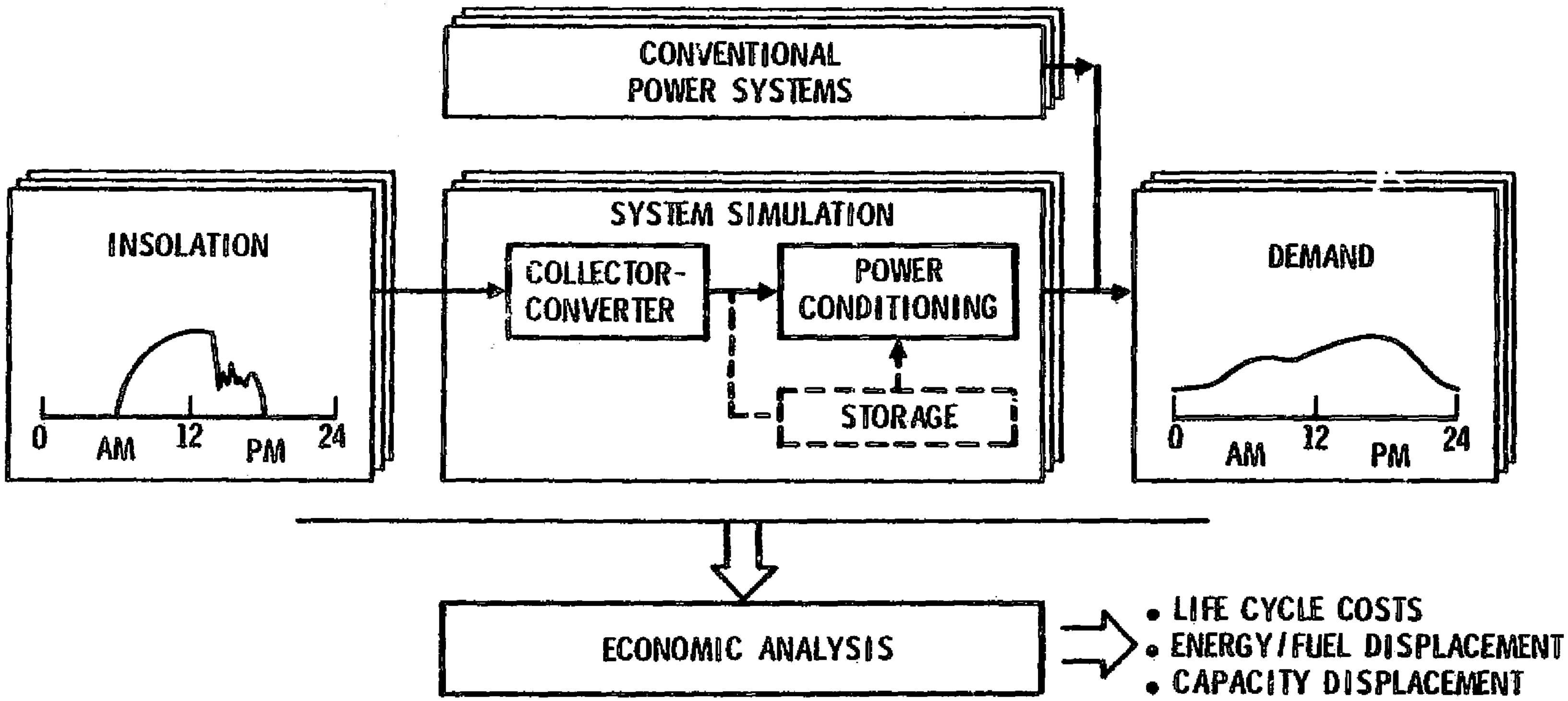
TO SUPPORT THE PLANNING, DEVELOPMENT, AND GUIDANCE OF THE NATIONAL PHOTOVOLTAIC PROGRAM BY BROAD-BASED STUDIES DESIGNED TO

- IDENTIFY AND EVALUATE PHOTOVOLTAIC APPLICATIONS LIKELY TO HAVE MAJOR ENERGY IMPACT
- IDENTIFY AND EVALUATE APPROPRIATE STRATEGIES FOR STIMULATING THE GROWTH OF PHOTOVOLTAIC MARKETS
- IDENTIFY AND MAKE INITIAL EVALUATION OF CRITICAL ISSUES, DEFINE SCOPE OF SUBSEQUENT DETAILED EXAMINATIONS

AND THROUGH SPECIAL QUICK-RESPONSE ANALYSES OF TOPICS EFFECTING PROGRAM STRATEGY OR PLANS

Photovoltaic Mission Analysis
APPROACH

- CENTRAL ELEMENT IS COMPUTER SIMULATION OF PERFORMANCE AND ECONOMICS OF PHOTOVOLTAIC SYSTEMS IN CANDIDATE APPLICATIONS



- APPLICATION EVALUATIONS SERVE AS BASIS FOR
  - STUDIES OF STRATEGIES (incentives, subsidies) FOR ACHIEVING EARLY PHOTOVOLTAIC MARKET PENETRATION
  - ASSESSMENTS OF MARKET SIZE
  - INITIAL STUDIES OF OTHER CRITICAL ISSUES
  - ASSISTANCE IN PROGRAM PLANNING AND GUIDANCE

Photovoltaic Mission Analysis

ACCOMPLISHMENTS

APPLICATIONS		BREAKEVEN ARRAY PRICE	CONCLUSIONS
CENTRAL STATION (utility)		$100-300/kW$_{pk}$	• FLAT-PLATE SYSTEMS CAN COMPETE WITH COAL IN MOST AREAS OF U.S. BY 2000 • SYSTEMS WITH MEDIUM OR HIGH CONCENTRATION CAN COMPETE BY 2000 IN SOUTHWEST IF THERMAL ENERGY IS PROFITABLY USED
INTERMEDIATE LOAD CENTERS ON-SITE		$800-900/kW$_{pk}$ (School) $300-500/kW$_{pk}$ (Shopping center) $300-400/kW$_{pk}$ (Office building)	• OF CASES EXAMINED -- SCHOOL, SHOPPING CENTER, OFFICE BUILDING -- SCHOOL APPEARS TO BE MOST ATTRACTIVE • SCREENING IDENTIFIES LOW-RISE APARTMENTS, PULP/PAPER MILLS AS ATTRACTIVE CANDIDATES FOR FURTHER STUDY
RESIDENTIAL ON-SITE	ELECTRIC ONLY	$250-600/kW$_{pk}$	• OWNERSHIP BY HOME-OWNER HAS SIGNIFICANT FINANCIAL ADVANTAGE OVER OWNERSHIP BY UTILITY
	TOTAL ENERGY	$\gtrsim$ $1000/kW$_{pk}$	• COST-EFFECTIVE SYSTEMS REQUIRE SUBSTANTIAL BACK-UP • ALL-PHOTOVOLTAIC SYSTEMS TEND TO BE PREFERABLE TO SYSTEMS WITH SOLAR THERMAL PANELS (separate or combined)

Photovoltaic Mission Analysis

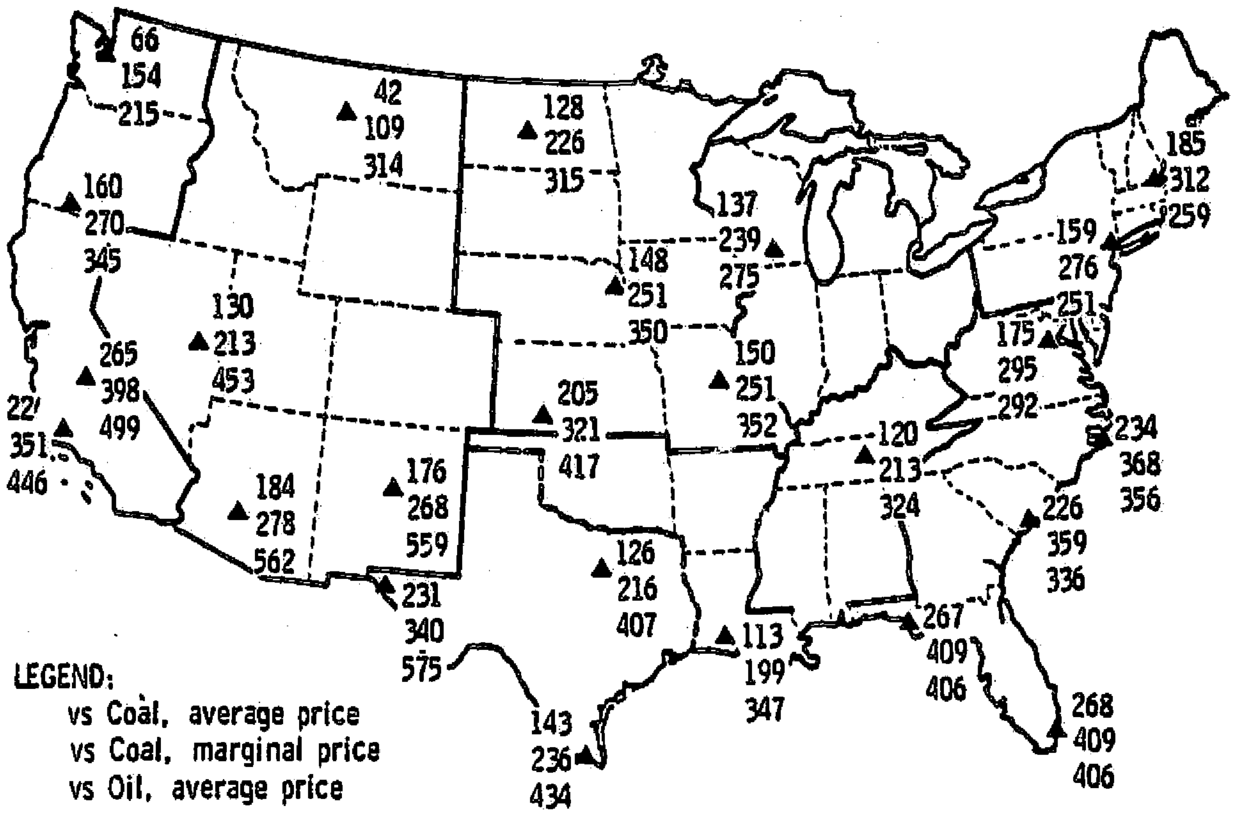
ACCOMPLISHMENTS

CRITICAL ISSUES	
MAGNITUDE OF NEAR-TERM (1976-1986) MARKETS	• U.S. NON-MILITARY MARKET COULD REACH 25 MW_{pk}/YEAR BY 1986
CONVERSION EFFICIENCY REQUIREMENTS	• FOR FLAT-PLATE UTILITY SYSTEMS, MINIMUM EFFICIENCY IS ~5% FOR ZERO ARRAY PRICE, >12% FOR \$300/kW_{pk} ARRAY PRICE • HIGH-CONCENTRATION UTILITY SYSTEMS MAY BE COMPETITIVE OUTSIDE SOUTHWEST BY 2000 IF CELL EFFICIENCY IS ≥ 35%
REGIONAL VARIATION OF INSOLATION	• FLAT-PLATE UTILITY SYSTEMS WILL BE ABLE TO COMPETE OVER MUCH OF U.S. IN 2000 IF ARRAY PRICE IS \$100-300/kW • HIGH-CONCENTRATION SYSTEMS WILL BE ABLE TO COMPETE IN SOUTHWEST IN 2000 IF THERMAL ENERGY IS PROFITABLY USED
THE VALUE OF ELECTRIC STORAGE	• ELECTRIC STORAGE PROVIDES NO ECONOMIC ADVANTAGE IF ITS LIFE-CYCLE COST IS MORE THAN ABOUT \$30/kWh
SOCIETAL BENEFITS OF PHOTOVOLTAIC POWER	• THE NON-INTERNALIZED SOCIETAL COSTS OF COAL-FIRED GENERATION AMOUNT TO AT LEAST 5 mills/kWh
STRATEGIES TO STIMULATE EARLY PHOTOVOLTAIC MARKET PENETRATION	• SUBSTANTIAL PHOTOVOLTAIC PENETRATION OF UTILITY APPLICATIONS (reaching 4% of U.S. requirements in 2000) COULD BE FINANCED BY RELATIVELY SMALL SUBSIDY FROM UTILITY CUSTOMERS (~\$8/year per residential customer)
ENVIRONMENTAL AND OCCUPATIONAL HAZARDS OF ARRAY PRODUCTION	• HAZARDS EXIST BUT ARE CONTROLLABLE BY STANDARD INDUSTRIAL PROCEDURES, EXCEPT, PERHAPS, IN CASE OF COMBUSTION OF CdS/Cu_2 ARRAYS

Breakeven Array Prices in 2000

1975 DOLLARS PER kWpk

PHOTOVOLTAIC CENTRAL STATION POWER PLANTS vs
NEW FOSSIL-FUEL INTERMEDIATE-LOAD PLANTS



Pennies a Day

FINANCING FINANCING EARLY DEPLOYMENT OF PHOTOVOLTAIC CENTRAL STATION POWER PLANTS BY MEANS OF A USER SUBSIDY

OBJECTIVE:

- TO DETERMINE THE COST TO RESIDENTIAL CUSTOMERS OF SUBSIDIZING PHOTOVOLTAIC POWER PLANT DEPLOYMENT THROUGH INCREASES IN PER-kWh CHARGES FOR ELECTRIC ENERGY

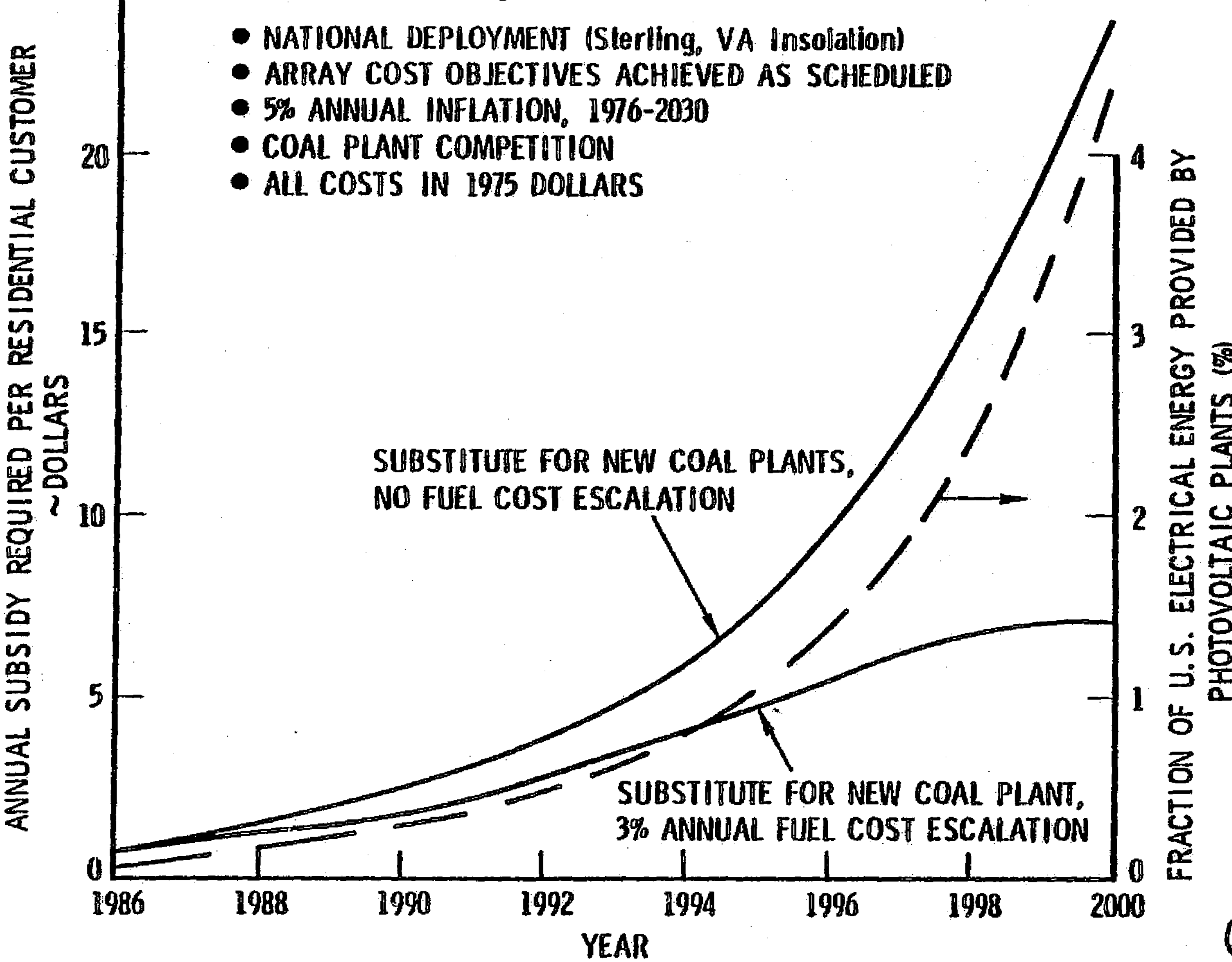
ASSUMPTIONS:

- BEGINNING IN 1986, PHOTOVOLTAIC POWER PLANTS ARE INSTALLED AT AN EXPONENTIALLY-INCREASING RATE, PROVIDE 4.4% OF U.S. ELECTRICITY IN YEAR 2000
- ADDITIONAL COST OF GENERATION IS ADDED TO ELECTRICITY BILLS OF ALL CUSTOMERS ON A PER-kWh BASIS

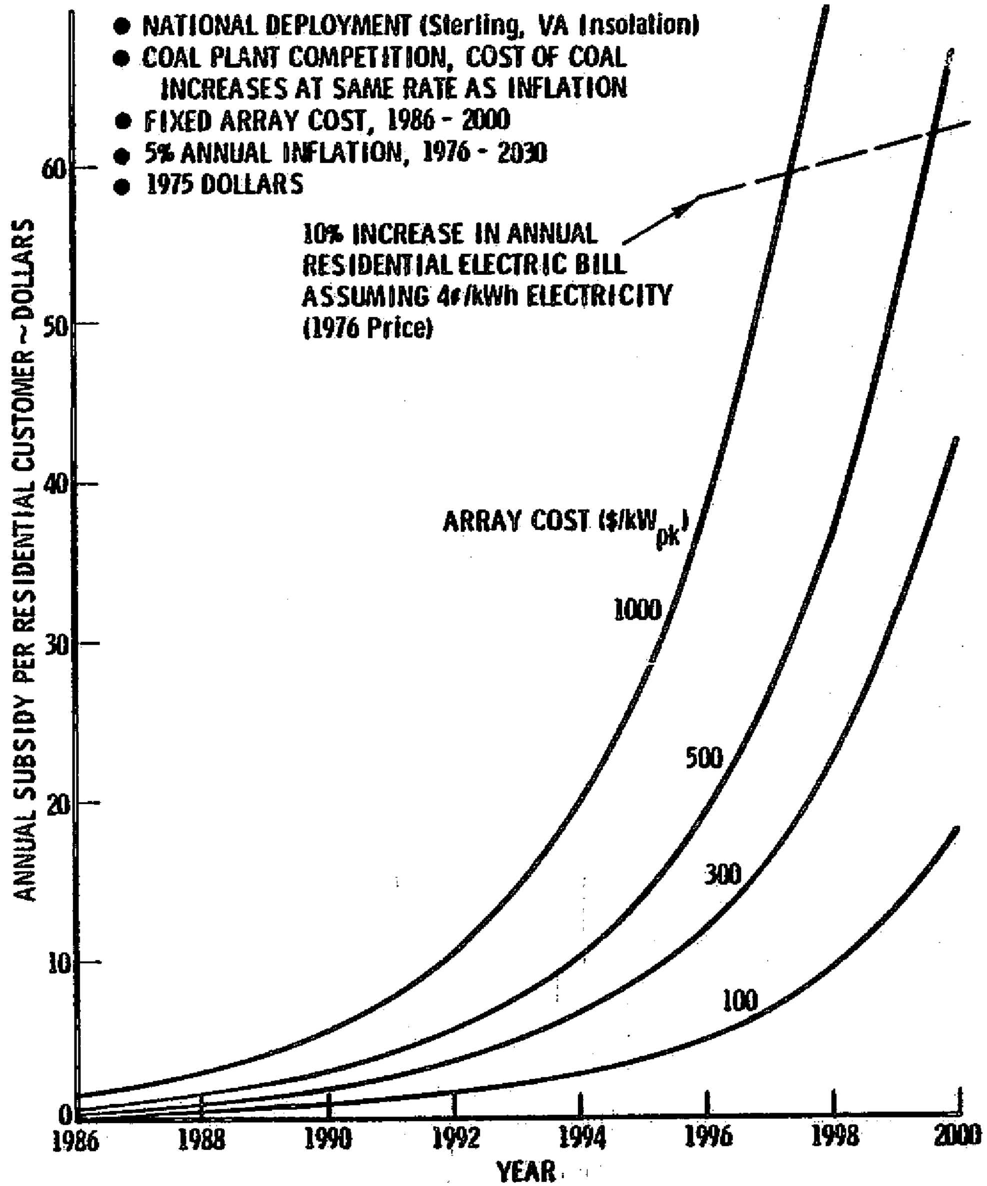
JUSTIFICATION:

- CONSTRUCTION OF NUCLEAR POWER PLANTS IS IMPEDED BY
  - WASTE DISPOSAL UNCERTAINTIES
  - HAZARDS OF FUEL DIVERSION, SABOTAGE BY TERRORISTS
  - SITING PROBLEMS
- COAL-FIRED POWER PLANT CONSTRUCTION IS ALSO INHIBITED BY ENVIRONMENTAL CONCERNS (cancellation of Kaiparowits plant is an example)
- DOMESTIC OIL SUPPLIES ARE LIMITED AND INCREASED OIL IMPORTATION IS UNDESIRABLE BECAUSE OF
  - THREAT OF EMBARGO, POLITICAL LEVERAGE
  - NEGATIVE EFFECT ON U.S. BALANCE OF TRADE
- DOMESTIC GAS SUPPLIES ARE ALSO LIMITED; HAZARDS OF LNG STORAGE ARE IMPEDING SELECTION OF STORAGE SITES
- BECAUSE OF THEIR IMMENSE VALUE AS CHEMICAL FEEDSTOCKS, USE OF COAL AND OIL AS FUEL IS QUESTIONABLE PUBLIC POLICY

Annual Subsidy Required Per Residential Customer



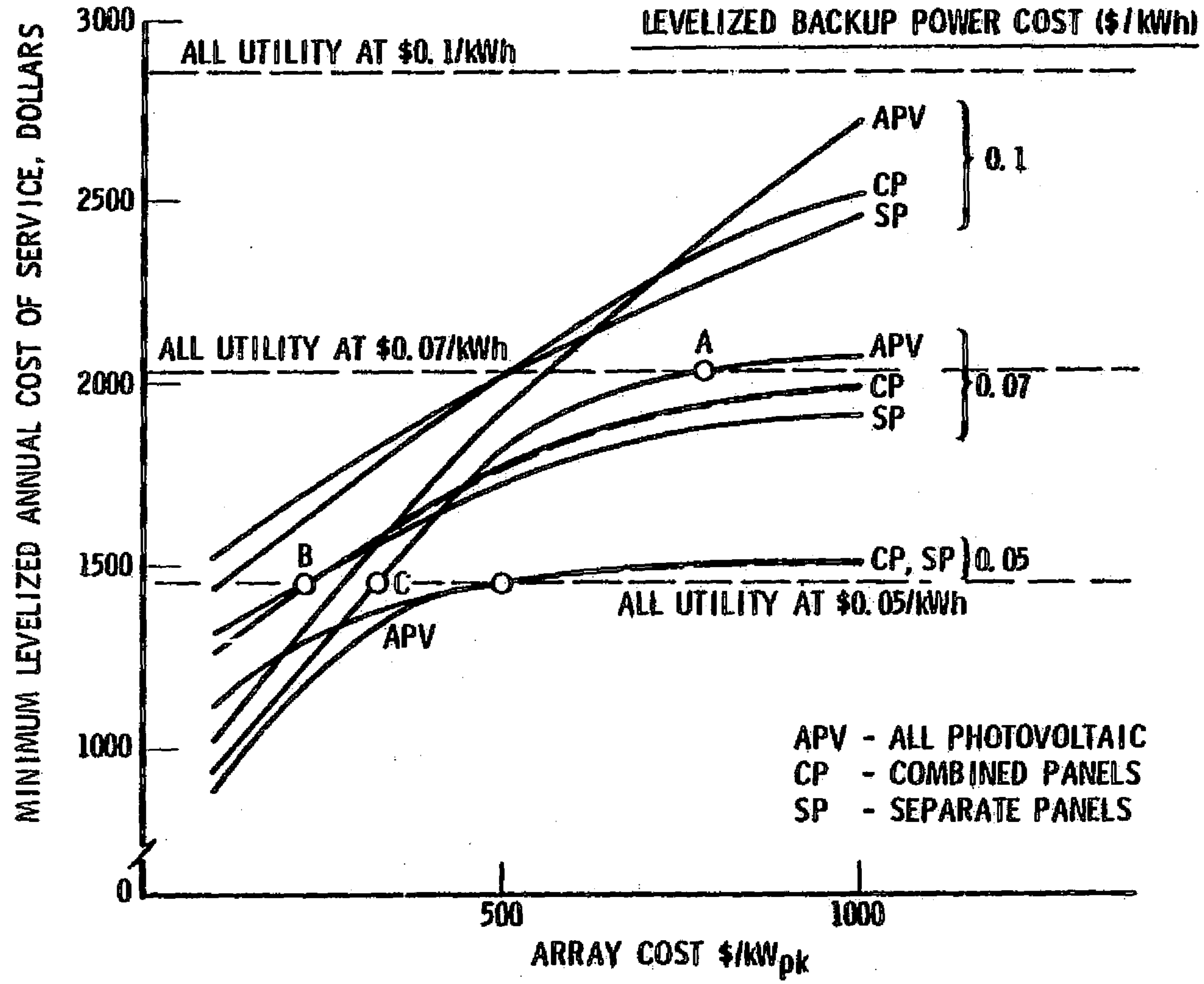
Annual Subsidy Per Residential Customer



Photovoltaic Total Energy Systems

MINIMUM LEVELIZED ANNUAL COST OF SERVICE

- SINGLE-FAMILY RESIDENTIAL APPLICATION
- PHOENIX, TOTAL DEMAND 28,850 kWh
- CRF - 0.09



Applications Screening Data Base

- USE OF SCREENING CRITERIA REQUIRED EXTENSIVE SEARCH FOR RELEVANT DATA
  - 469 REPORTS (many multi-volume) RECEIVED AND REVIEWED
    - RESIDENTIAL, COMMERCIAL, INDUSTRIAL, AGRICULTURAL APPLICATIONS
    - DATA ON ENERGY CONSUMPTION, INVENTORY STATISTICS, OPERATIONAL PRACTICES, COSTS
  - SEVERAL MAJOR DATA TAPES UTILIZED
    - 1974 AGRICULTURAL ENERGY DATA BASE (FEA/DOA)
    - 1960 - 1975 ENERGY CONSUMPTION BY END USE, ENERGY PRICES (FEA)
    - 1974 ANNUAL SURVEY OF MANUFACTURES, FUELS AND ELECTRIC ENERGY CONSUMED (U.S. Census)
  - OTHER SPECIAL RESOURCES EMPLOYED
    - PROJECTIONS OF ENERGY DEMAND AND PRICES TO 2015, BY STATE AND CONSUMING SECTOR, WITH SPECIAL AGRICULTURAL PRICE FORECAST FOR 6 WESTERN STATES (Sherman H. Clark Associates)
    - CONSULTANTS' REPORTS ON TYPICAL FARM OPERATIONS IN KANSAS, ARIZONA

- UNAVAILABILITY OF MANY DESIRED CATEGORIES OF STATISTICAL INFORMATION PROMPTED RECOMMENDATION THAT DOE ENLIST COOPERATION OF DOC IN EXTENDING
  - CENSUS OF HOUSING
    - ADD DATA ON BUILDING SIZE, DWELLING UNIT SIZE, NUMBERS OF STORIES, ROOF CONSTRUCTION AND ORIENTATION, ROOF AREA, EXTERIOR PARKING AREA
    - SEGREGATE BY COUNTY AND BUREAU OF ECONOMIC ANALYSIS AREA
  - CENSUS OF COMMERCE
    - INCLUDE INSTITUTIONAL BUILDINGS
    - SEGREGATE GEOGRAPHICALLY BY COUNTY
  - CENSUS OF MANUFACTURES
    - INCLUDE ENERGY CONSUMPTION DATA AT COUNTY LEVEL AND INDIVIDUAL PLANT LEVEL OF AGGREGATION
  - CENSUS OF AGRICULTURE
    - INCLUDE DATA ON ENERGY CONSUMPTION BY FARM OPERATION, AS A FUNCTION OF LOCATION, TIME OF YEAR

Results of Initial Screening of Application Classes in the Building and Industrial Sectors

BUILDINGS (1)		INDUSTRIES (2)		
[SINGLE-FAMILY HOUSES]	*	[2611, 21, 31]	[PULP AND PAPER MILLS]	*
[LOW-RISE APARTMENTS]	*	[2046]	[WET CORN MILLING]	*
[OFFICE BUILDINGS]	*	[3275]	[GYPSUM PRODUCTS]	
[STORES]	*	2075	SOYBEAN OIL MILLS	
[SHOPPING CENTERS]	*	2077	FATS AND OILS	
RESTAURANTS		2261	TEXTILE FINISHING	
MOTELS		2022	CHEESE PRODUCTS	
WAREHOUSES		2023	CONDENSED AND EVAPORATED MILK	
[SUPERMARKETS]	*	2034	DEHYDRATED FRUITS AND VEGETABLES	
HOTELS		2421	SAWMILLS, PLANING MILLS	
[SCHOOLS]	*	2011	MEATPACKING	
HOSPITALS		2033	CANNED FRUITS AND VEGETABLES	
CHURCHES		2082	MALT BEVERAGES	
NURSING HOMES		2834	PHARMACEUTICAL PRODUCTS	
SOCIAL		2063	BEET SUGAR	*
LIBRARIES/MUSEUMS				

NOTE (1) RANK-ORDERED BY GROWTH RATE AND ENERGY CONSUMPTION

NOTE (2) RANK ORDERED BY VALUE ADDED BY ENERGY CONSUMED IN MANUFACTURE

[ ] SELECTED FOR TOTAL ENERGY EVALUATION

* SELECTED FOR ALL-ELECTRIC EVALUATION

Application Rankings Resulting from Screening

	SYSTEMS	
	PHOTOVOLTAIC TOTAL ENERGY (1)	PHOTOVOLTAIC ELECTRIC (2)
BUILDINGS		
LOW-RISE APARTMENTS	1	1
OFFICES	2	4
STORES, MISC RETAIL	3	3
SINGLE FAMILY HOUSES	4	2
SCHOOLS	5	5
SHOPPING CENTERS	6	6
INDUSTRIES		
PULP/PAPER GROUP	1	1
GYPSUM PRODUCTS	2	3
WET CORN MILLING	3	2

(1) BUILDING RANKING BASED ON USE OF ABSORPTION COOLING
(2) BUILDING RANKING BASED ON USE OF VAPOR COMPRESSION COOLING

Recent Major Results/Conclusions

- IF ARRAY REDUCTION OBJECTIVES ARE ACHIEVED AS SCHEDULED, IT IS LIKELY THAT PHOTOVOLTAIC SYSTEMS WILL BE COMPETITIVE WITH UTILITY POWER FOR
  - SINGLE FAMILY RESIDENTIAL TOTAL ENERGY APPLICATIONS IN THE SOUTHWEST BY THE MID-1980s, AND IN THE MIDWEST BY THE MID-1990s
  - ELECTRIC-ONLY SCHOOL APPLICATIONS IN THE SOUTHWEST BY THE MID-1980s, AND OFFICE BUILDINGS AND SHOPPING CENTERS IN THE SAME REGION BY THE MID-1990s
- PHOTOVOLTAIC SYSTEMS USING CONCENTRATION MAY BE LESS ATTRACTIVE IN COMPARISON TO FLAT PLATE SYSTEMS THAN PREVIOUSLY THOUGHT, PARTICULARLY IN THE EAST AND SOUTH. BY THE YEAR 2000 IN THE SOUTHWEST, HOWEVER, COMPETITIVE PHOTOVOLTAIC POWER FOR UTILITY APPLICATIONS COULD BE PROVIDED BY
  - FLAT-PLATE SYSTEMS
  - HIGH-CONCENTRATION SYSTEMS $(X \geq 500)$ IN WHICH THERMAL ENERGY IS PROFITABLY USED
- SCREENING OF OTHER POTENTIALLY ATTRACTIVE APPLICATIONS INDICATES THAT FUTURE STUDIES SHOULD CONSIDER USE OF PHOTOVOLTAIC POWER FOR
  - LOW-RISE APARTMENTS
  - PULP/PAPER MILLS
- LARGE-SCALE DEPLOYMENT OF PHOTOVOLTAIC POWER PLANTS DURING THE 1986-2000 PERIOD COULD BE FINANCED BY RELATIVELY SMALL INCREASES IN CONSUMER ELECTRIC BILLS
  - PHOTOVOLTAIC ENERGY PRODUCTION COULD REACH 4% OF U.S. TOTAL BY 2000
  - REQUIRED SUBSIDY WOULD AMOUNT TO ONLY ABOUT $8 PER YEAR PER RESIDENTIAL CUSTOMER

Planned Activities

- ANALYSIS OF HYBRID PHOTOVOLTAIC/THERMAL-ELECTRIC POWER PLANT CONCEPT
- EXAMINATION OF STRATEGIES FOR EARLY PENETRATION OF GRID-CONNECTED APPLICATIONS
- INVESTIGATION OF TECHNICAL IMPACT OF FEEDBACK TO GRID OF EXCESS POWER FROM ON-SITE PHOTOVOLTAIC SYSTEMS
- INTEGRATION OF RESULTS OF MISSION/SYSTEM STUDIES OF GRID-CONNECTED PHOTOVOLTAIC APPLICATIONS
- EXAMINATION, INTEGRATION, COMPARISON OF PHASE I (design phase) RESULTS OF PRDA 35/38 STUDIES
- PHOTOVOLTAIC MARKET PENETRATION PROJECTIONS
- EXAMINATION OF UTILITY/GRID INTERFACE ISSUES
- EVALUATION OF SELECTED PHOTOVOLTAIC APPLICATIONS
- TECHNICAL AND MANAGEMENT SUPPORT TO THE PHOTOVOLTAIC PROGRAM

PLANNING AND ANALYSIS

FOR

DEVELOPMENT OF PHOTOVOLTAIC

ENERGY CONVERSION SYSTEMS

Richard D. Tabors

MIT/Energy Laboratory

N79-25487

MIT ENERGY LABORATORY

PLANNING AND ANALYSIS FOR DEVELOPMENT OF PHOTOVOLTAIC ENERGY CONVERSION SYSTEMS

PROJECT AREAS

I. DEMAND AND DECISION ANALYSIS

II. MARKET ANALYSIS

III. INSTITUTIONAL ANALYSIS

IV. SOCIAL COST ANALYSIS

V. PERFORMANCE/STANDARDS ANALYSIS

RESIDENTIAL SYSTEMS 50% BUY BACK
(A) TIME OF DAY RATES
(B) FLAT RATES

		SYSTEM NET PRESENT VALUE $	$/WP * SYSTEM	$/WP * MODULE
PHOENIX	A	5800	1.10	.89
	B	5600	1.05	.84
BOSTON	A	3700	.56	.42
	B	3400	.48	.35
OMAHA	A	2900	.35	.24
	B	3300	.46	.33

* ASSUMES $.41 PER WP FOR BOS

UTILITY SYSTEMS
6500 MW

% SYSTEM CAPACITY	SYSTEM WORTH PER SYSTEM WATT SOUTHEAST	NORTHEAST	SOUTHWEST	NORTHCENTRAL
3	.48 **	.55 **	.49 **	.43 **
6	.45	.54	.49	.41
9	.44	.53	.49	.41
12	.44	.53	.49	.38
15	.43	.52	.49	.37
18	.43	.52	.49	.36

** TO CALCULATE $/WP MODULE SUBTRACT BOS ESTIMATED BY SERI TO BE $.38/WP.

MARKET STUDIES

RESULTS OF SUN DAY, BOSTON COMMON COMPARED WITH NEBRASKA STATE FAIR

- 82% CHOSE PV OVER CONVENTIONAL SYSTEMS COMPARED TO 51% IN NEBRASKA
- ATTITUDES EXPRESSED TOWARD PV NOT SIGNIFICANTLY DIFFERENT
- DEMOGRAPHIC CHARACTERISTICS OF INTERVIEWED POPULATION NOT DIFFERENT
- SUN DAY CONCERN WAS ECOLOGICAL BENEFITS OF PV WHILE NEBRASKA CONCERN TECHNOLOGICAL FEASIBILITY

CONCLUSION

- SUN DAY RESPONDENTS WERE INNOVATORS BUT NOT POSSIBLE TO IDENTIFY THIS GROUP GIVEN ANALYTIC METHOD AND VARIABLES CHOSEN

INSTITUTIONAL ANALYSIS

RE EVALUATION OF NEBRASKA AGRICULTURAL COMMUNITY

PV IS AN UNDIFFERENTIATED TECHNOLOGY, I.E. THE AGRICULTURAL COMMUNITY CAN NOT "ROUTINELY" ACCEPT OR REJECT THE TECHNOLOGY

AGRICULTURAL UNIVERSITY IS A CRITICAL ENTRY POINT INTO THE INSTITUTIONAL FRAMEWORK -- IT IS NECESSARY BUT NOT SUFFICIENT -- OFFERS LEGITIMACY NOT MARKETING

DEPLOYMENT STRATEGIES FOR PHOTOVOLTAICS

BACKGROUND: PV IS AN ENERGY CONSUMING TECHNOLOGY REQUIRING ENERGY NOW TO PRODUCE ENERGY IN THE FUTURE

BASIC QUESTION: HOW CAN WE AVOID COSTLY MISTAKES IN OUR LONG TERM ENERGY STRATEGY ?

ANSWER/ APPROACH: REQUIRES THE DECOUPLING OF THE TARGET OR THE OBJECTIVE FROM THE PATHWAY TO ACHIEVE THE OBJECTIVE

STANDARDS AND PERFORMANCE CRITERIA

BACKGROUND TO STANDARDS AND CRITERIA
- LEGAL
- ECONOMIC
- INSTITUTIONAL

ANALYSIS OF SHAC PROGRAM

PRELIMINARY PROBLEMS

- SINGLE STRATEGY -- SUBSIDY
- ASSUMES PERFECT INFORMATION
- ACTUAL MARKET HIGHLY FRAGMENTED

PRELIMINARY SUCCESS

- BREADTH OF PARTICIPATION

A SUMMARY OF SYSTEMS DEFINITION PROJECT ACTIVITIES

Gary J. Jones
Kent L. Biringer

Photovoltaic Systems Definition Project
Sandia Laboratories
Albuquerque, NM 87185

Presented at the Technology and Applications Program
Semi-Annual Review Meeting
November 7-9, 1978
Washington, DC

A SUMMARY OF SYSTEMS DEFINITION PROJECT ACTIVITIES*

N79-25488

Gary J. Jones
Kent L. Biringer
Albuquerque, NM 87185

ABSTRACT

The Systems Definition Project at Sandia Laboratories in support of the DOE National Photovoltaic Program has as its objective to provide design information and subsystem requirement definition to the overall program. This includes application analysis and conceptual design for the wide variety of systems, system tradeoff studies and engineering design for the more promising application types, and the identification of the technology status and requirements for major subsystems and components.

During the past six months work has been completed on the residential design and analysis contracts, hybrid photovoltaic/solar thermal electric conversion contract and development of prototype combined photovoltaic/thermal flat-plate collectors. Other work in application analysis and conceptual design is nearing completion in the agricultural sector, commercial/industrial sector and central power sector as is subsystem work in low cost structure concepts and power conditioning design and prototype development.

Contracts dealing with DC load identification, residential load centers, utility/customer interfacing, simplified design methods, and advanced power conditioning are all about to be placed.

Further work in system definition and analysis as well as subsystem assessment are planned for the coming months.

To be included are studies of design sensitivity to alternate energy costs and plans for a second PV power conditioning workshop.

*** PROJECT OVERVIEW ***

GARY J. JONES
KENT L. BIRINGER

SEMIANNUAL REVIEW
NOVEMBER 7, 1978

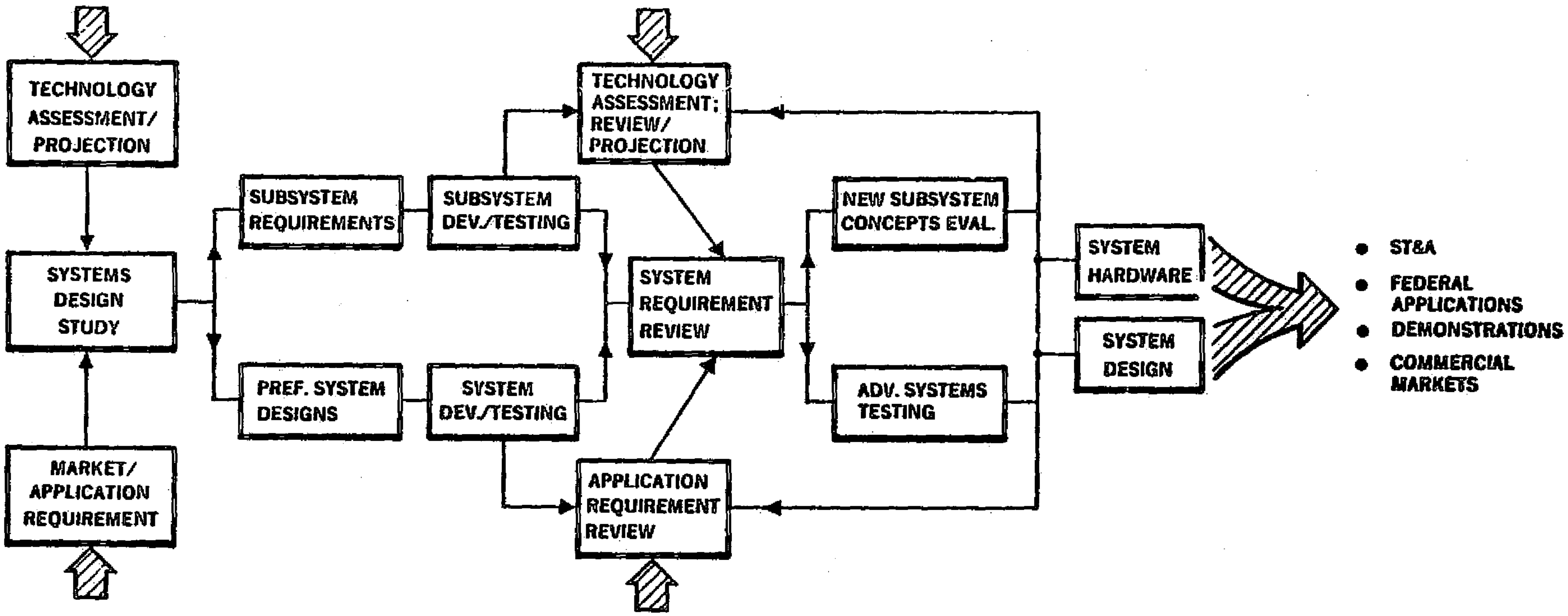
PRESENTATION OUTLINE

- → PROJECT DESCRIPTION
- COMPLETED ACTIVITIES
- CURRENT ACTIVITIES
- SELECTED STUDY SUMMARIES
- NEW ACTIVITIES
- KEY PLANNED ACTIVITIES
- SUMMARY

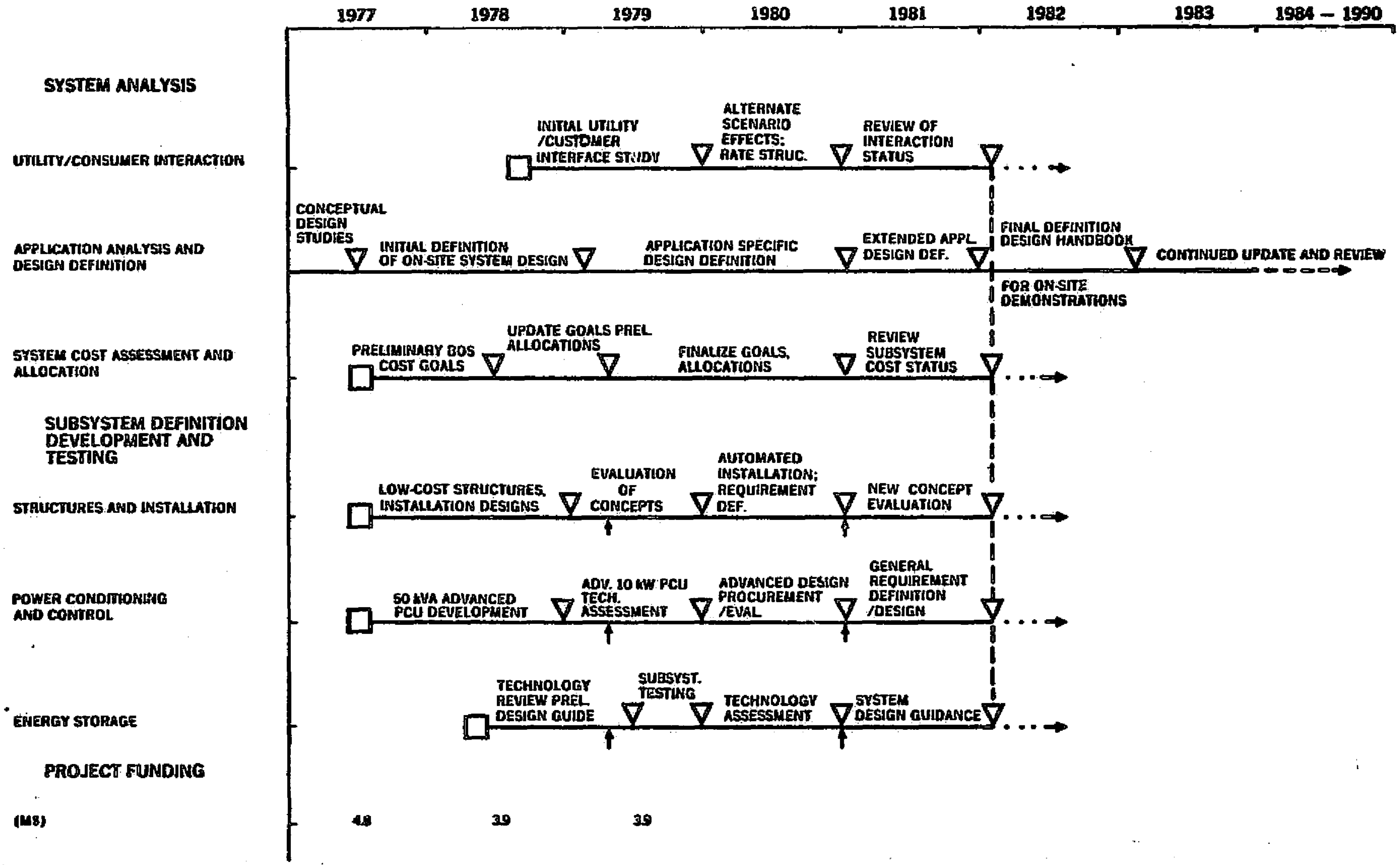
I. SYSTEM ANALYSIS: ANALYSIS OF MARKET SECTORS TO DETERMINE MOST PROMISING APPLICATIONS, AND THE DESIGN OF OPTIMAL SYSTEMS FOR THESE APPLICATIONS.

II. SUBSYSTEM DEFINITION AND DEVELOPMENT: DETERMINATION OF THE TECHNICAL AND ECONOMIC REQUIREMENTS OF THE NON-PHOTOVOLTAIC SEGMENTS OF A PHOTOVOLTAIC SYSTEM ("BALANCE OF SYSTEM")

SYSTEMS DEFINITION AND DEVELOPMENT INFORMATION DEVELOPMENT CHAIN



SYSTEM DESIGN AND DEFINITION OVERVIEW FOR ON-SITE APPLICATIONS



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COMPLETED ACTIVITIES

CONTRACTS:

- ▷ CONCEPTUAL DESIGN OF PHOTOVOLTAIC SYSTEMS, (GE, WESTINGHOUSE, SPECTROLAB)
- ▷ AUGMENTED SOLMET SOLAR DATA TAPES, (AEROSPACE)
- ▷ COMBINED PV/THERMAL CONCENTRATOR MODELING, (ARIZONA STATE UNIV.)
- ▷ FABRICATION OF COMBINED FLAT PLATE COLLECTORS, (ARCO SOLAR, SPECTROLAB)
- ▶ REGIONAL RESIDENTIAL SYSTEM DESIGN, (GE, WESTINGHOUSE)
- ▷ HYBRID PHOTOVOLTAIC/THERMODYNAMIC ELECTRIC GENERATION, (SPECTROLAB)

IN-HOUSE:

- ▷ INITIAL ARRAY EFFICIENCY/AREA RELATED COST TRADEOFFS
- ▷ PUBLICATION OF SOLCEL SYSTEM MODELING CODE
- ▷ PRELIMINARY BALANCE OF SYSTEM COST ANALYSIS
- ▷ CELL MISMATCH PROPERTIES ANALYSIS
- ▷ ENERGY STORAGE PERSPECTIVES IN PV CENTRAL POWER STATIONS

BALANCE OF SYSTEM PRICE DATA FOR MAJOR APPLICATIONS (1975$)

	RESIDENTIAL	INDUSTRIAL/ COMMERCIAL ON-SITE	CENTRAL POWER STATION
POWER CONDITIONING UNIT PRICE PROJECTIONS $\$/kW_p$	130-260	195	60-125
INSTALLATION/ STRUCTURES $\$/kW_p$	20-400 +400/SYSTEM	400-1000	200-400
WITHOUT ENERGY STORAGE	200-710*	595-1195	260-525
ENERGY STORAGE (3 kWH/kW_p)	400-625**	N.A.	N.A.
PROJECTED BOS PRICE $\$/kW_p$	600-1335	595-1195	250-510
ALLOWED BOS PRICE $\$/kW_p$	400-880 (1050-1925)	740-1440	375-600

* 8 kW_p SYSTEM

** LIFECYCLE COSTS FOR A 20-YEAR SYSTEM LIFE

CURRENT ACTIVITIES - SYSTEM ANALYSIS

CONTRACTS:

- ▶ AGRICULTURAL SECTOR ANALYSIS, (BDM)
- ▶ SERVICE/COMMERCIAL/INSTITUTIONAL/INDUSTRIAL SECTOR ANALYSIS, (RTI)
- ▷ CENTRAL STATION TEST FACILITY PRELIMINARY DESIGN, (GE, BECHTEL)

IN-HOUSE:

- ▷ CONTINUED BALANCE OF SYSTEM REQUIREMENTS ASSESSMENT
- ▷ ENERGY STORAGE/SELLBACK TRADEOFFS

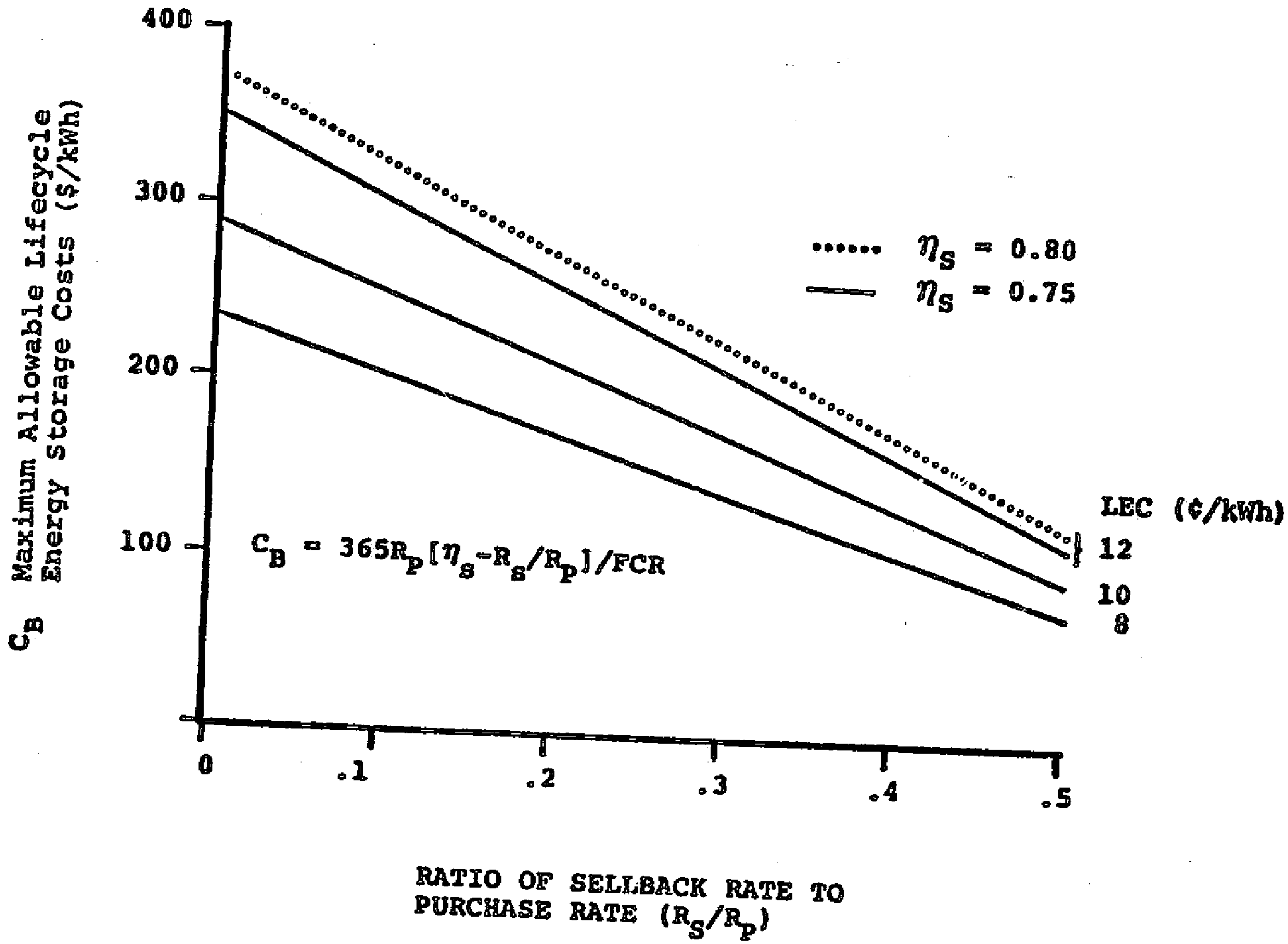
CURRENT ACTIVITIES - SUBSYSTEM DEFINITION AND DEVELOPMENT

CONTRACTS:

- ▶ LOW-COST STRUCTURE DESIGN, (BECHTEL, MOTOROLA)
- ▶ ARRAY DESIGN TRADEOFFS AND TRANSIENT EFFECTS STUDY, (BDM)
- ▶ LIGHTNING INDUCED ARRAY EFFECTS, (MISSION RESEARCH)
- ▶ 50 kVA ADVANCED POWER CONDITIONING UNIT, (WESTINGHOUSE AED)
- ▶ 10 kW POWER CONDITIONING UNIT, (ABACUS)
- ▷ EVALUATION OF COMMERCIAL BATTERIES, (ESB)

IN-HOUSE:

- ▶ COMBINED FLAT PLATE COLLECTOR TESTING
- ▷ ADVANCED CONCEPTS TEST FACILITY


400
300
200
100
C_B Maximum Allowable Lifecycle Energy Storage Costs ($/kWh)
η_S = 0.80
η_S = 0.75
LEC (¢/kWh)
12
10
8
$C_B = 365R_P[\eta_S - R_S/R_P]/FCR$
0
.1
.2
.3
.4
.5
RATIO OF SELLBACK RATE TO PURCHASE RATE (R_S/R_P)

REGIONAL RESIDENTIAL SYSTEMS DESIGN STUDIES

CONTRACTORS: 1) GENERAL ELECTRIC COMPANY
2) WESTINGHOUSE ELECTRIC COMPANY

CONTRACT AMOUNT: $658,000 TOTAL

STATUS: FINAL REPORT DRAFTS REVIEWED, REVISIONS IN PROGRESS

GENERAL ELECTRIC

SCOPE - PV RESIDENTIAL STUDY

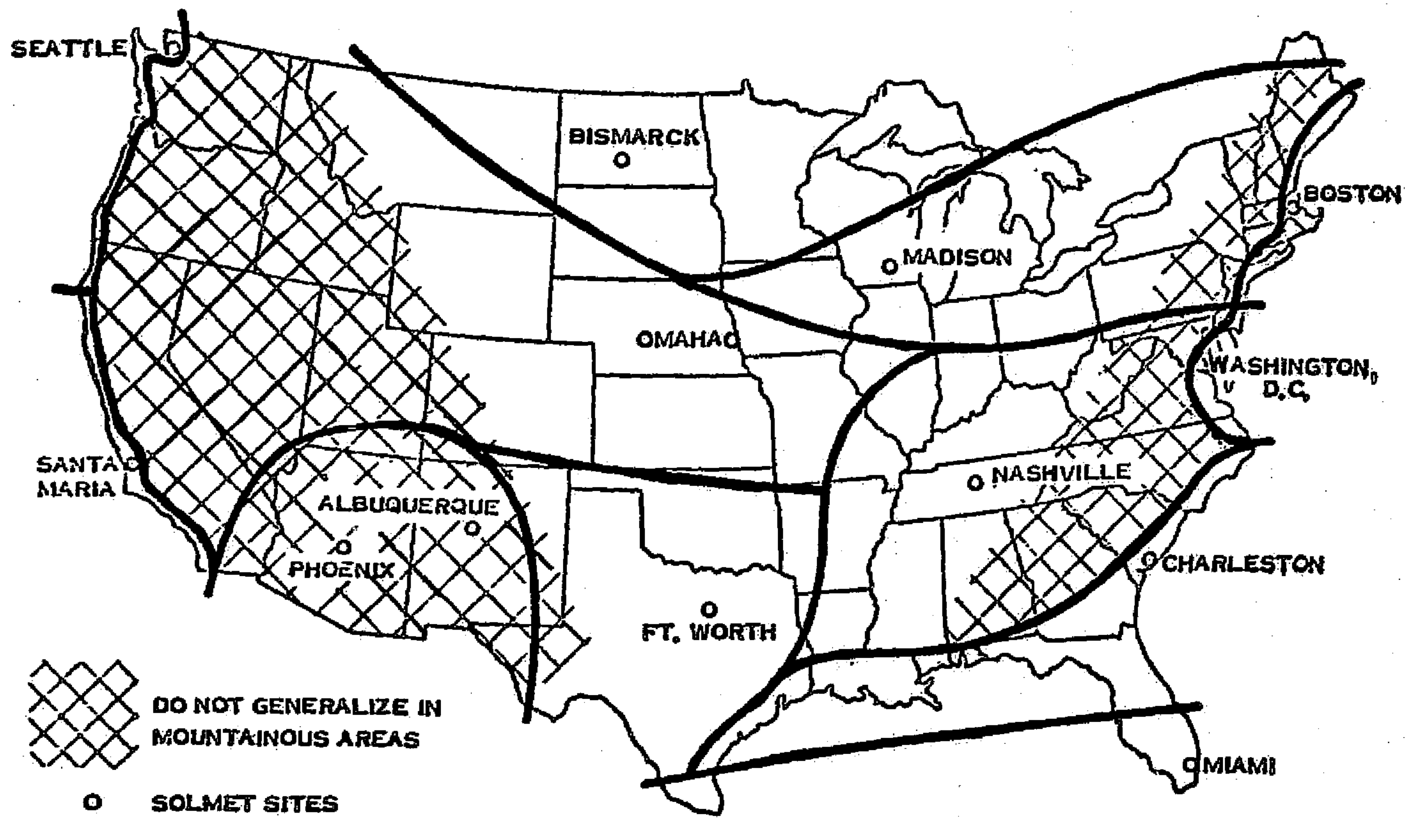
space division

- DIVIDE U.S. INTO REGIONS OF SIMILAR CLIMATE
- PREPARE RESIDENCE DESIGNS FOR 1986 PERIOD
    - SINGLE STORY DETACHED (SOUTHERN CLIMATE)
    - TWO STORY DETACHED (NORTHERN CLIMATE)
    - MULTI-FAMILY TOWNHOUSE
- SOLARIZE RESIDENCES
    - PV-ONLY
    - COMBINED PV/THERMAL COLLECTORS
    - SIDE-BY-SIDE PV & THERMAL COLLECTORS
- ANALYZE PERFORMANCE & ECONOMICS IN VARIOUS REGIONS
- RANK ORDER CONCEPTS
- PREPARE CONCEPTUAL DESIGNS
    - TEST-BED FACILITY
    - HABITABLE RESIDENCE
- RANK TEST PROGRAMS

GENERAL ELECTRIC

REGIONAL APPROXIMATION FOR SELECTED SOLMET SITES

space division



SELECT SYSTEMS FOR BOSTON

TYPE	AREA	STORAGE (KWH)	ENERGY DISPLACED (EQUIV.)	%	SOLAR FM	SYSTEM FM/FM
COMBINED	70-30T	20	11,900	74	.90	.95
SEPARATE						
AIR COOLED P.V.	50	20	12,500	76	.95	.98
EVAC. THERMAL	70					
COMBINED & PHASE CHANGE STORAGE	70	20	13,500	EST. 82	.85	.90

SELECT SYSTEMS FOR PHOENIX

TYPE	AREA	STORAGE (KWH)	ENERGY DISPLACED (EQUIV.)	%	SOLAR FM	SYSTEM FM/FM
ALL ELECTRIC	70	30	16,050	90	.45	.53

BASED ON HIGH VOLUME PRODUCTION ESTIMATED FOR THE YEAR 2000.

THE ALL ELECTRIC IS BY FAR THE SUPERIOR SYSTEM FOR THE PHOENIX SITE.

IN STRUCTURES DESIGNED FOR SOLAR ENERGY SYSTEMS FOR BOSTON, MOST PEOPLE WOULD NOT REQUIRE AIR-CONDITIONING.

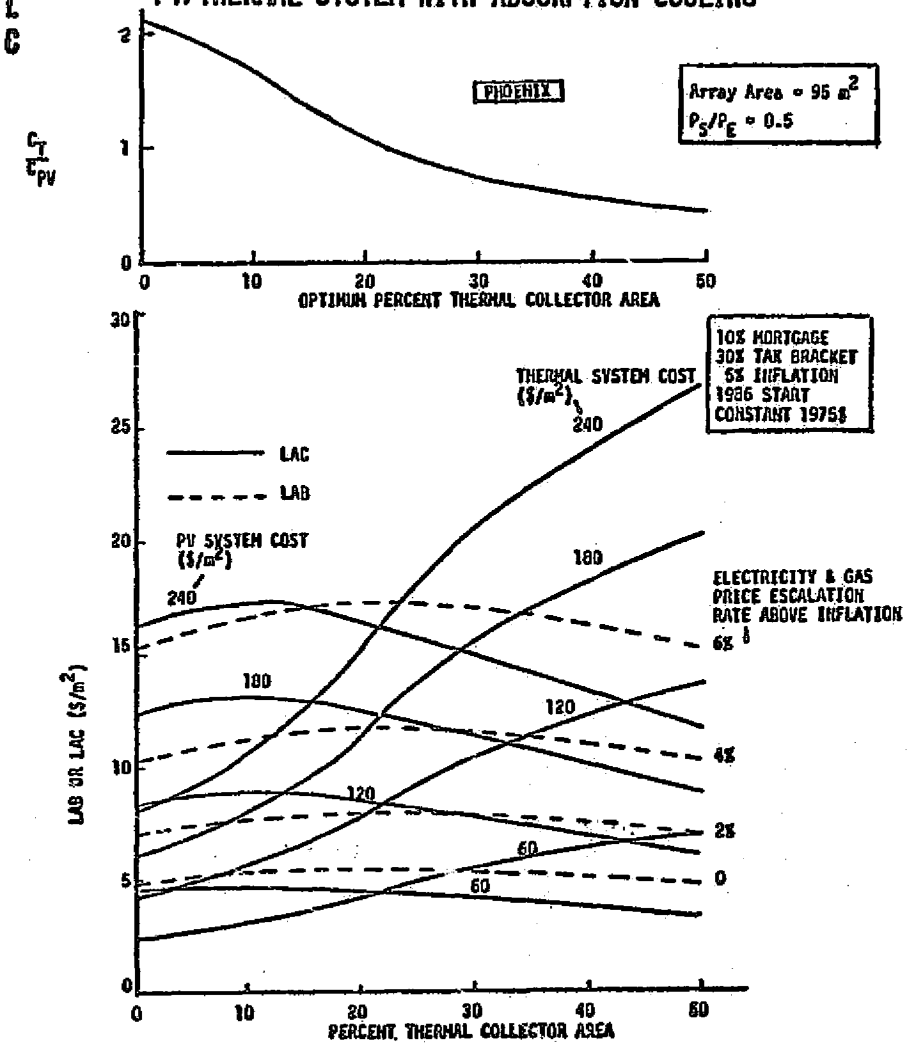
T = ADDITIONAL THERMAL ONLY.

AREA IN m^2, ENERGY IN KWH/YR.

GENERAL ELECTRIC

space division

PARAMETRIC DATA FOR SIDE-BY-SIDE PV/THERMAL SYSTEM WITH ABSORPTION COOLING



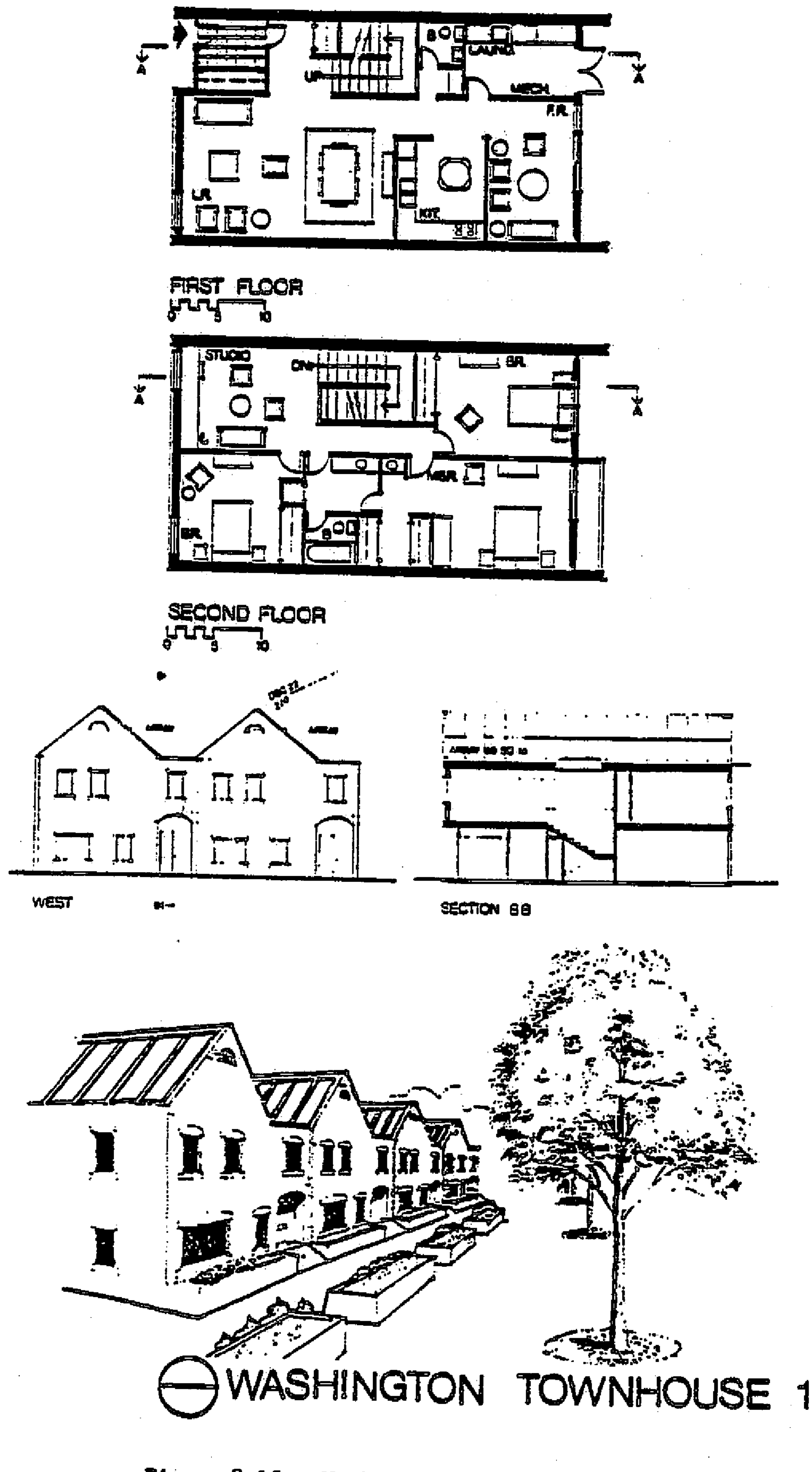


Figure 7.15 - Washington, D.C. Townhouse 1

GENERAL ELECTRIC

MAJOR PROGRAM CONCLUSIONS

space division

BASED ON ASSUMED ECONOMIC SCENARIO

- PV SYSTEMS WITH UTILITY SELLBACK RATES GREATER THAN 50% OF THE BUY RATE ARE MORE ATTRACTIVE THAN SYSTEMS WITH BATTERY STORAGE
- MOST SITES SHOW ECONOMIC VIABILITY IN THE 1986 TIME FRAME AT 50¢/WATT CELL COSTS
- SIDE-BY-SIDE PV/THERMAL SYSTEMS SHOW ECONOMIC VIABILITY IF PV SYSTEM TO THERMAL SYSTEM COST RATIO IS NEAR 1
- IMMEDIATE IMPLEMENTATION OF PV - ONLY SYSTEM TEST FACILITIES IN THE SOUTHWEST, NORTHEAST AND SOUTHEAST IS RECOMMENDED.

CONCLUSIONS

I. PHOTOVOLTAIC TOTAL ENERGY SYSTEMS FOR NEW RESIDENCES WILL BE VIABLE VIRTUALLY EVERYWHERE IN THE UNITED STATES BEFORE 2000 –

IF HIGH VOLUME PRODUCTION OF THE PHOTOVOLTAIC MODULES AND AUXILIARY SUBSYSTEMS IS ATTAINED.

II. HIGH VOLUME PRODUCTION WILL NOT BE ACHIEVED WITHOUT SOME FORM OF PRECOMMERCIALIZATION.

III. THE DOE GOAL OF $\$500/kW_p$ BY 1985 IS AN ADEQUATE STARTING POINT FOR THE PRECOMMERCIALIZATION PERIOD.

IV. THE OBJECTIVE SHOULD BE FOR SOLAR TO SUPPLY THE BULK OF THE TOTAL ENERGY REQUIREMENT OF THE RESIDENCE.

V. ELECTRICAL STORAGE IS ESSENTIAL IF A HIGH BUY/SELL RATIO OF SELLBACK IS NOT VIABLE ON A LARGE SCALE.

VI. WHILE ELECTRICAL STORAGE IS NOW FEASIBLE, DEVELOPMENT IS NEEDED TO (1) INCREASE CYCLE LIFE AND (2) ELIMINATE MAINTENANCE.

VII. THE STRUCTURE SHOULD BE DESIGNED AS PART OF THE SYSTEM.

VIII. STRUCTURES DESIGNED NOW SHOULD CONSIDER FUTURE APPLICATION OF PHOTOVOLTAIC SYSTEMS.

IX. PASSIVE SOLAR DESIGN CAN IMPROVE THE SYSTEM PERFORMANCE.

X. THREE BASIC SYSTEMS DOMINATE: (1) ALL ELECTRIC, (2) COMBINED, (3) SEPARATE (USUALLY THE LAST CHOICE).

XI. STAND-ALONE SYSTEMS ALWAYS FAVOR THE COMBINED IN THE COOLER REGIONS.

XII. A MODULARIZED TEST BED FACILITY IS SUGGESTED TO OPTIMIZE HABITABLE DWELLING DESIGN.

Sandia Laboratories
Solar Energy

PHOTOVOLTAIC SYSTEM DEFINITION PROJECT

LOW-COST STRUCTURE DESIGN STUDIES

CONTRACTORS: 1) BECHTEL NATIONAL, INC.
2) MOTOROLA, INC.

CONTRACT AMOUNT: $331,000 TOTAL

STATUS: WORK COMPLETE, FINAL REPORTS BEING DRAFTED

SUPPORT TYPE AND EXAMPLES

TYPE OF SUPPORT STRUCTURE	EXAMPLES
TRUSS	STRUTS RAILS FOLDING THREE POINT FOUNDATION
FRAME	CANTILEVER
THIN OR THICK SHELL	GUNITE CONCRETE INFLATABLE WOOD, PLYWOOD, ETC.
DIRECT ATTACHMENT TO EXISTING STRUCTURE	ROOF TRANSMISSION LINE TOWER
INTEGRAL PART OF STRUCTURE	ROOF TRANSMISSION LINE TOWER

INCLUDED COSTS

AVERAGE SITE PREPARATION

SURVEYING AND LOCATION MARKING

EARTHWORK FOR FOUNDATIONS

SUPPLY AND FABRICATION OF MATERIALS

INSTALLATION OF SUPPORT STRUCTURES

FIELD CONSTRUCTION COSTS

EXCLUDED COSTS

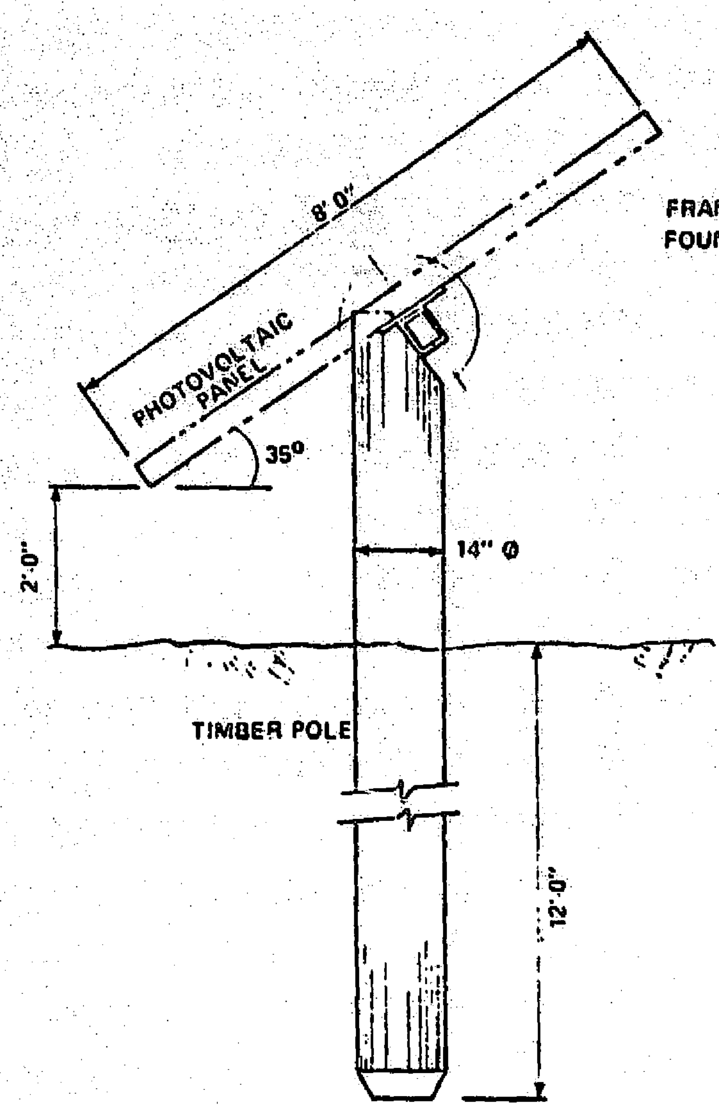
PHOTOVOLTAIC MODULES

PANEL FRAMEWORKS AND HARDWARE

LAND ACQUISITION

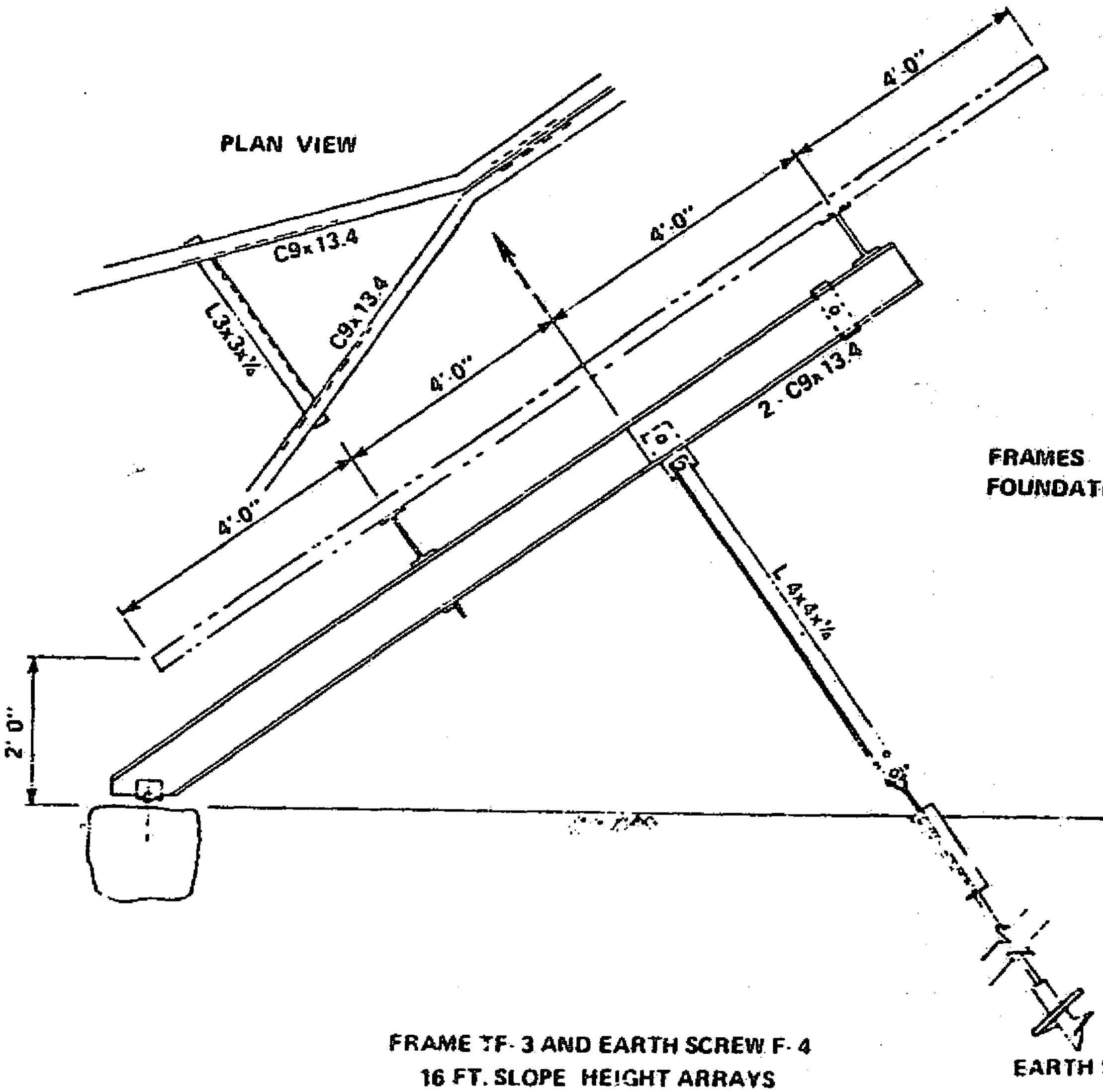
MECHANICAL AND ELECTRICAL SYSTEMS

BALANCE OF PLANT STRUCTURES, FACILITIES



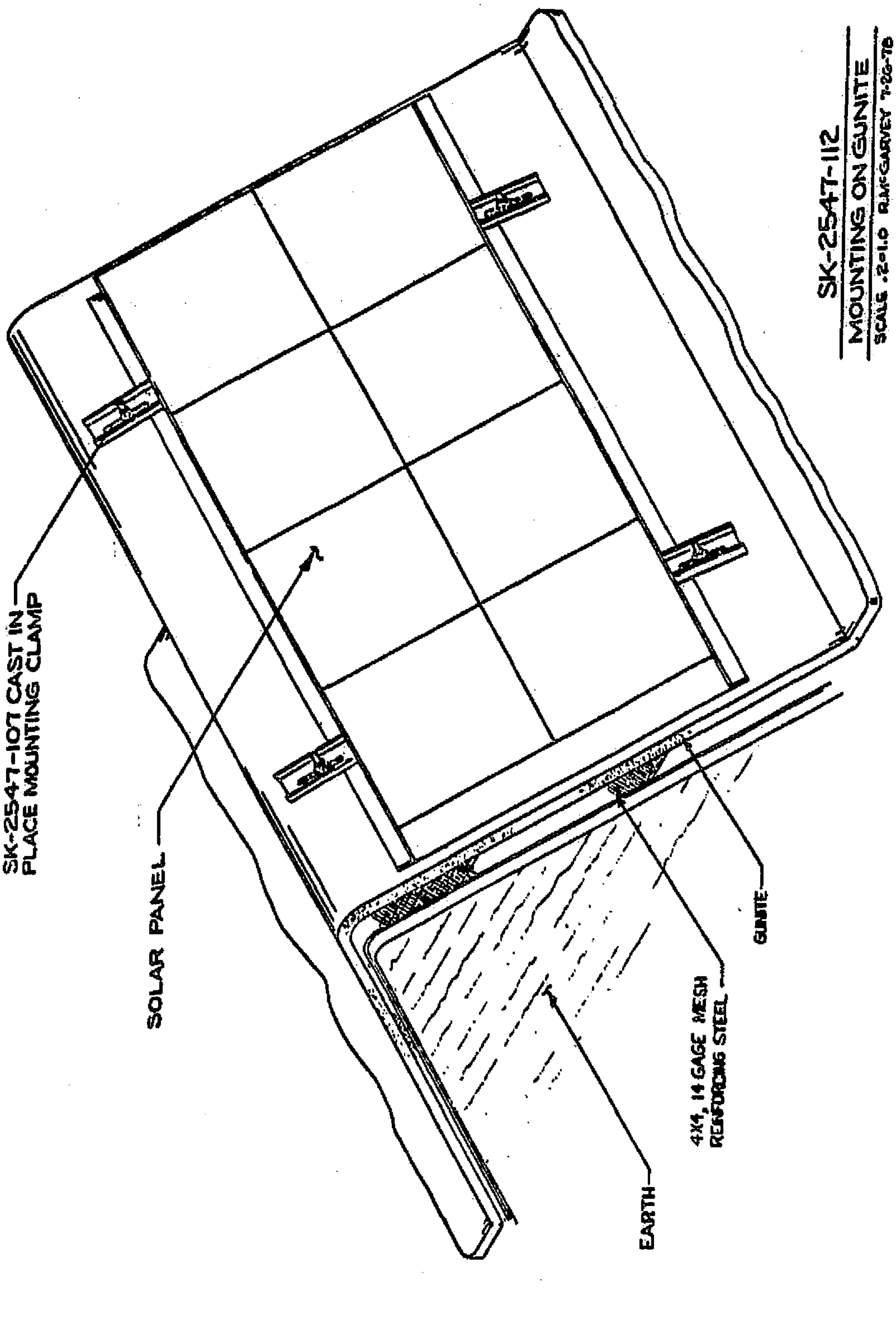
1975 $ / SQ. FT.	
FRAMES	$ 1.00
FOUNDATIONS	.94
	$ 1.94

POLE FOUNDATION— SINGLE TORSION BEAM
8 FT. SLOPE HEIGHT ARRAYS



	1975 $ / SQ. FT.
FRAMES	$ 1.60
FOUNDATION	.53
	$ 2.13

FRAME TF-3 AND EARTH SCREW F-4
16 FT. SLOPE HEIGHT ARRAYS



SK-2547-107 CAST IN PLACE MOUNTING CLAMP
SOLAR PANEL
4X4, 14 GAGE MESH REINFORCING STEEL
GUNITE
EARTH
SK-2547-112
MOUNTING ON GUNITE
SCALE .2=1.0 R.McGARVEY 7-26-78

FIGURE 2-5

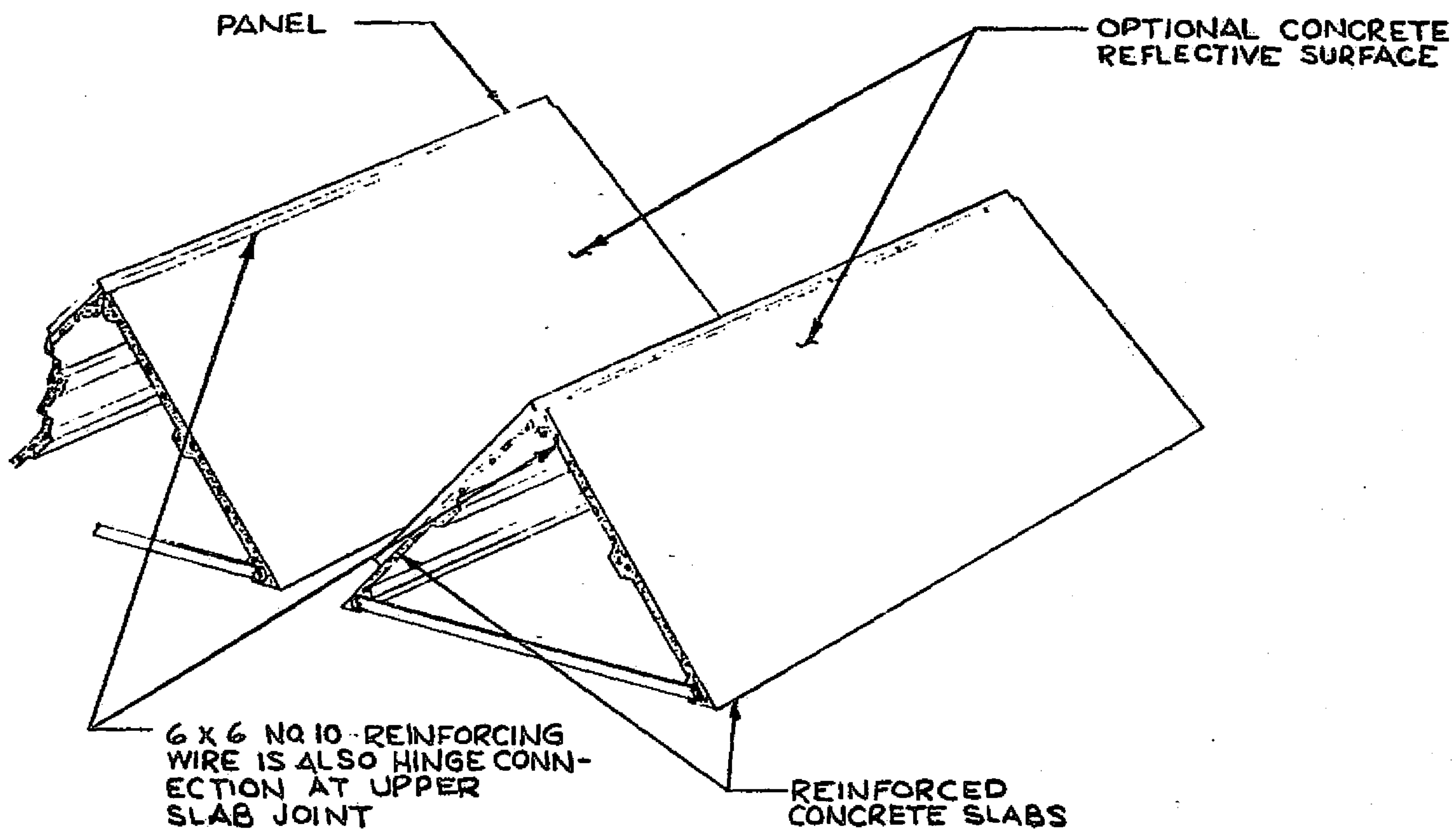


FIGURE 2-7 CONCRETE SLAB

PRELIMINARY

MINIMUM COST ESTIMATES
($/SQ. FT.)

TRUSS	
Concrete Foundation	1.50 - 2.50
Ground Anchor Type Foundation	1.00 - 2.00
FRAME OR POST	
Concrete Foundation	1.50 - 2.00
Without Concrete Foundation	1.00 - 2.00
GUNITE	1.50 - 2.00
CONCRETE SLAB	2.00 - 2.50

ANALYSIS OF THE EFFECT OF LIGHTNING ON SOLAR PHOTOVOLTAIC ARRAYS

CONTRACTOR: MISSION RESEARCH CORPORATION

CONTRACT AMOUNT: $97,700

STATUS: CELL VULNERABILITY MODEL COMPLETE.
INVESTIGATING PROTECTION STRATEGIES.

OBJECTIVES

DETERMINE RESPONSE OF PV SYSTEMS TO LIGHTNING ENVIRONMENT.

DETERMINE LIGHTNING PROTECTION SCHEMES FOR PV SYSTEMS.

LIGHTNING EFFECTS STUDY

TASKS

- DETERMINE CELL MODEL AND CELL VULNERABILITY MODELS.
- SURVEY ARRAY DESIGN CONCEPTS.
- DEVELOP LIGHTNING SOURCE MODEL.
- PERFORM TRANSIENT ANALYSIS OF CELLS, MODULES, AND ARRAYS.
- DEVELOP PROTECTION STRATEGIES AND HARDNESS DESIGN CRITERIA.

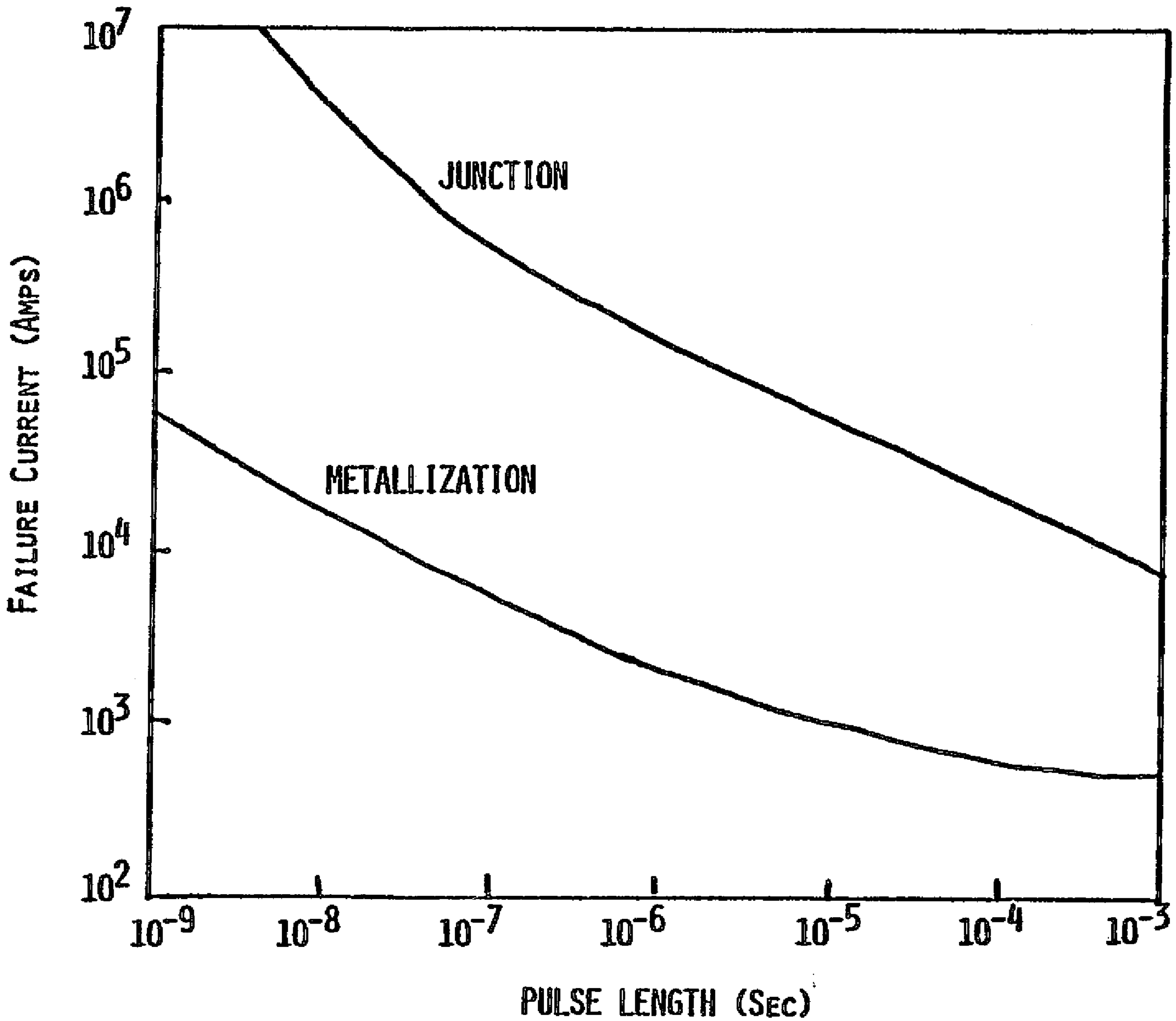


FIGURE 1. SOLAR CELL FAILURE THRESHOLD BASED ON PULSED CURRENT (THREE-INCH DIAMETER CELL WITH OCLI FINGER GEOMETRY)

ANALYSIS OF DESIGN TRADEOFFS AND TRANSIENT EFFECTS IN LARGE PHOTOVOLTAIC ARRAYS

CONTRACTOR: BDM CORPORATION

CONTRACT AMOUNT: $290,300

STATUS: COMPUTER CODE (PVTAP) DEVELOPED. USING CODE TO DEVELOP DESIGN GUIDELINES.

OBJECTIVES

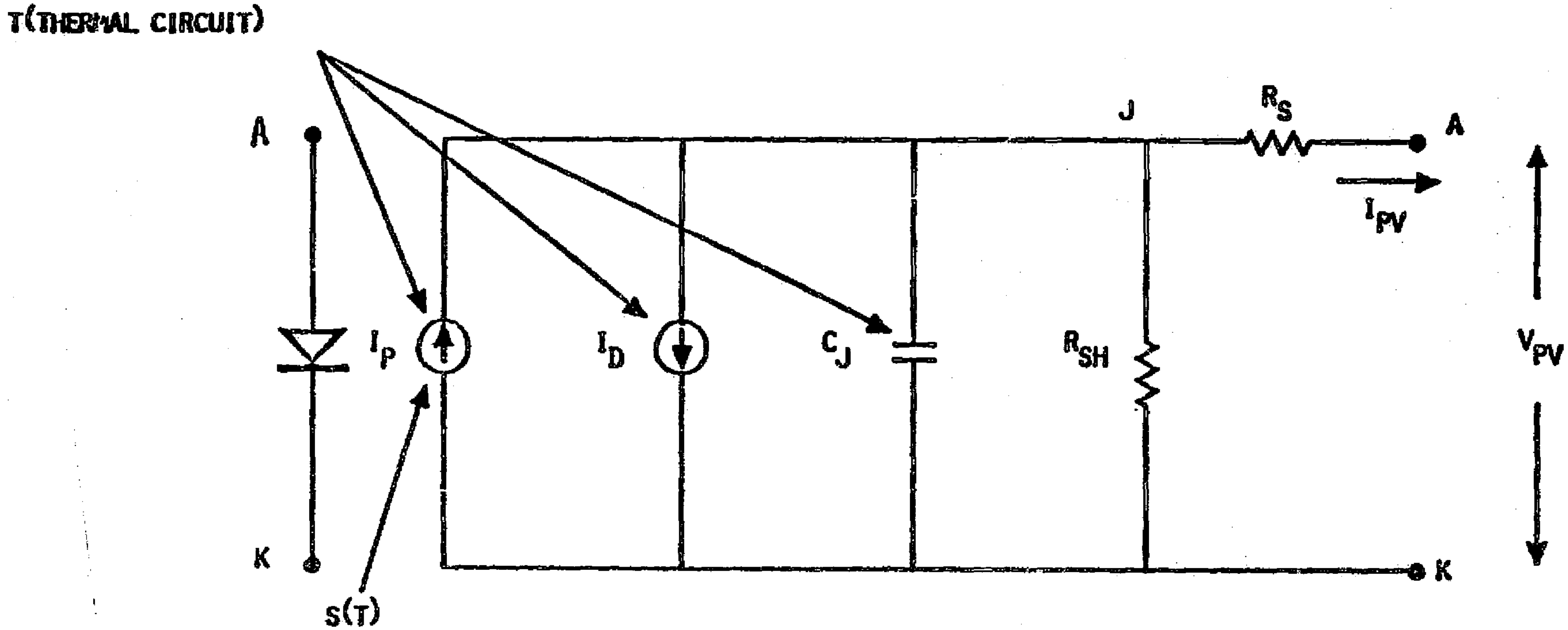
- DEVELOP AN UNDERSTANDING OF THE IMPACT OF TRANSIENTS ON ARRAY PERFORMANCE
- PROVIDE A COMPUTER CODE WHICH IS A PRACTICAL TOOL FOR ARRAY ANALYSIS
- PROVIDE PRELIMINARY DESIGN GUIDELINES FOR 100 kW TO 1 MW PV ARRAYS

TRANSIENT EFFECTS STUDY

TASKS

- PHOTOVOLTAIC ARRAY MODEL DEVELOPMENT
- COMPUTER SIMULATION CODE DEVELOPMENT
- ANALYSIS OF DESIGN TRADEOFFS VS TRANSIENT EFFECTS AND THE DEVELOPMENT OF DESIGN GUIDELINES

PHOTOVOLTAIC CELL EQUIVALENT CIRCUIT



I_P = LIGHT-GENERATED PHOTOCURRENT

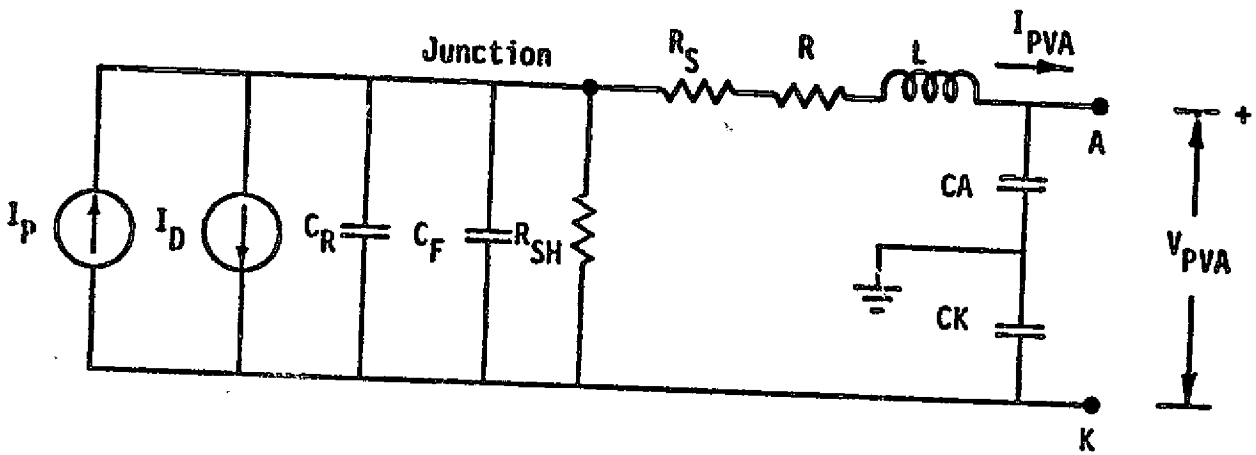
I_D = STANDARD DIODE JUNCTION CURRENT

C_J = JUNCTION CAPACITANCE

R_{SH} = SHUNT RESISTANCE

R_S = SERIES RESISTANCE

PV AGGREGATE MODEL



TYPICAL AGGREGATION TECHNIQUES

SERIES	PARALLEL
$R_A = \Sigma R_i$	$R_A = \frac{1}{\Sigma \frac{1}{R_i}}$
$C_A = \frac{1}{\Sigma \frac{1}{C_i}}$	$C_A = \Sigma C_i$
$I_{PA} = MIN\ (I_{Pi})$	$I_{PA} = \Sigma I_{Pi}$
$I_{SA} = \frac{\Sigma I_{Si}}{n}$	$I_{SA} = \Sigma I_{Si}$
$M_A = \Sigma M_i$	$M_A = \frac{\Sigma M_i}{n}$

APPLICATION ANALYSIS AND PHOTOVOLTAIC SYSTEM CONCEPTUAL DESIGN FOR SERVICE/COMMERCIAL/INSTITUTIONAL AND INDUSTRIAL SECTORS

Contract No. 07-6936
Research Triangle Institute

- INDIVIDUAL LOADS OF 25 kW OR LARGER, UPPER LIMIT UNDEFINED
- SECTORS INCLUDED ARE (SCII)

  SERVICE
  COMMERCIAL
  INSTITUTIONAL
  INDUSTRIAL

- SYSTEMS ARE

  ON USER PREMISES
  NOT RESIDENTIAL
  NOT AGRICULTURAL
  NOT CENTRAL STATION

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GUIDELINES

TASK I:	**DEFINE APPLICATION SUBSECTORS BASED ON LIKE ATTRIBUTES.**
TASK II:	**RANK APPLICATION SUBSECTORS BASED ON POTENTIAL FOR ELECTRIC ENERGY MARKET PENETRATION.**
TASK III:	**SELECT APPLICATIONS FOR DESIGN BASED UPON THEIR IMPACT ON TECHNOLOGY TRANSITION.**
TASK IV:	**DESIGN CONCEPTUAL DEMONSTRATION SYSTEM BASED UPON COST EFFECTIVENESS FOR SUCCESSFUL DEMONSTRATION.**

RTI

ORDERED 1974 SCII
ELECTRIC ENERGY CONSUMED

RANK	SIC CODE	SIC CODE DESCRIPTION	PURCHASED ELECTRIC ENERGY (MILLION kWh)	CUMULATIVE ENERGY	PERCENT OF TOTAL	CUMULATIVE PERCENT OF TOTAL
1.	33	PRIMARY METAL INDUSTRIES	171,783.9	171,783.9	13.682 %	13.682 %
2.	28	CHEMICALS, ALLIED PRODUCTS	130,603.9	302,387.8	10.402 %	24.085 %
3.	54	FOOD STORES	55,391.9	357,779.6	4.412 %	28.496 %
4.	82	PUB. & PAR. SCHOOLS (D)	49,646.8	407,426.4	3.954 %	32.451 %
5.	26	PAPER AND ALLIED PRODUCTS	42,988.5	450,414.9	3.424 %	35.875 %
6.	46	PIPE LINES, EXC. NAT. GAS	40,469.7	490,884.6	3.223 %	39.098 %
7.	20	FOOD AND KINDRED PRODUCTS	38,786.1	529,670.6	3.089 %	42.187 %
8.	80	HEALTH SERVICES	37,572.7	567,243.3	2.993 %	45.180 %
9.	65	REAL ESTATE	31,092.8	598,336.1	2.476 %	47.656 %
10.	58	EATING & DRINKING PLACES	30,887.5	629,223.6	2.460 %	50.116 %
11.	49	ELECT., GAS, & SANIT. SERVICES	30,488.3	659,711.8	2.428 %	52.545 %
12.	32	STONE, CLAY, GLASS PRODUCTS	30,353.6	690,065.4	2.418 %	54.962 %
13.	37	TRANSPORTATION EQUIPMENT	29,846.0	719,911.4	2.377 %	57.339 %
14.	53	GENERAL MERCHANDISE STORES	29,600.7	749,512.1	2.358 %	59.697 %
15.	29	PETROLEUM AND COAL PRODUCTS	28,651.8	778,163.9	2.282 %	61.979 %
16.	22	TEXTILE MILL PRODUCTS	28,303.1	806,466.9	2.254 %	64.233 %
17.	35	MACHINERY, EXCEPT ELECTRIC	27,411.9	833,878.8	2.183 %	66.417 %
18.	34	FABRICATED METAL PRODUCTS	26,505.6	860,384.3	2.111 %	68.528 %
19.	36	ELECTRIC, ELECTRONIC EQUIP	25,936.0	886,320.3	2.066 %	70.593 %
20.	99	NONCLASSIFIABLE ESTABLISHMTS	20,225.9	906,546.1	1.611 %	72.204 %

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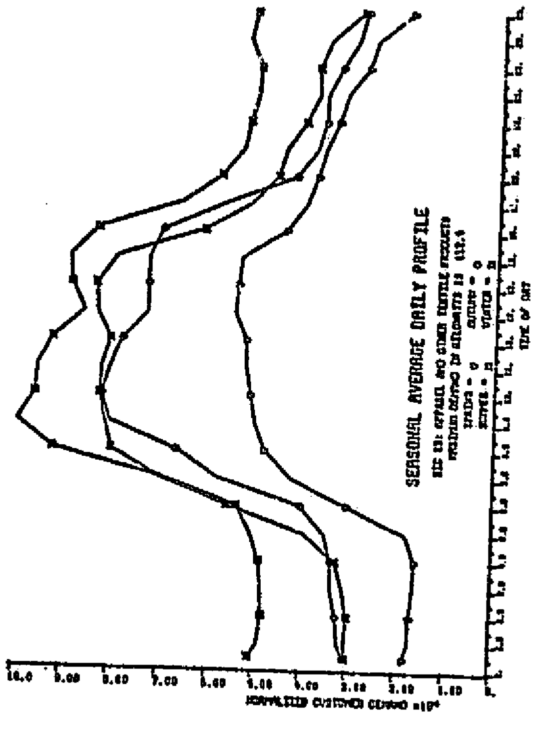
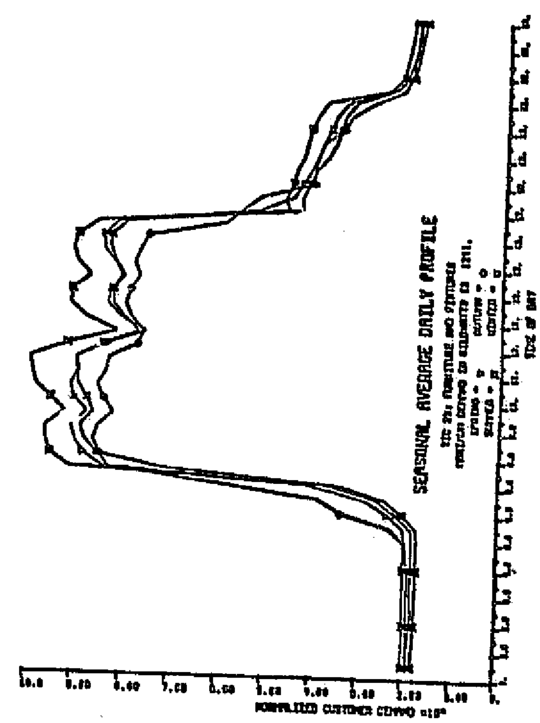
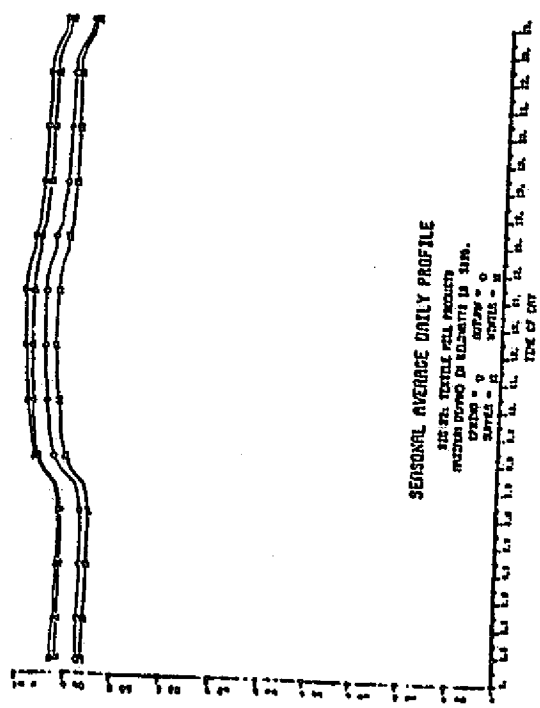
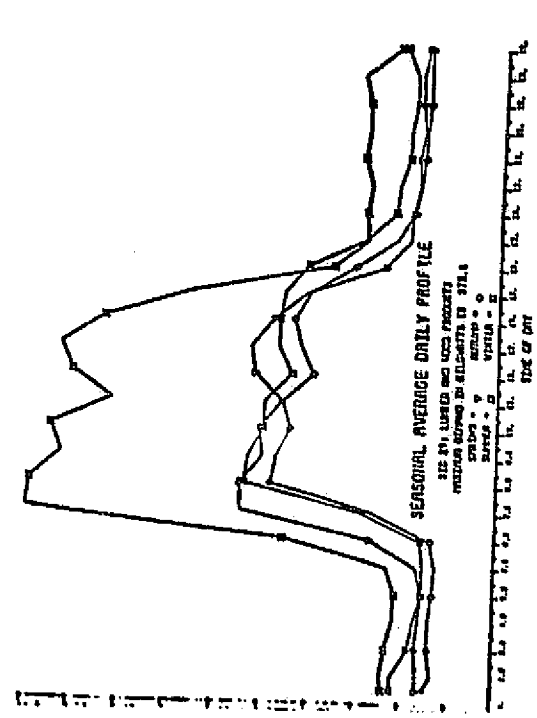

SEASONAL AVERAGE DAILY PROFILE


SEASONAL AVERAGE DAILY PROFILE


SEASONAL AVERAGE DAILY PROFILE


SEASONAL AVERAGE DAILY PROFILE

RELATIVE IMPACT OF ENERGY AND UTILIZATION ON PHOTOVOLTAIC POTENTIAL

SIC CODE	SIC LABEL	PHOTOVOLTAIC POTENTIAL	RANK	ENERGY MILLIONS kWh	RANK	U FACTOR	RANK
28	CHEMICALS, ALLIED PRODUCTS	182,616.	1	131,494.6	2	0.2679	35
33	PRIMARY METAL INDUSTRIES	162,130.	2	164,649.2	1	0.2023	60
54	FOOD STORES	77,426.	3	54,940.3	3	0.2742	32
82	PUB. & PAR. SCHOOLS (0)	65,177.	4	49,242.0	4	0.2673	45
80	HEALTH SERVICES	65,100.	5	37,266.4	8	0.3408	10
32	STONE, CLAY, GLASS PRODUCTS	54,964.	6	29,994.0	12	0.3585	6
53	GENERAL MERCHANDISE STORES	52,368.	7	29,359.7	14	0.3475	9
20	FOOD & KINDRED PRODUCTS	51,999.	8	38,346.3	7	0.2634	39
58	EATING & DRINKING PLACES	51,517.	9	30,636.9	10	0.3283	13
46	PIPE LINES, EXC. NAT. GAS	50,819.	10	40,139.7	6	0.2475	49
26	PAPER & ALLIED PRODUCTS	49,506.	11	41,708.5	5	0.2426	50
49	ELECT., GAS, & SANIT. SERVICES	44,264.	12	30,240.3	11	0.2846	28
65	REAL ESTATE	41,065.	13	30,839.1	9	0.2591	43
35	MACHINERY, EXCEPT ELECTRIC	40,695.	14	27,019.3	17	0.3012	19
29	PETROLEUM & COAL PRODUCTS	37,526.	15	26,896.9	15	0.2563	46
22	TEXTILE MILL PRODUCTS	34,917.	16	27,899.0	16	0.2419	51
34	FABRICATED METAL PRODUCTS	33,283.	17	26,138.0	18	0.2542	48
36	ELECTRIC, ELECTRONIC EQUIP	31,712.	18	24,770.1	19	0.2545	47
42	MOTOR FREIGHT TRANS. & WAREH'ING	29,604.	19	18,751.7	23	0.3085	16
50	WHOLESALE--DURABLE GOODS	28,886.	20	19,451.8	22	0.2896	27

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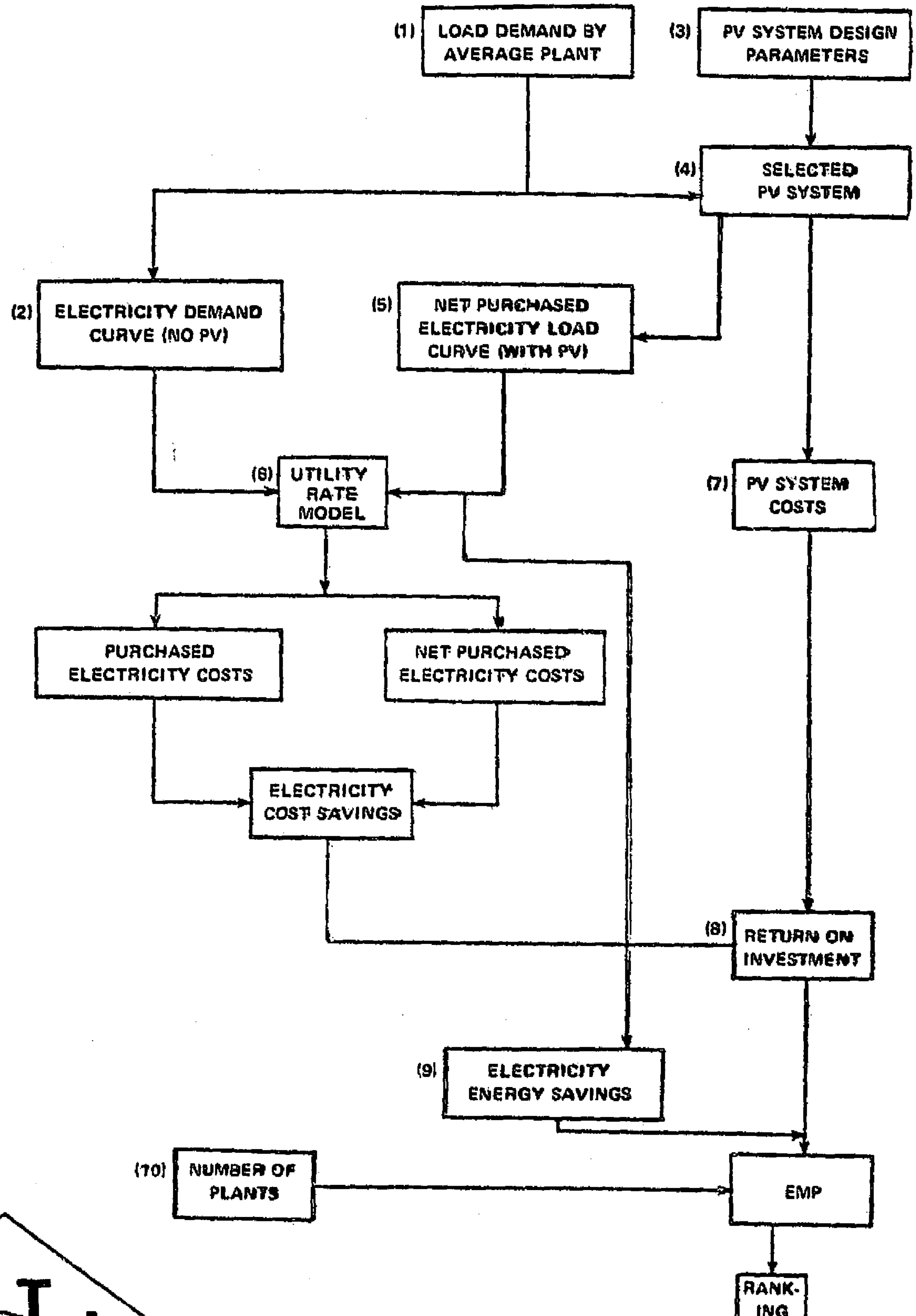
TASK II METHODOLOGY



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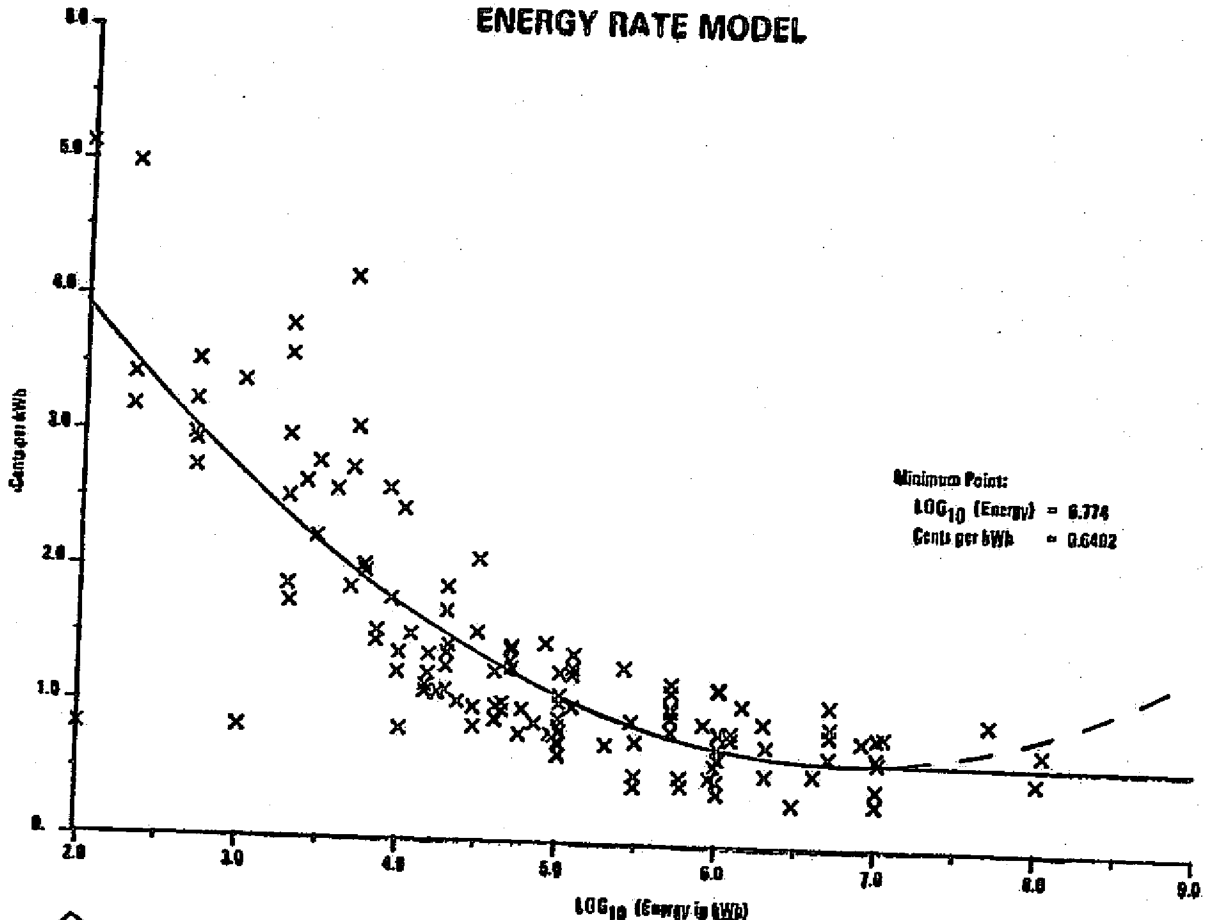

ENERGY RATE MODEL
Cents per kWh
6.0
5.0
4.0
3.0
2.0
1.0
0.
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
LOG10 (Energy in kWh)
Minimum Point:
LOG10 (Energy) = 6.774
Cents per kWh = 0.6402

APPLICATIONS RANKING

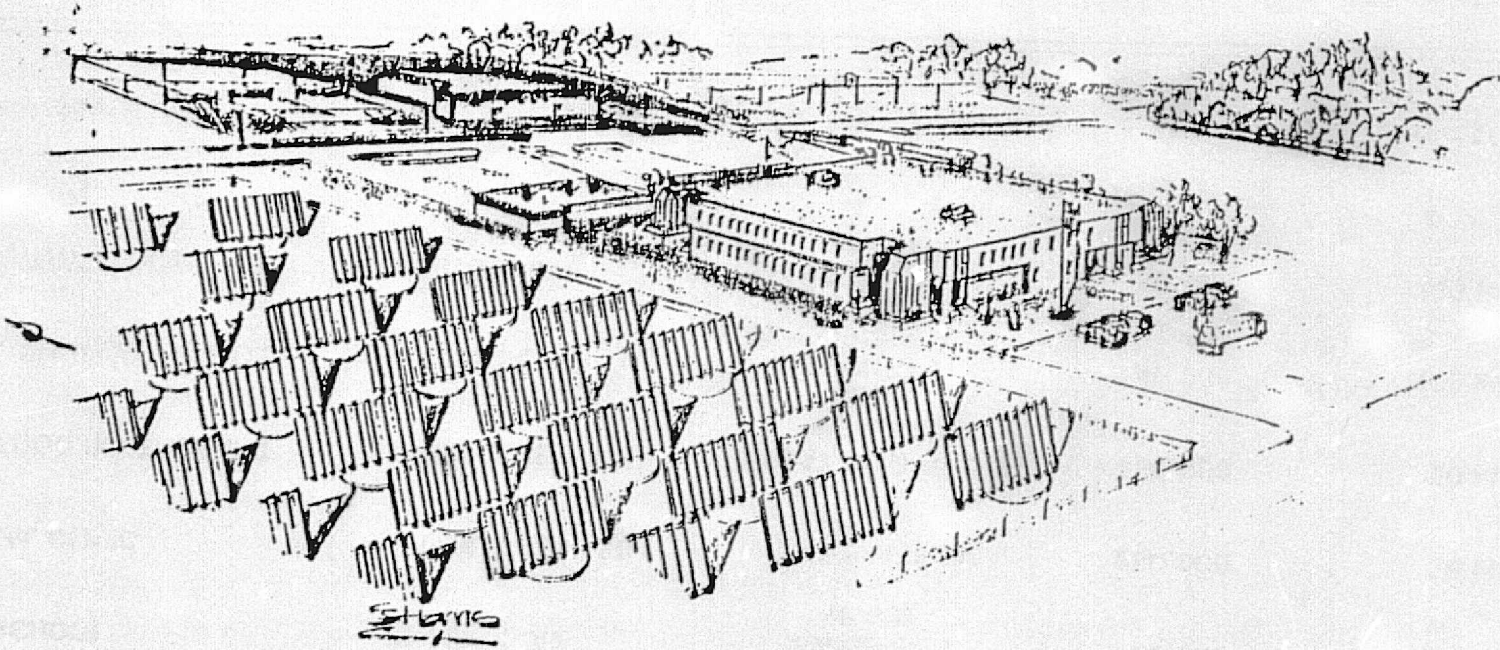
ARRAY COST = $\$50/m^2$
INVERTER COST = \$100/kW
BATTERY COST = \$25/kWh

	EMP = EP•E	EP > O
82	SCHOOLS, PRIMARY & SECONDARY	YES
86	MEMBERSHIP ORGANIZATIONS	YES
80	HEALTH SERVICES	YES
54	FOOD STORES	YES
58	EATING & DRINKING PLACES	YES
83	SCHOOLS, POST-SECONDARY	YES
53	GENERAL MERCHANDISE STORES	YES
35	MACHINERY, EXCEPT ELECTRICAL	YES
73	BUSINESS SERVICES	YES
28	CHEMICALS & ALLIED PRODUCTS	YES

RTI

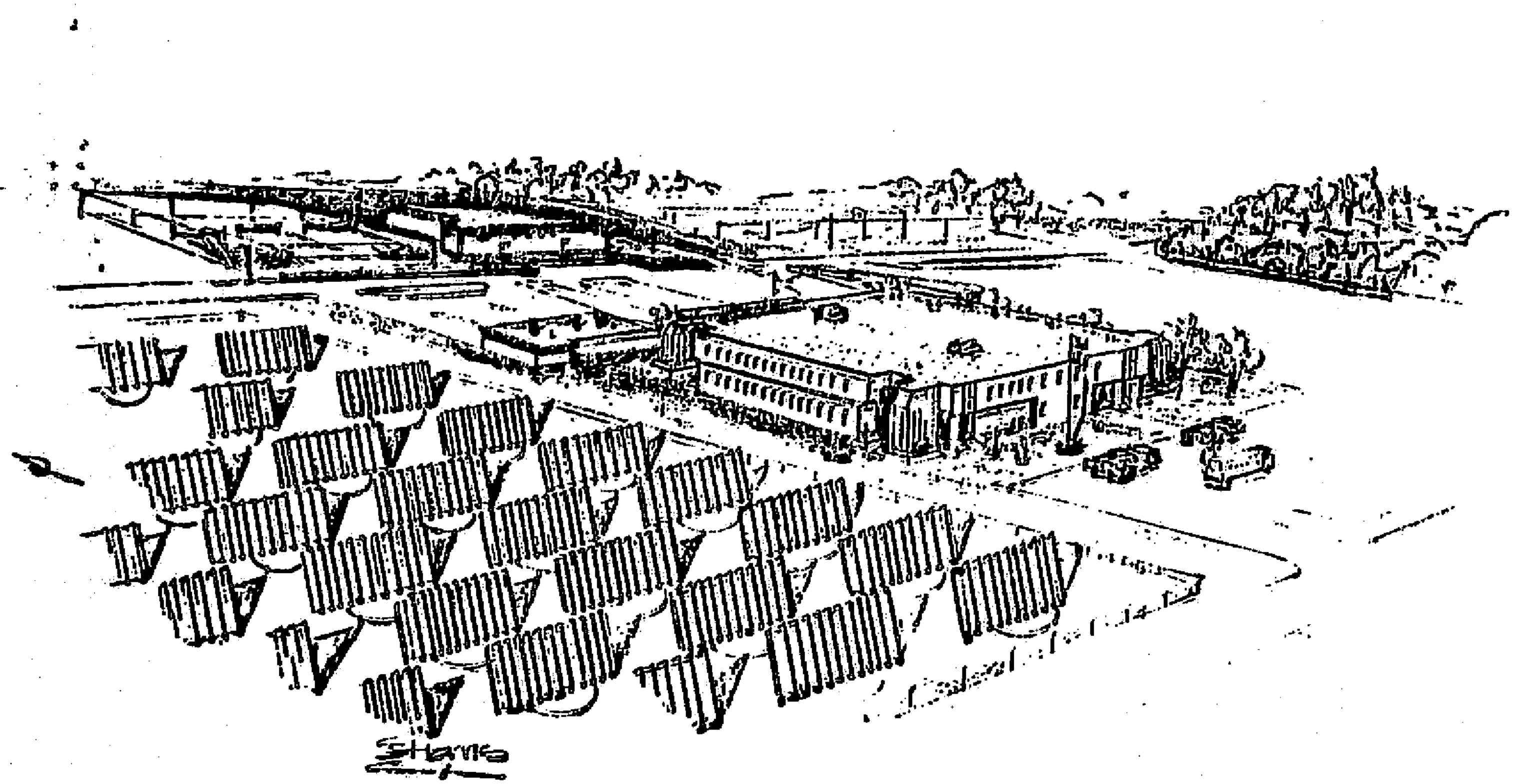
RATIONALE SELECTED APPLICATIONS

	APPLICATION	LOCATION	COLLECTOR	NO. OF ESTABLISHMENTS	SIZE
82	HIGH SCHOOL	PHOENIX, AZ	2-AXIS-PV/T (0.93)	25,000	300 kW
80	MEDICAL CLINIC	CHARLESTON, SC	FLAT PLATE-PV (−0.27)	250,000	30 kW
58	FAST-FOOD RESTAURANT	NASHVILLE, TN	FLAT PLATE-PV (−0.13)	260,000	50 kW
53	SMALL SHOPPING CENTER	MADISON, WI	1-AXIS-PV (0.30)	40,000	100 kW
35	MACHINERY FABRICATOR	BOSTON, MA	FLAT PLATE-PV (0.05)	40,000	200 kW
	↑	↑	↑	↑	↑
	EMP	CLIMATIC REGIONS POPULATION	$\frac{\sum \left(\frac{DN}{TH} - 1 \right)}{YEAR}$	PUBLIC EXPOSURE	$25 < kW < 100$



PHOTOVOLTAIC POWERED HIGH SCHOOL

J.E. SIRRINE COMPANY
(North Carolina Division)
Engineers
Raleigh North Carolina 27607



PHOTOVOLTAIC POWERED
HIGH SCHOOL

J.E. SIRRINE COMPANY
[illegible]
Engineers
[illegible]

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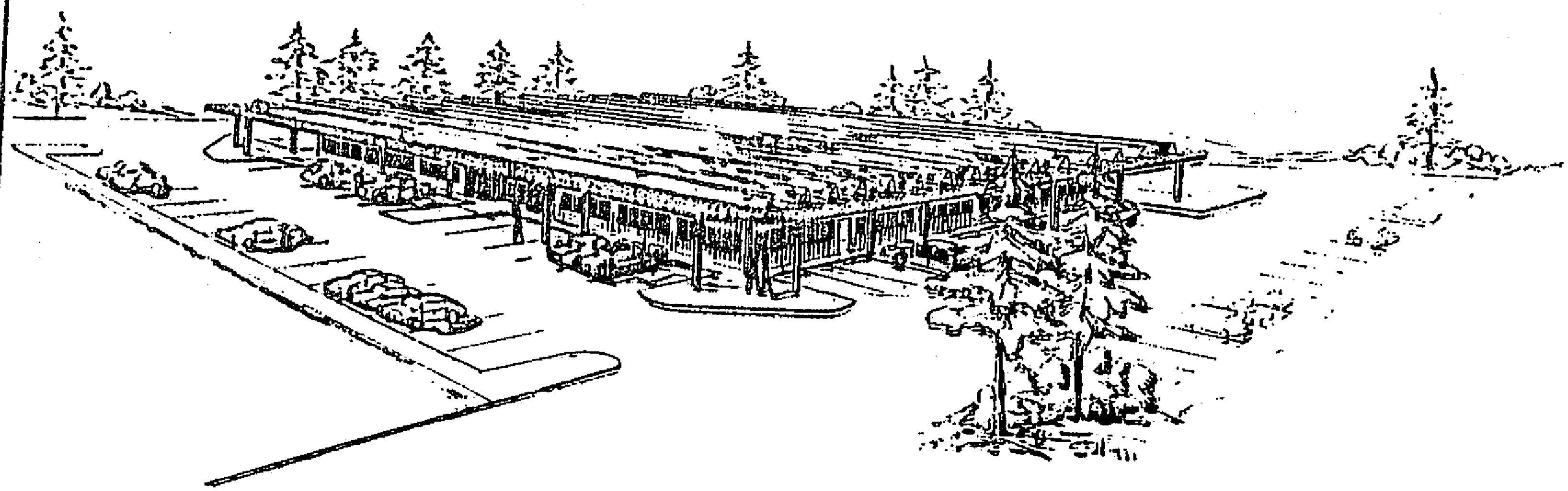

PHOTOVOLTAIC POWERED
MEDICAL CENTER

J.E. SIRRINE COMPANY
Engineers

1-69

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THE BDM CORPORATION

PHOTOVOLTAIC APPLICATIONS DEFINITION AND PHOTOVOLTAIC SYSTEMS DEFINITION STUDY IN THE AGRICULTURAL SECTOR

PRIME CONTRACTOR — THE BDM CORPORATION
SUBCONTRACTOR — GENERAL ELECTRIC COMPANY

PROGRAM OBJECTIVES

(1) SUMMARIZE THE VARIOUS FORMS OF ENERGY CONSUMPTION IN THE AGRICULTURAL SECTOR

(2) IDENTIFY THOSE AGRICULTURAL APPLICATIONS THAT CAN MOST EFFECTIVELY EMPLOY P/V POWER SYSTEMS

(3) IDENTIFY EFFECTIVE P/V SYSTEMS DESIGNS FOR THESE APPLICATIONS

(4) OBTAIN PERFORMANCE AND COST ESTIMATES FOR THESE DESIGNS

6356/76W

PROGRAM SCOPE

- U.S. AGRICULTURE (GENERALLY LARGE SCALE, UTILITY CONNECTED)
- ON-FARM APPLICATIONS
- EMPHASIS ON LONGER TERM LARGE SCALE MARKETS (NOT SMALL REMOTE APPLICATIONS OR SPECIALIZED PRACTICES)
- EXISTING RATHER THAN MODIFIED FARM OPERATIONS

8346/78W

KEY ISSUES

- IDENTIFYING PHOTOVOLTAIC APPLICATIONS THAT COULD PROVIDE A LARGE MARKET BASE FOR PHOTOVOLTAIC UTILIZATION
- IDENTIFYING PHOTOVOLTAIC APPLICATIONS THAT COULD HAVE SIGNIFICANT IMPACTS ON FUTURE ENERGY CONSUMPTION
- FINDING APPLICATIONS IN THE AGRICULTURAL SECTOR THAT ARE COMPATIBLE WITH PHOTOVOLTAIC CHARACTERISTICS
- ESTABLISHING WELL-DEFINED, YET GENERALIZABLE, PHOTOVOLTAIC APPLICATIONS DESPITE WIDELY VARYING ON-FARM OPERATIONS AND COMMODITY MIXES
- ESTABLISHING AGRICULTURAL APPLICATION PACKAGES THAT CAN MAKE PHOTOVOLTAIC SYSTEMS COST-EFFECTIVE IN SPITE OF SEASONAL USAGE VARIATIONS

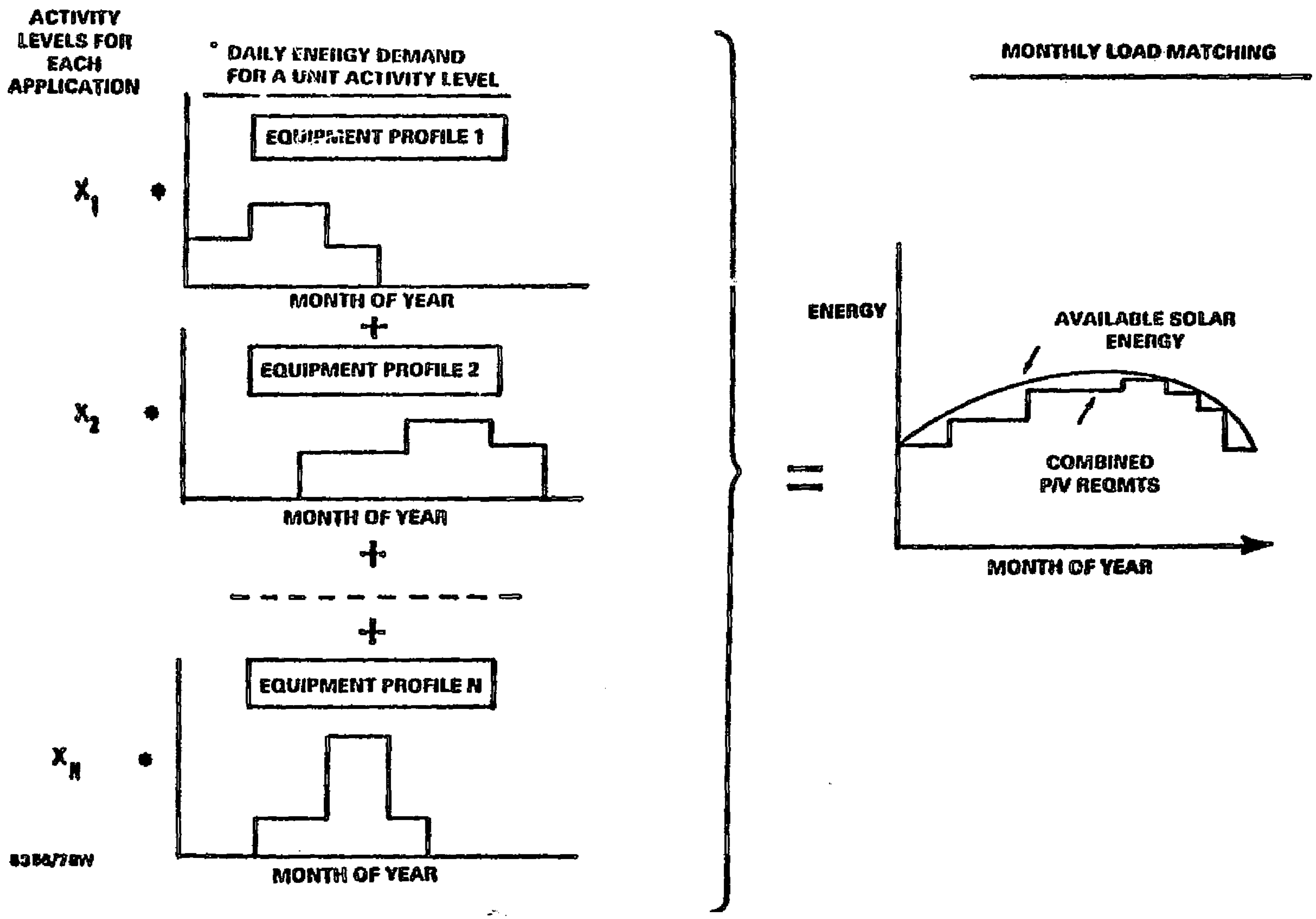
6366/78W

AGRICULTURAL SUBSECTORS

CROP	LIVESTOCK	FERTILIZER	OTHER
ROW CROP	DAIRY	NITROGEN	GREENHOUSE
SMALL GRAIN	BEEF	PHOSPHATE	REMOTE
FORAGE	HOGS	POTASSIUM	
VEGETABLE	POULTRY		
ORCHARD	SHEEP		
OTHER	OTHER		

NOTE: REPRESENTATIVE FARMS OFTEN CUT ACROSS SEVERAL SUBSECTORS.

APPROACH-COMBINE LOAD PROFILES FROM REPRESENTATIVE FARMS TO MATCH AVAILABLE SOLAR INSOLATION



8386/78W

AGRICULTURAL APPLICATIONS - GENERAL CONCLUSIONS

- SEASONAL LOAD PROFILES FOR LIVESTOCK GENERALLY PROVIDE A GOOD YEAR-ROUND MATCH WITH INSOLATION (E.G., VENTILATION IS HIGHER IN SUMMER THAN WINTER AND IS PRIMARILY DAYTIME)
- DAILY LOAD PROFILES FOR LIVESTOCK CAN SOMETIMES BE POORLY MATCHED IF THERE ARE CRITICAL PEAK LOADS OCCURRING AT LOW INSOLATION TIMES (E.G., DAIRY); THIS DEPENDS GREATLY ON STORAGE COST AND PERFORMANCE
- MOBILE FIELD OPERATIONS (E.G., BATTERY-POWERED TRACTORS) PROVIDE POOR APPLICATIONS BECAUSE OF HIGH POWER REQUIREMENTS AND ERRATIC USAGE
- ON-FARM ELECTROLYSIS OF HYDROGEN FOR FUEL DOES NOT APPEAR TO BE COST EFFECTIVE IN THE NEAR TERM (ALTHOUGH SEASONAL STORAGE CAPABILITIES ARE ATTRACTIVE)

6354/78W

AGRICULTURAL APPLICATIONS — GENERAL CONCLUSIONS (CONT'D)

- PRODUCTION OF FERTILIZER IS A HIGH TECHNOLOGY, CAPITAL INTENSIVE INDUSTRIAL PROCESS NOT SUITED FOR ON-FARM OPERATION, EVEN IF HYDROGEN ELECTROLYSIS WERE COST EFFECTIVE.
- IRRIGATION DOES NOT APPEAR TO BE GENERALLY ATTRACTIVE BECAUSE OF THE LIMITED ANNUAL OPERATING CYCLE AND THE VERY HIGH ENERGY DEMANDS (WHICH MAKE IT DIFFICULT TO MATCH WITH OTHER APPLICATIONS); HOWEVER, YEAR-ROUND IRRIGATION MAY BE ATTRACTIVE, PARTICULARLY SINCE THE LOADS ARE NON-CRITICAL AND CAN BE MATCHED TO WEATHER-DEPENDENT ARRAY POWER.
- REMOTE LIVESTOCK WATERING AND PASTURE IRRIGATION PROVIDE GOOD NEAR-TERM MARKETS IN AREAS WHERE UTILITY POWER IS UNAVAILABLE.

PROMISING PHOTOVOLTAIC APPLICATIONS

FARM	PRIMARY LOADS
POULTRY-LAYERS*	VENTILATION, FEEDING, LIGHTING, EGG COOLING
POULTRY-BROILERS	VENTILATION, BROODER HEAT, FEEDING, LIGHTING
HOGS + FEED CROPS*	VENTILATION, SPACE HEATING, BROODER HEATING, PEN CLEANING, FEEDING, IRRIGATION, GRAIN DRYING
BEEF FEEDLOT + GRAIN FEED CROPS*	FEEDING, WATERING, LIGHTING, IRRIGATION DRYING
DAIRY*	WATER HEATING, MILK COOLING, MILKING, FEEDING
REMOTE LIVESTOCK	WATERING, PASTURE IRRIGATION, REMOTE DOMESTIC
YEAR-ROUND VEGETABLE FARM*	IRRIGATION

*CHOSEN FOR CONCEPTUAL DESIGN

8356/7SW

FLAT PLATE COMBINED COLLECTORS

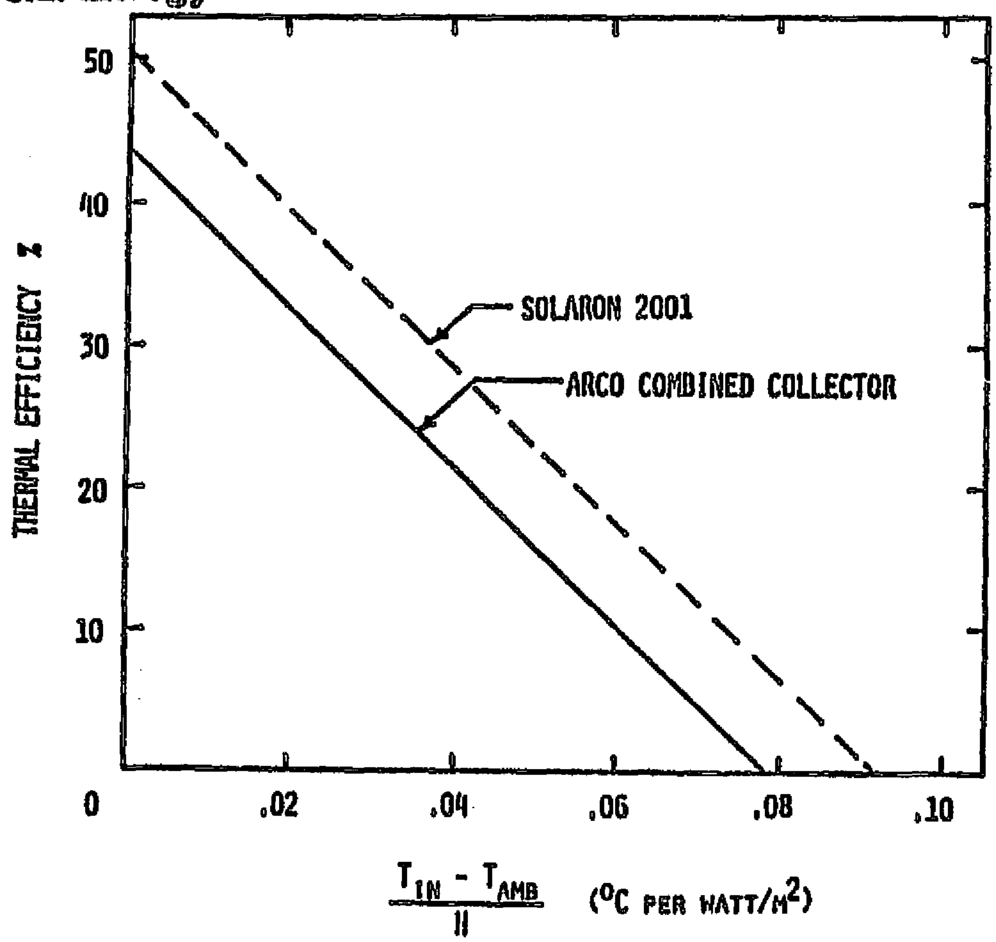
- UTILIZATION OF BOTH THERMAL AND ELECTRICAL ENERGY
  - SPACE HEATING SYSTEMS
  - HOT WATER SYSTEMS
  - PRE-HEATING FOR PROCESS HEAT
- MODULAR - LARGE OR SMALL SYSTEMS
- DISTRIBUTED SYSTEMS - LOCATE NEAR THERMAL LOAD
- NO TRACKING REQUIRED
- ELECTRICAL AND THERMAL EFFICIENCIES DECREASE WITH INCREASING TEMPERATURE

TABLE I

SPECTROLAB AIR-COOLED COMBINED COLLECTOR PERFORMANCE

	TRACKING PLATFORM SYLMAR, CA	FIXED PLATFORM ALBUQUERQUE, NM
OPEN CIRCUIT VOLTAGE	17.7 V	16.9 V
SHORT CIRCUIT CURRENT	7.1 A	7.4 A
MAXIMUM ELECTRICAL POWER	83.0 W	77.2 W
AMBIENT AIR TEMPERATURE	35°C	38°C
OUTLET AIR TEMPERATURE	64°C	76°C
COMPUTED CELL TEMPERATURE	73°C	81°C
AIR FLOW RATE	30.7 CFM	30.7 CFM
THERMAL OUTPUT	500 W	520 W
ELECTRICAL EFFICIENCY*	6.8%	5.7%
THERMAL EFFICIENCY*	46.8%	40.4%

*BASED UPON TOTAL PANEL AREA OF 1.345 M^2



ARCO AIR COLLECTOR

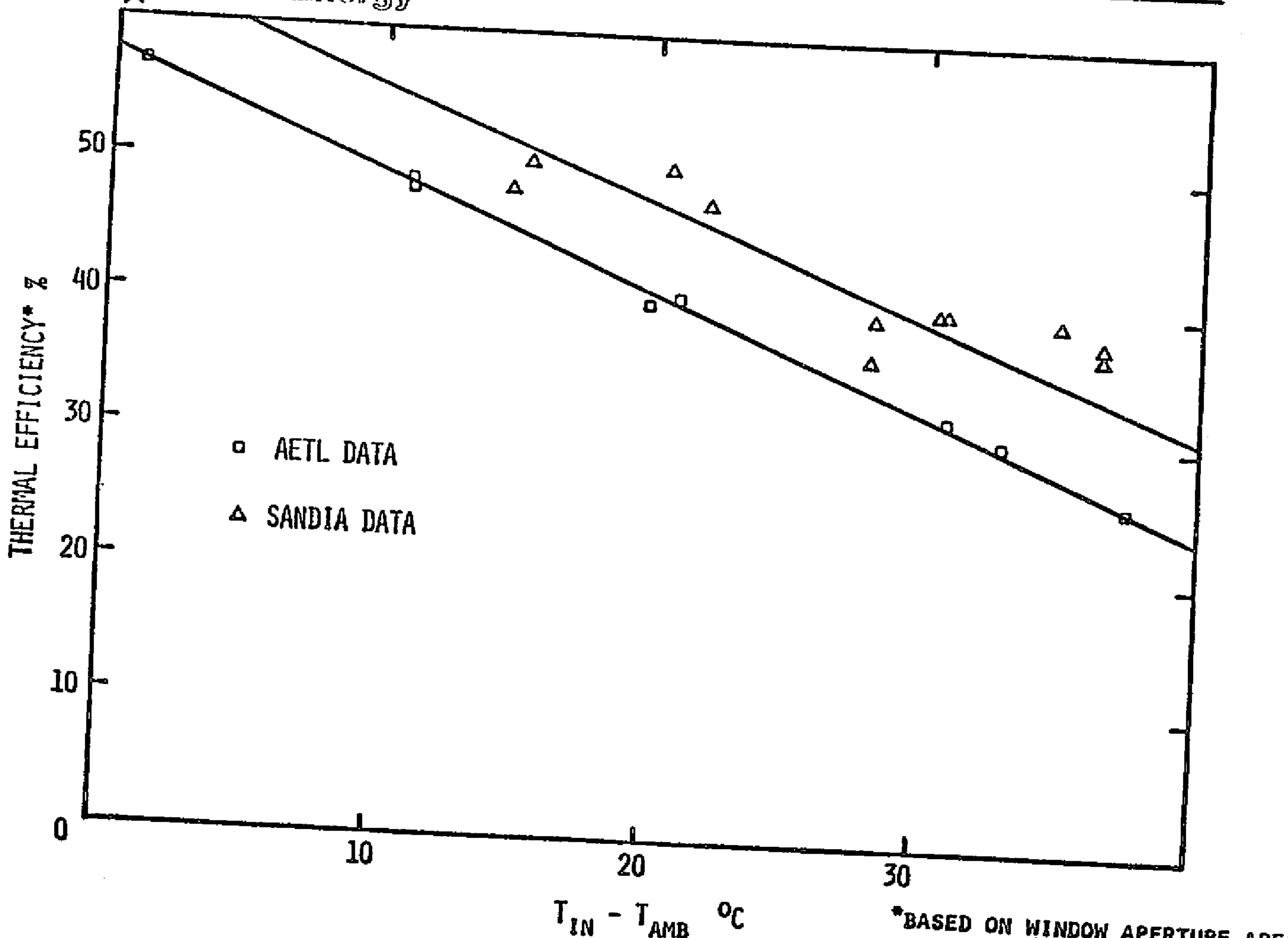
TABLE II

ELECTRICAL PERFORMANCE SUMMARY
AIR-COOLED COMBINED COLLECTOR

TEST	INSOLATION (H) W/M^2	$(T_{IN} - T_{AMB})/H$ $^oC/W/M^2$	TEMPERATURE DIFFERENCE (INLET-AMBIENT) (^oC)	FLOW RATE (SCFM)	MAX POWER (W)	ELECTRICAL EFFICIENCY* (%)
A	794	0	0	3	62.9	5.0
B	810	.053	42.8	3	45.3	3.5
C	854	.053	45	2	43.0	3.2
D	687	0	0	2	66.2	6.0

*BASED UPON 17.19 FT^2 TOTAL EXPOSED PANEL AREA

DATA SUPPLIED BY ARCO



ARCO WATER COLLECTOR

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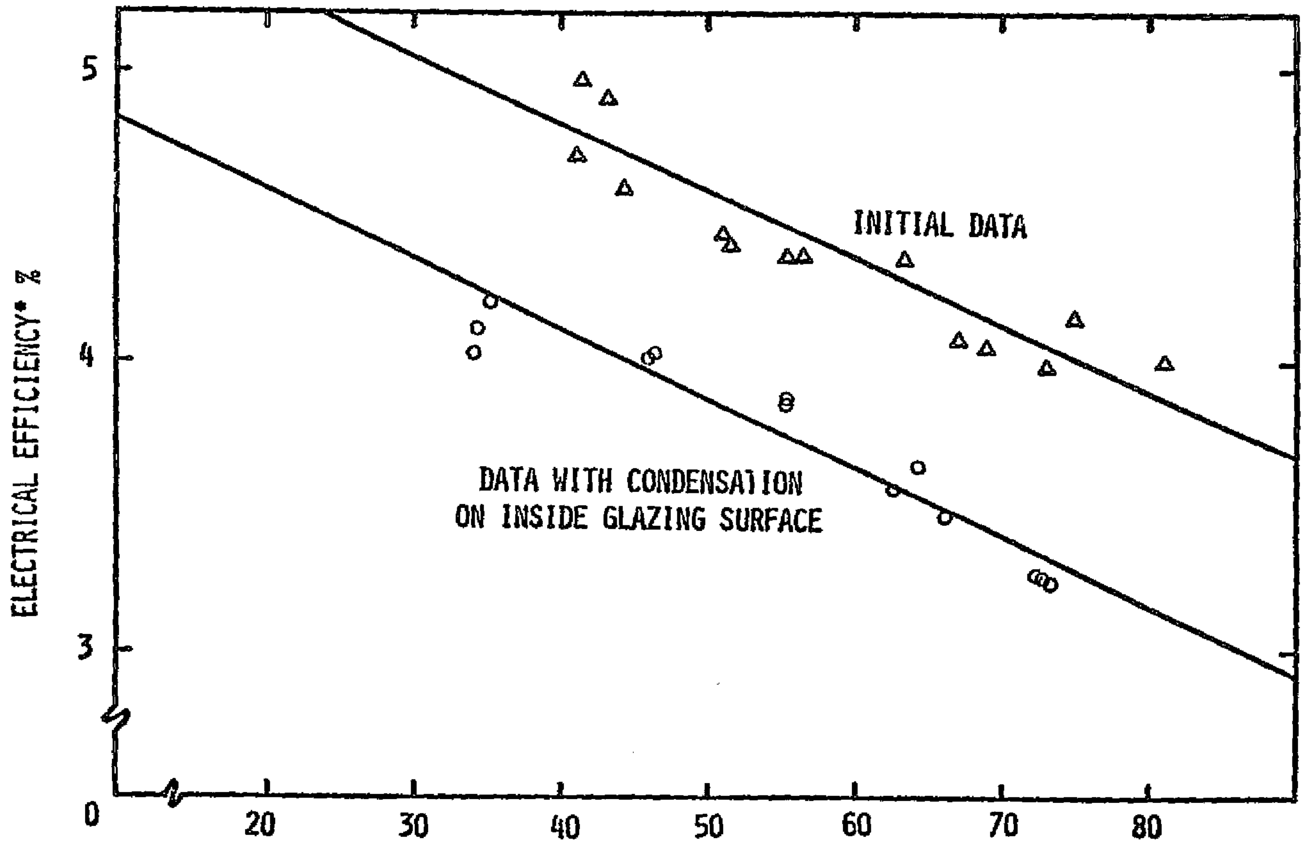
Solar Energy

PHOTOVOLTAIC SYSTEM DEFINITION PROJECT



*BASED ON WINDOW APERTURE ARE.

ARCO WATER COLLECTOR

50 kW PHOTOVOLTAIC POWER CONDITIONING UNIT

WESTINGHOUSE AEROSPACE ELECTRICAL DIVISION

90% COMPLETE - COMPLETION DATE: NOVEMBER 30, 1978

HARDWARE CONSTRUCTED, TESTING IN PROGRESS

- 50 kW SELF COMMUTATED PV POWER CONDITIONING UNIT
- BOTH STAND-ALONE AND UTILITY FEEDBACK MODES
- ~90% EFFICIENT OVER 80% OF OPERATING RANGE
- AUTOMATIC MAZIMUM POWER TRACKING IN UTILITY MODE
- AUTOMATIC WAKE-UP/SHUT-DOWN CONTROL
- INPUT: 250 ± 50 VDC
- OUTPUT: 208 VAC 3ϕ

10 kW PHOTOVOLTAIC POWER CONDITIONING UNIT

ABACUS CONTROLS, INC.

30% COMPLETE - COMPLETION DATE: APRIL 15, 1979

- MODIFICATION OF UNIT BUILT FOR NASA/LeRC
- 10 kW TRANSISTORIZED PV POWER CONDITIONING UNIT
- BOTH STAND-ALONE AND UTILITY FEEDBACK MODES
- ~90% EFFICIENT OVER 80% OF OPERATING RANGE
- AUTOMATIC MAXIMUM POWER TRACKING IN UTILITY MODE
- AUTOMATIC WAKE-UP/SHUT-DOWN LOGIC
- INPUT: 250 ± 50 VDC
- OUTPUT: 115 VAC 1ϕ

PRESENTATION OUTLINE

- PROJECT DESCRIPTION
- COMPLETED ACTIVITIES
- CURRENT ACTIVITIES
- SELECTED STUDY SUMMARIES
- → NEW ACTIVITIES
- KEY PLANNED ACTIVITIES
- SUMMARY

C-2

Sandia Laboratories
Solar Energy

PHOTOVOLTAIC SYSTEM DEFINITION PROJECT

NEW ACTIVITIES

APPLICATION ANALYSIS

CONTRACT	STATUS
• DC LOAD IDENTIFICATION AND PV DESIGN STUDY	CONTRACT BEING NEGOTIATED
• RESIDENTIAL LOAD CENTER STUDY	PROPOSALS RECEIVED

ENGINEERING SUPPORT

• UTILITY/CUSTOMER INTERFACE STUDY	PROPOSALS IN REVIEW
• INSTITUTIONAL ISSUES STUDY	RFP ISSUED
• SIMPLIFIED DESIGN METHODS	RFP ISSUED

SUBSYSTEMS

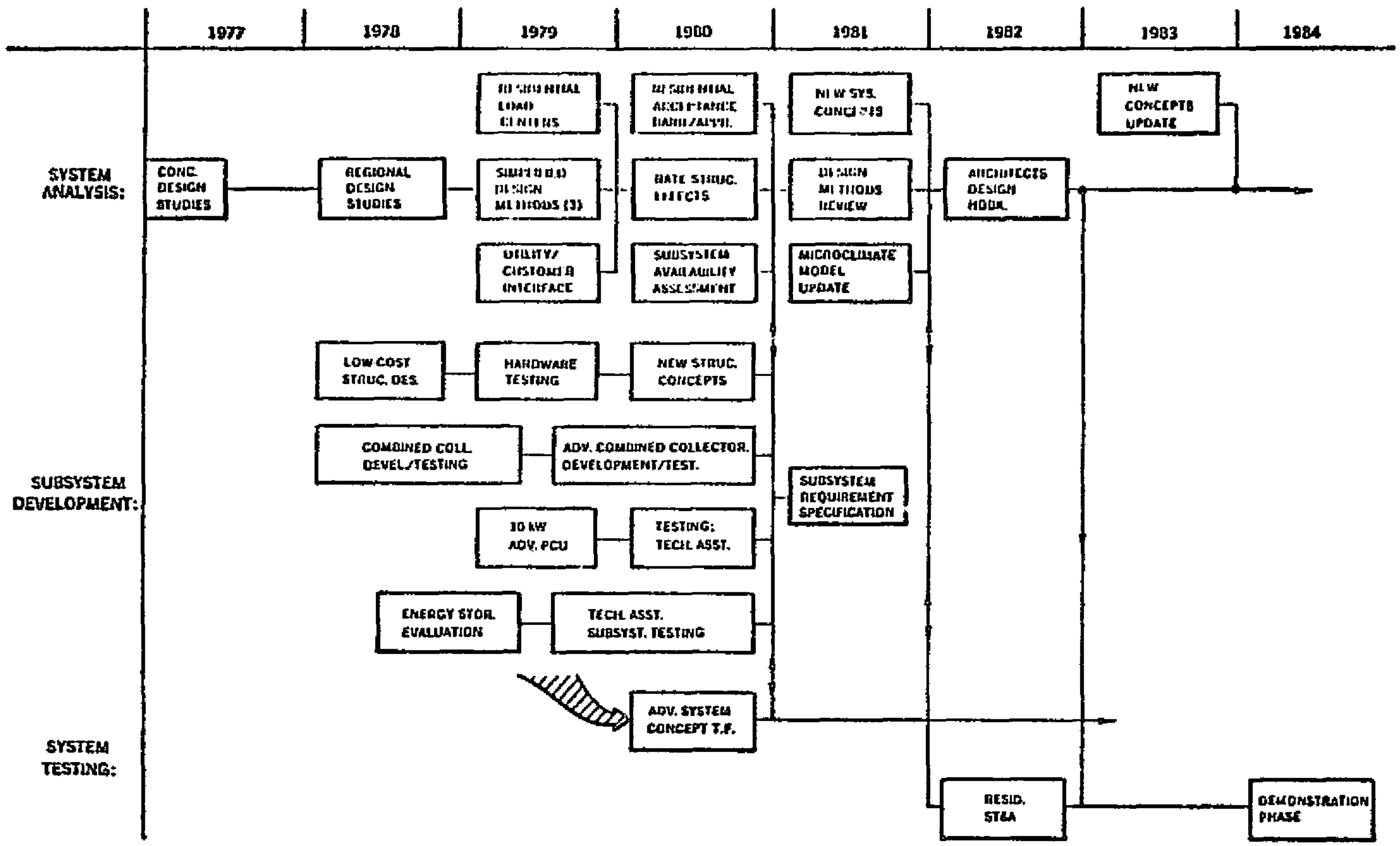
• 10 kW ADVANCED POWER CONDITIONING UNIT	RFP ISSUED

KEY PLANNED ACTIVITIES

SYSTEMS AND SUBSYSTEMS

- SUBSYSTEM OPTIMIZATION AND TRADEOFF STUDY
- ENERGY SCENARIO EFFECTS STUDY
- SUBSYSTEM AVAILABILITY ASSESSMENT
- POWER CONDITIONING TECHNOLOGY STUDY
- DESIGN OF 50 kW ARRAY SIMULATOR
- BATTERY STORAGE SYSTEM CONTROL DESIGN AND INSTALLATION
- PROTOTYPE LOW COST STRUCTURES
- WIND TUNNEL TESTING FOR LARGE ARRAY FIELDS
- PUBLICATION OF SUBSYSTEM REQUIREMENTS DOCUMENT
- PUBLICATION OF SYSTEM ANALYSIS SUMMARY DOCUMENT
- 2ND PV POWER CONDITIONING WORKSHOP

RESIDENTIAL SECTOR PLAN



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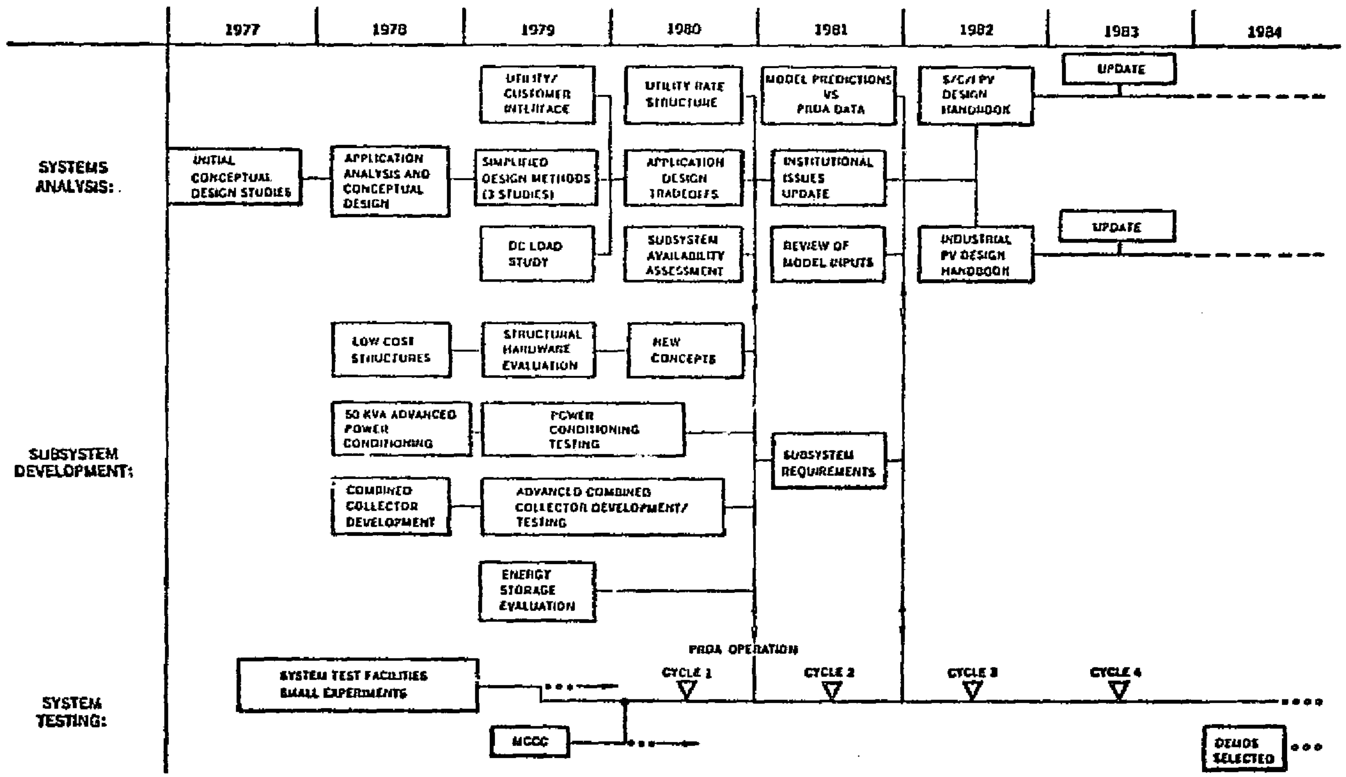
PHOTOVOLTAIC SYSTEM DEFINITION PROJECT

S/C/I AND INDUSTRIAL SECTOR PLANS



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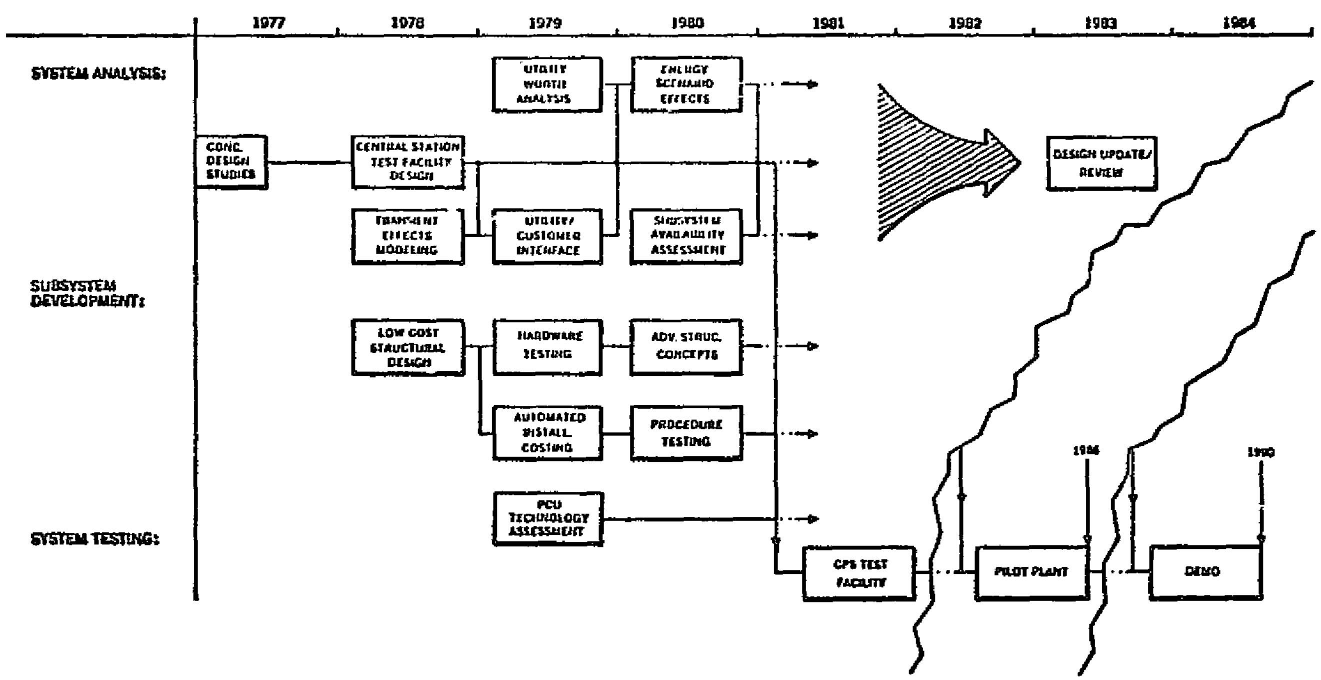
PHOTOVOLTAIC SYSTEM DEFINITION PROJECT

CENTRAL POWER SECTOR PLAN



LOW-COST SOLAR ARRAY PROJECT

W. T. Callaghan, Acting Manager

Jet Propulsion Laboratory

LOW-COST SOLAR ARRAY PROJECT

W. T. Callaghan, Acting Manager

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103

Introduction

The Low-Cost Solar Array (LSA) Project is managed as a part of the Photovoltaics Branch of the DOE Division of Distributed Solar Technology by the Caltech Jet Propulsion Laboratory (JPL) under contract to NASA.

The management approach to the LSA Project, in particular the Project policy of stressing industrial involvement, integrating the industry's results to support industry growth, and including small business, is focused on the objective of achieving a $0.50/W$_p$ module with a twenty-year lifetime and an efficiency of greater than 10% by 1986.

The assessment of state-of-the-art technology, essentially concluded in FY-77 and FY-78, is now being advanced in each of the technology development tasks. During FY-79, the Project will continue to focus its efforts toward the scale-up of technical feasibility. Process and material candidates which show acceptable potential in meeting Project goals will continue to be investigated.

Integration of technical development with highly precise costing systems is critical to achievement of the Project's overall goals. In FY-78, these economic analysis systems were developed into full operation and integrated with all facets of the Project.

Technology Development

Major emphasis of the FY-78 LSA Project was directed toward the scale-up of those processes in silicon material, sheet and array production which have been identified as potential \$500/kW approaches. During this period, the Union Carbide low-cost silane approach to produce silicon material has completed experimental investigation to demonstrate the scalability of critical process elements. Economic reduction of this silane will be demonstrated in a free space reactor including collecting of the resulting silicon dust and melting it in a continuous process consistent with a potential crystal furnace melt replenishment scheme. Battelle Memorial Institute has initiated the design development of a 25-to-50 metric ton Experimental Process System Development Unit (EPSDU).

Progress was also being realized during FY-78 in the development and test of several laboratory-scaled silicon sheet growth processes. Most visible were the Mobil-Tyco Edge-defined Film-fed Growth (EFG) and advanced Czochralski growth and cutting approaches. Demonstrations of the growth of five ribbons five centimeters wide at a rate of five centimeters per minute were accomplished. The EFG machine is being developed with continuous melt replenishment capability and to produce solar cells with high yield and greater than 11% efficiency. The advanced Czochralski technology effort demonstrated continuous melt replenishment schemes. In addition, 10.4% efficiency was demonstrated by Honeywell using silicon on a ceramic material 4.1 cm^2 in area and 15.5% efficiency was demonstrated by Westinghouse using a web-dendritic process on a 6.4 cm^2 area.

Progress in array production technology continues to be demonstrated with the identification of cost-effective cell-module manufacturing processes, and effort is being initiated to combine these processes into complete sequences to evaluate the resulting impacts upon product cost and performance.

SAMIS/SAMICS

The Solar Array Manufacturing Industry Simulation (SAMIS) methodology is a procedure for obtaining price estimates and cost breakdowns for a user-specified manufacturing process sequence. The user must supply a description of each manufacturing process — specifically, certain parameters such as output rate and machine costs and direct requirements of the process (labor, supplies, and facilities). The Solar Array Manufacturing Industry Costing Standards (SAMICS) supplies standardizing assumptions — input prices, indirect requirements relationships, and company structure. SAMIS then simulates the industry within the computer: It explicitly generates overhead (supervisors, guards, etc.), pays taxes, insurance premiums, bills, and salaries. It replaces capital, recovers start-up losses, repays loans, and produces a SAMICS-specified rate of return on equity.

SAMICS is available now, both as a manual procedure which uses simplifying assumptions for the generation of indirect expenses, and as a computer program (SAMIS III).

Engineering

The activities of the LSA Engineering Area involve requirement generation, module engineering activities and environmental testing research and development. The present emphasis on module requirements is in the area of module structural design criteria for large central power station modules. A contract with Bechtel defined minimum-cost structural design approaches for flat plate modules. Boeing Engineering completed a contract to determine the cost/benefit of reducing structural costs by inclosing the modules in a transparent enclosure. An array wind loading contract is in process by Boeing to determine loads under field conditions. In addition, Burt Hill Kosar Rittlemann Associates is defining requirements for residential arrays. Cooperation with SERI continues regarding the generation of array performance standards.

Operations

Deliveries of Block III production modules were just over 50% complete by the end of October, and all deliveries are expected to be complete in early 1979. A request for proposal for the design and prototype module fabrication of Block IV (third generation) modules has just been released. Proposals are being solicited for both intermediate load and residential type modules.

Module test and evaluation at JPL is continuing. Block III environmental qualification test results show further improvement over previous production blocks; no modules have shown significant electrical output degradation as a result of these tests. Field tests at JPL sites show typical soiling effects to be a 6-7% decrease in power output after thirty days exposure, with little difference in soil accumulation rates for glass and silicone rubber superstrates. Analysis of test and field problems/failures shows that cracked cells remain the most common cause of electrical degradation; significant progress has been made in the use of laser scanning techniques for laboratory analysis of this problem.

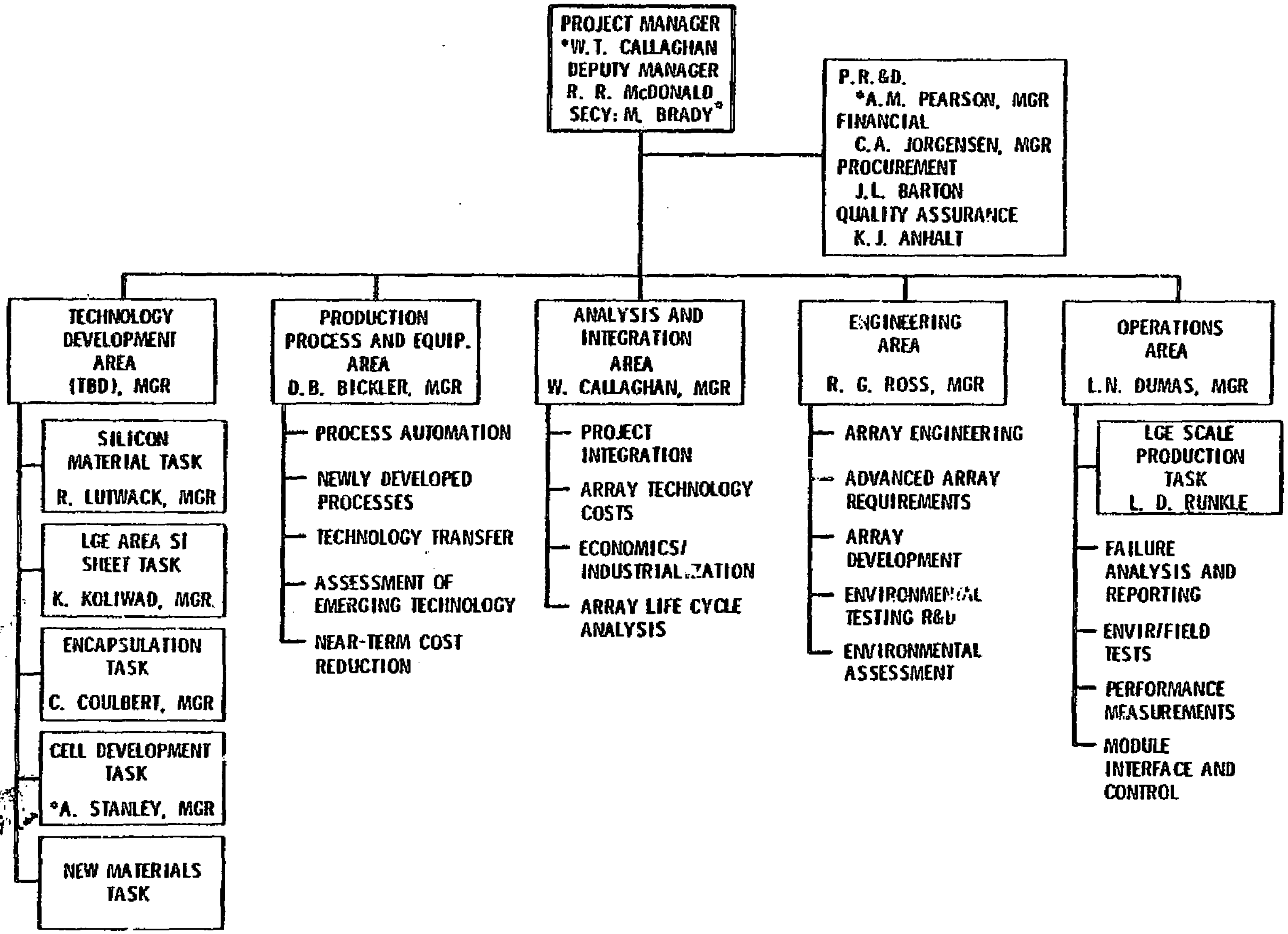
LOW-COST SOLAR ARRAY PROJECT

PROJECT SUMMARY

- GENERAL PROJECT PLAN
- HIGHLIGHTS OF 6 MONTHS PROGRESS
- PLANS FOR NEXT 6 MONTHS
- FOCUS ON TECHNICAL AND ECONOMIC ASPECTS OF $0.50/$W_{pk}$ PROCESS

WTC
11/7/78

LOW-COST SOLAR ARRAY PROJECT



* ACTING
(TBD) - TO BE DETERMINED

11/7/78

LOW-COST SOLAR ARRAY PROJECT

PROJECT SUMMARY

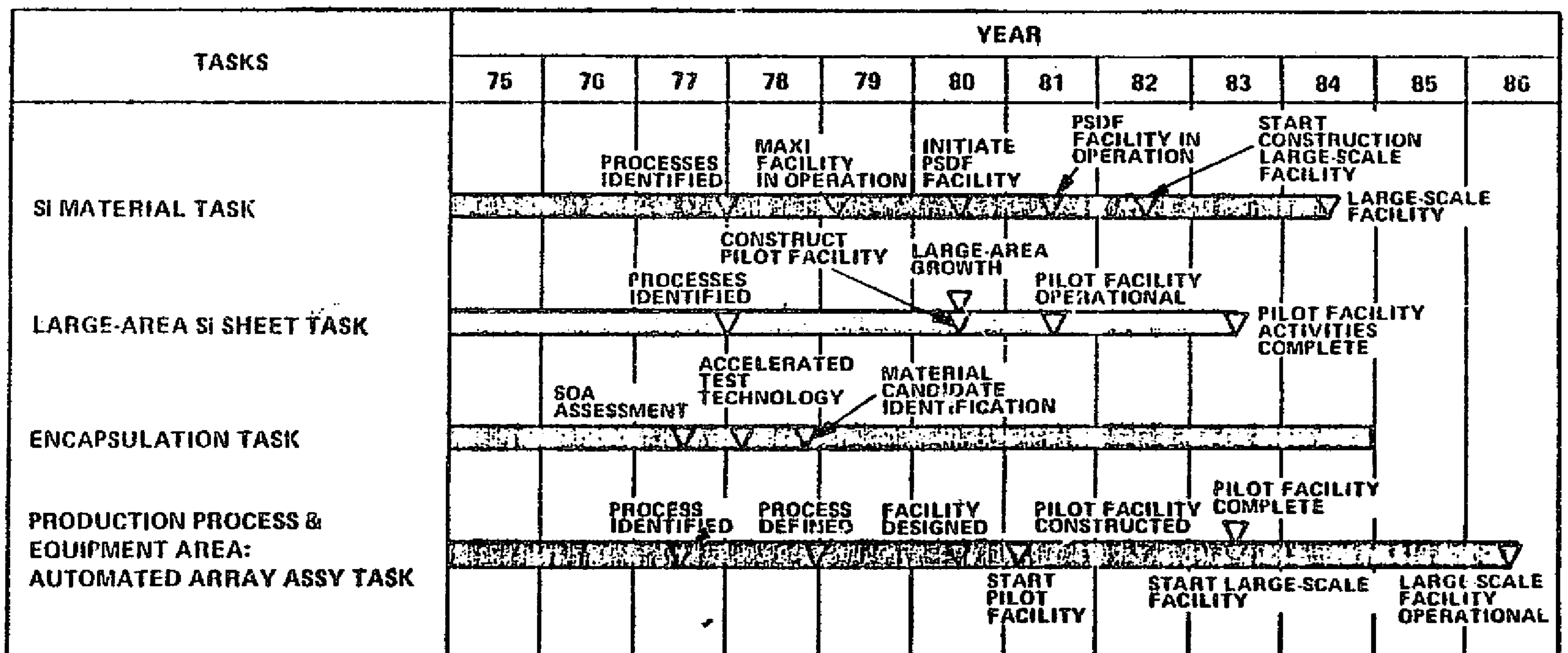
- PROGRESS AND PLANS SUMMARIES
  - MATERIALS TASK - R. LUTWACK
  - LARGE AREA SHEET TASK - K. KOLIWAD
  - PRODUCTION PROCESS TASK - D. BICKLER
  - PROJECT ANALYSIS - R. CHAMBERLAIN
  - ENGINEERING AND OPERATIONS - R. ROSS

WTC
11/7/78

LOW-COST SOLAR ARRAY PROJECT

SUMMARY PLAN AND MILESTONES

- PROJECT OBJECTIVE: FY86 $500/KW, 500MW/YR, COMMERCIAL READINESS ACHIEVED
- 5-YEAR OBJECTIVE: FY81 TECHNOLOGY AND ECONOMIC POTENTIAL DEMONSTRATED
- TECHNOLOGY READINESS
- PHASE II COMMERCIAL READINESS



1. IDENTIFY/ASSESS POTENTIAL PROCESSES
2. EVALUATE SCALEABILITY
3. PROOF OF TECHNOLOGY EXPERIMENT/DEMONSTRATION

LOW-COST SOLAR ARRAY PROJECT

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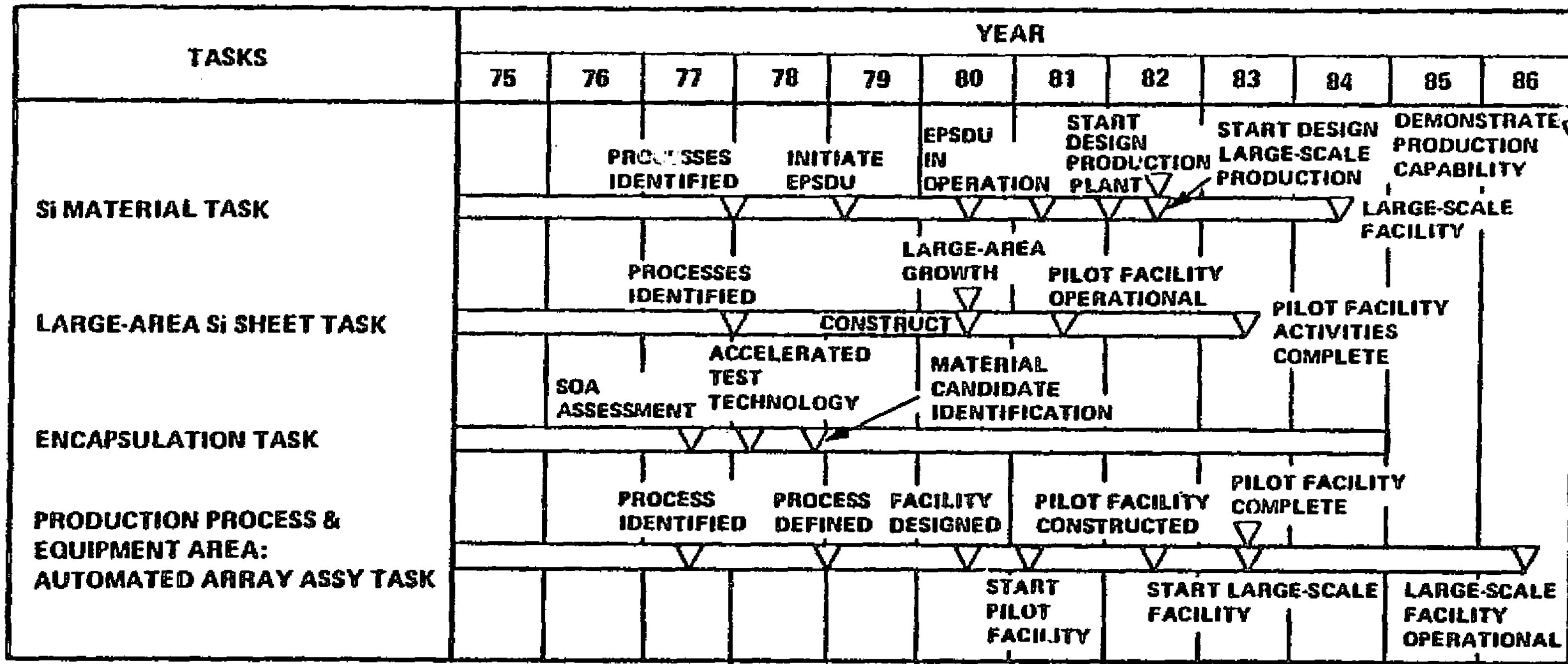

1. IDENTIFY/ASSESS POTENTIAL PROCESSES
2. EVALUATE SCALABILITY
3. PROOF OF TECHNOLOGY EXPERIMENT/DEMONSTRATION

RRL
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LOW-COST SOLAR ARRAY PROJECT

SILICON MATERIAL TASK APPROACH

- PROCESS DEVELOPMENTS
  - PHASE I - TECHNICAL FEASIBILITY
  - PHASE II - SCALE-UP EXPERIMENTS
  - PHASE III - EXPERIMENTAL PROCESS SYSTEM DEVELOPMENT UNITS
  - PHASE IV - LARGE SCALE PRODUCTION PLANTS

- PROCESS DEVELOPMENTS - SUPPORTING SUBTASKS
  - EFFECTS OF IMPURITIES
  - MATERIALS OF CONSTRUCTION
  - COMPOSITION ANALYSES
  - ECONOMIC ANALYSES
  - IN-HOUSE EXPERIMENTAL PROGRAM
  - JPL ANALYSIS
  - CONSULTANTS
    - CHEMICAL PROCESSING
    - CHEMICAL ENGINEERING
    - SOLID STATE PHYSICS

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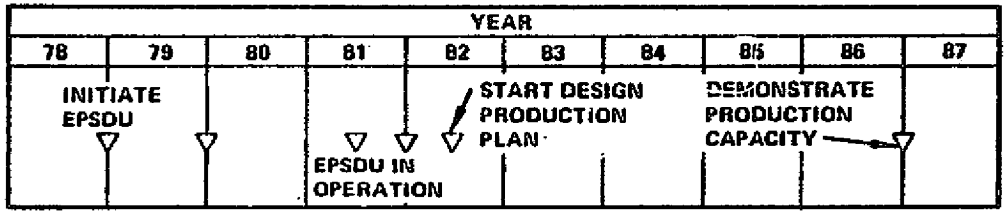
LOW-COST SOLAR ARRAY PROJECT

GENERAL PLAN

SILICON MATERIAL TASK



PROCESS DEVELOPMENTS

- UNION CARBIDE
- BATTELLE
- MOTOROLA
- WESTINGHOUSE
- DOW CORNING
- SRI
- SCHUMACHER
- AEROCHEM
- TEXAS INSTRUMENTS - BATTELLE

IMPURITY EFFECTS

- WESTINGHOUSE
- C.T. SAH

SUPPORT

- NATIONAL BUREAU OF STANDARDS
- LAMAR UNIVERSITY
- LAWRENCE LIVERMORE LABORATORY

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LOW-COST SOLAR ARRAY PROJECT

STATUS-NOVEMBER 1978

PROCESS DEVELOPMENTS

- UNION CARBIDE
  - CONTINUOUS PRODUCTION SiH_4 PDU SHOWN
  - FSR OPERATED AT 0.45 kg/hr
  - PRODUCT COST ESTIMATES
  - EPSDU DESIGN
- BATTELLE
  - REACTOR RECOVERY SYSTEM REDESIGNED
  - REACTOR DEVELOPMENT CONTINUED
  - PRELIMINARY PRODUCT COST CALCULATION REFINED
- MOTOROLA
  - DESIGN EXPERIMENTAL UNIT REVIEWED
  - NEW APPARATUS DEMONSTRATED
- WESTINGHOUSE
  - PROCESS DEMONSTRATION UNIT DESIGN COMPLETED
  - ASSEMBLY SYSTEMS FOR SUPPORT TASKS COMPLETED
- DOW CORNING
  - DAR EXPERIMENTS
  - PRELIMINARY PRODUCT COST ESTIMATE
- SRI
  - $Si_{(e)}$ - $NaF_{(e)}$ SEPARATION DEMONSTRATED
- AEROCHEM (FLAME CHEMISTRY)
  - REACTION CHARACTERISTICS DETERMINED

RLL
11/7/78

LOW-COST SOLAR ARRAY PROJECT

STATUS-NOVEMBER 1978 (contd)

- SCHUMACHER
  - BROMOSILANE REACTION SYSTEMS CHARACTERIZED
  - COUNTERCURRENT FLOW REACTOR TESTED
- TEXAS INSTRUMENTS - BATTELLE
  - PROGRAM PLAN APPROVED

- IMPURITY EFFECTS
  - WESTINGHOUSE
    - ANALYTICAL MODEL DEVELOPED
    - EFFECTS IN n-BASE AND p-BASE COMPARED
    - INGOT GROWTH RATES
    - BULK LIFETIME INCREASES BY GETTERING
    - IMPURITY EFFECTS RELATED TO DIFFUSION LENGTH
  - C.T. SAH ASSOCIATES
    - IMPURITY EFFECT MODEL DESCRIBED
    - MODEL TESTED USING Au
- SUPPORTING EFFORTS
  - NATIONAL BUREAU OF STANDARDS
    - IMPURITY CONCENTRATION MEASUREMENTS
  - LAWRENCE LIVERMORE LABORATORIES
    - IMPURITY CONCENTRATION MEASUREMENTS
  - LAMAR UNIVERSITY
    - ANALYSIS UNION CARBIDE PROCESS COMPLETED
  - AEROCHEM
    - COMPUTER CODE DEVELOPMENT

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LOW-COST SOLAR ARRAY PROJECT

SILICON MATERIAL TASK

- PROCESS DEVELOPMENTS
  - UNION CARBIDE
    - EPSDU DETAILED ENGINEERING DESIGN
    - PROCESS AND ECONOMIC ANALYSIS
    - SiH_4 PYROLYSIS DEVELOPMENT
  - BATTELLE
    - EPSDU FABRICATION AND INSTALLATION
    - REACTOR DEVELOPMENT
  - MOTOROLA
    - 1 kg/hr UNIT
    - REACTOR CHARACTERIZATION
  - WESTINGHOUSE
    - CHEMISTRY, KINETICS, INJECTION SYSTEMS CHARACTERIZED
    - PROCESS DEMONSTRATION UNIT CHECKED-OUT
  - DOW CORNING
    - PRODUCT PURITY DEMONSTRATED
  - SRI
    - PRACTICABILITY LIQUID PHASE SEPARATION SHOWN
    - Si PURITY DEMONSTRATED

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SILICON MATERIAL TASK (contd)

- AEROCHEM (FLAME CHEMISTRY)
  - PRODUCT SEPARATION DEMONSTRATED
  - PRODUCT PURITY DEMONSTRATED
- SCHUMACHER
  - BROMOSILANE REACTORS CHARACTERIZED
- TEXAS INSTRUMENTS - BATTELLE
  - BATCH MODE OPERATION
- IMPURITY EFFECTS
  - WESTINGHOUSE
    - EXTEND IMPURITY MATRIX
    - DETERMINE EFFECTS OF PROCESSING
  - C.T. SAH ASSOCIATES
    - REFINE MODEL
    - CHARACTERIZE RECOMBINATION CENTERS
- SUPPORTING EFFORTS

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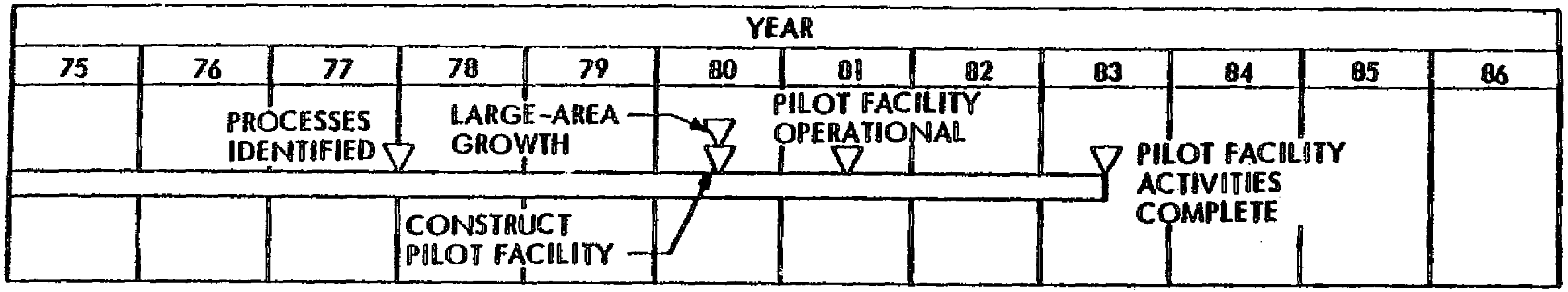
LOW-COST SOLAR ARRAY PROJECT
LARGE AREA SILICON SHEET TASK

SHEET TECHNOLOGY DEVELOPMENT APPROACHES



INGOT TECHNOLOGY

- ADVANCED CZOCHRALSKI GROWTH (ADV. Cz)
- HEAT EXCHANGE METHOD (HEM)
- WAFERING - MULTIPLE BLADE SLURRY SAW (MBS)
- MULTIPLE WIRE SAW (MWS)

SHAPED RIBBON TECHNOLOGY

- EDGE DEFINED FILM FED GROWTH (EFG)
- WEB-DENDRITIC GROWTH (WEB)
- RIBBON TO RIBBON GROWTH (RTR)

SUPPORTED FILM TECHNOLOGY

- SILICON-ON-CERAMIC GROWTH (SOC)
- EPITAXIAL ON LOW-COST SILICON SUBSTRATES (EPI)

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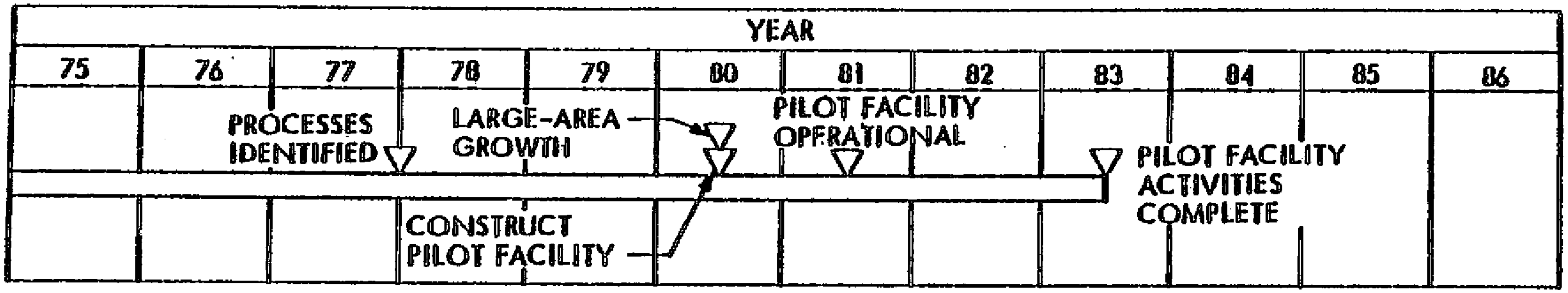
11/8/78

LOW-COST SOLAR ARRAY PROJECT
LARGE AREA SILICON SHEET TASK
STATUS-NOVEMBER 1978

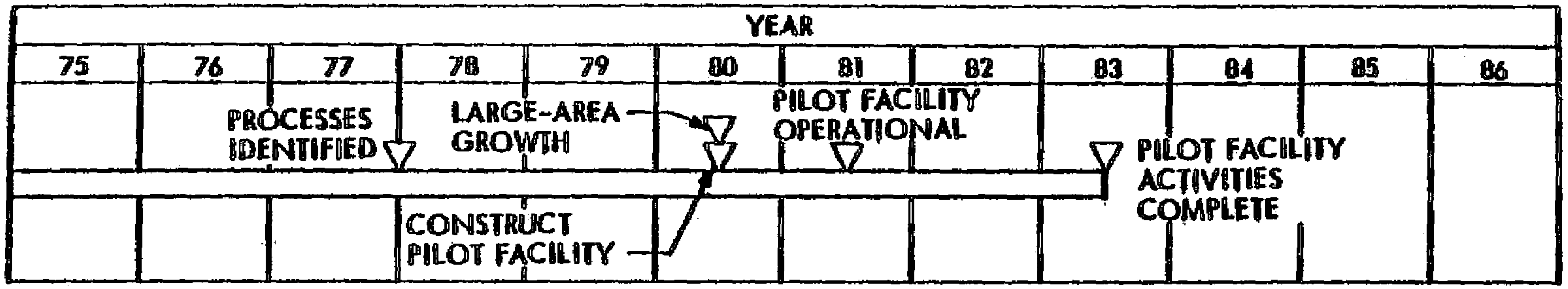


INGOT TECHNOLOGY

- ADVANCED Cz GROWTH
  - ADV. Cz GROWTH MACHINES BUILT
  - MELT REPLENISHMENT DEMONSTRATED
  - MULTIPLE INGOT GROWTH DEMONSTRATED (12 cm DIAM., 4 INGOTS, 50 kg TOTAL)
- CASTING BY HEAT EXCHANGE METHOD
  - 2.5 kg SHAPED INGOT CAST (> 80% SINGLE CRYSTAL)
- WAFERING
  - 1000 BLADE PROTOTYPE MBS SAW BUILT AND TESTING IN PROGRESS (10 cm DIA, 300μ WAFER, 200μ KERF, > 95% YIELD)
  - 300 WIRE MW PROTOTYPE SAW BUILT AND TESTING IN PROGRESS (10 cm DIA, 250μ WAFER, 250μ KERF, > 97% YIELD)

KK
11/8/78

LOW-COST SOLAR ARRAY PROJECT
LARGE AREA SILICON SHEET TASK
STATUS-NOVEMBER 1978



SHAPED RIBBON TECHNOLOGY

- SIMULTANEOUS GROWTH OF 5 EFG RIBBONS EACH 5 cm WIDE AT 5 cm/min IS ROUTINELY ACHIEVABLE
- CONSIDERABLE PROGRESS IN MINIMIZING THE CONTAMINATION-RELATED EFFECTS ON EFG CELLS (> 9% EFFICIENCY)
- 13 cm^2/min AREA GROWTH RATE HAS BEEN ACHIEVED FOR WEB-DENDRITIC RIBBONS
- 15.5% EFFICIENCY WEB-DENDRITIC CELLS HAVE BEEN DEMONSTRATED (6.4 cm^2 AREA)
- 55 cm^2/min AREA GROWTH RATE HAS BEEN ACHIEVED FOR RTR RIBBONS WITH CVD POLY FEEDSTOCK
- 6% EFFICIENCY RTR CELLS HAVE BEEN DEMONSTRATED (4 cm^2 AREA)

SUPPORTED FILM TECHNOLOGY

- 4.5 cm^2 SOC CELLS HAVE BEEN FABRICATED WITH >7% EFFICIENCY (SLOTTED MULLITE SUBSTRATE, BACK SIDE CONTACT)
- 12% EPI CELLS ON METALLURGICAL GRADE SI SUBSTRATES HAVE BEEN DEMONSTRATED

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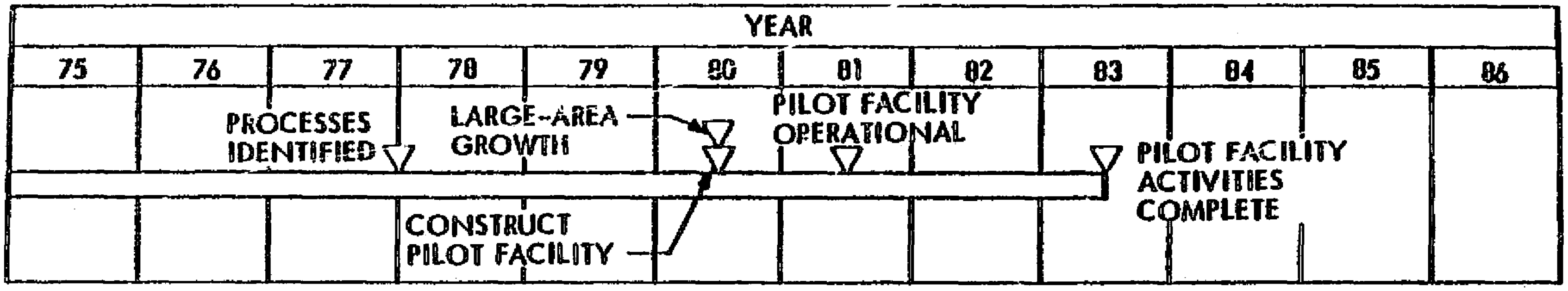
LOW-COST SOLAR ARRAY PROJECT
LARGE AREA SILICON SHEET TASK

PLANS UP TO APRIL 1979



INGOT TECHNOLOGY

- DEMONSTRATE GROWTH OF 100 kg Cz INGOT (10 cm DIA. AT 10 cm/hour WITH MELT REPLENISHMENT)
- ACHIEVE GROWTH OF 8 kg SHAPED HEM INGOT
- ACHIEVE WAFERING GOAL OF 25 SLICES/cm OF 10 cm DIA. INGOT

SHAPED RIBBON TECHNOLOGY

- DEMONSTRATE SIMULTANEOUS GROWTH OF EFG RIBBONS, 10 cm WIDE AT 5 cm/min (250 cm^2/min)
- ACHIEVE 25 cm^2/min AREA GROWTH RATE FOR WEB-DENDRITIC RIBBONS
- DEMONSTRATE >10% EFFICIENCY RTR CELLS AND ACHIEVE 100 cm^2/min AREA GROWTH RATE

SUPPORTED FILM TECHNOLOGY

- DEMONSTRATE >10% EFFICIENCY SOC CELLS
- DEMONSTRATE ROUTINE UTILIZATION OF HIGH THROUGHPUT EPI REACTOR

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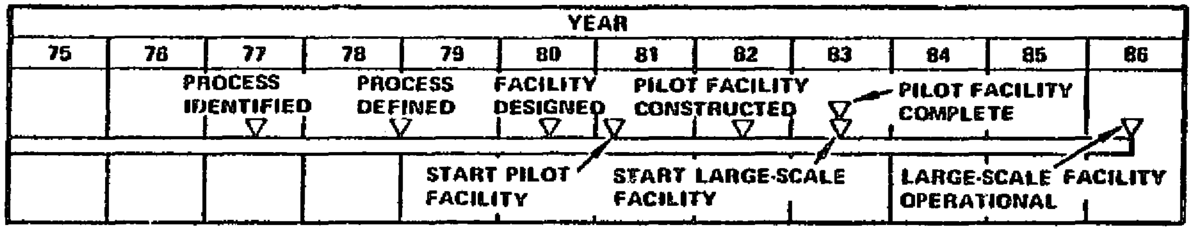
LOW-COST SOLAR ARRAY PROJECT

GENERAL PLAN

PRODUCTION PROCESS AND EQUIPMENT



PHASE II PROCESS DEVELOPMENT
- LOCKHEED
- MBA
- RCA
- SENSOR TECHNOLOGY
- SOLAREX
- TEXAS INSTRUMENTS
- WESTINGHOUSE
- MOTOROLA
- SPECTROLAB

SPECIAL PROCESS STUDIES
- SPIRE
- OCLI
- MOTOROLA
- SOLAREX
- B. ROSS
- KINETIC COATINGS

NEAR TERM COST REDUCTION
- ARCO
- KULICKE AND SOFFA
- SOLLOS
- MOTOROLA
- RCA
- SENSOR TECHNOLOGY

< $500/kW$_{pk}$ STRAWMAN FACTORY

	VALUE ADDED $/W
SILICON* PREPARATION	0.043
SHEET FABRICATION	0.134
CELL FABRICATION	0.119
MODULE FABRICATION	0.164
TOTALS	0.460

*BASED ON 10 $/kg SILICON

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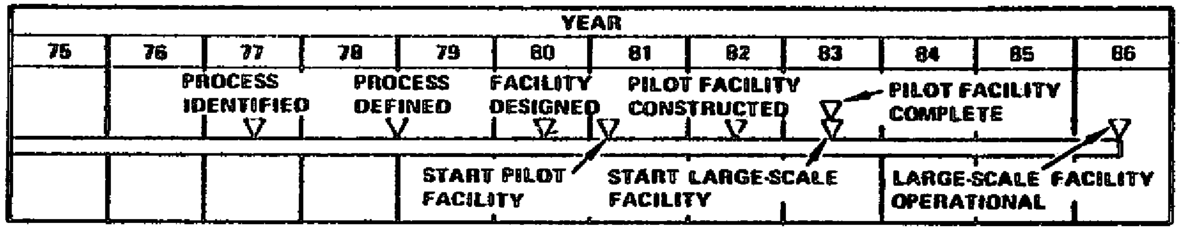
LOW-COST SOLAR ARRAY PROJECT

STATUS-OCTOBER 1979

PRODUCTION PROCESS AND EQUIPMENT



PHASE II PROCESS DEVELOPMENT

$500/kW$_{pk}$ STRAWMAN FACTORY

- ACHIEVABLE USING PROCESSES UNDER DEVELOPMENT
- GOAL MAY BE EXCEEDED

SEQUENCE DEVELOPMENT EFFORT STARTING

- PROCESSES SELECTED FOR USE IN SEQUENCES
- SEQUENCE OPTIONS AVAILABLE USING ALTERNATE KEY PROCESSES
- DEVELOPED PROCESSES ARE BEING VERIFIED

SPECIAL PROCESS STUDIES

- LARGE SCALE ION IMPLANTER DESIGN COMPLETED
- HIGH EFFICIENCY P/N CELLS/MODULES

METALLIZATION DEVELOPMENTS

- WORKSHOP HELD TO BRING IN NEW APPROACHES
- CONCERN OVER ENVIRONMENTAL/ENCAPSULATION REQUIREMENTS
- WORK ON THICK FILM METAL INKS WITHOUT FRIT
- PURSUING FURTHER REDUCTIONS IN PLATING SYSTEMS COSTS

NEAR TERM PRICE REDUCTION CONTRACTS

- SUPPORTED PROJECT IN RFP, PROPOSAL EVALUATION, AND CONTRACT MONITORING

PHASE III

- FIRST GENERATION SPRAY EQUIPMENT OPERATIONAL FOR JUNCTION FORMATION

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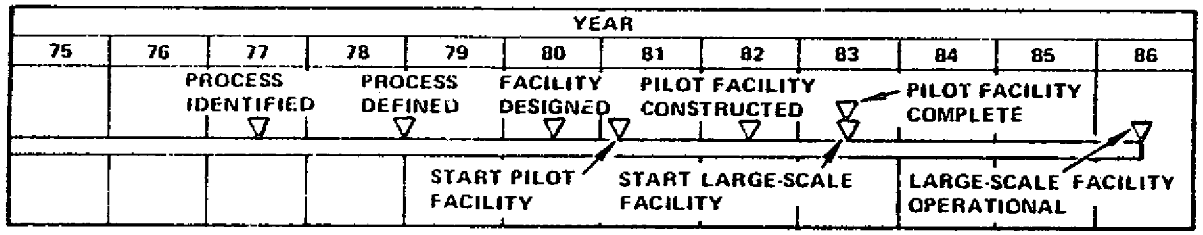
LOW-COST SOLAR ARRAY PROJECT

ANTICIPATED STATUS-APRIL 1979

PRODUCTION PROCESS AND EQUIPMENT



- WORK TOWARD 4c/WATT METALLIZATION SYSTEMS
- CONTINUE PROCESS SEQUENCE DEVELOPMENT
- BROADEN TECHNOLOGY TRANSFER
- DEVELOPMENT OF AUTOMATED ASSEMBLY EQUIPMENT
- MATERIAL HANDLING STUDIES

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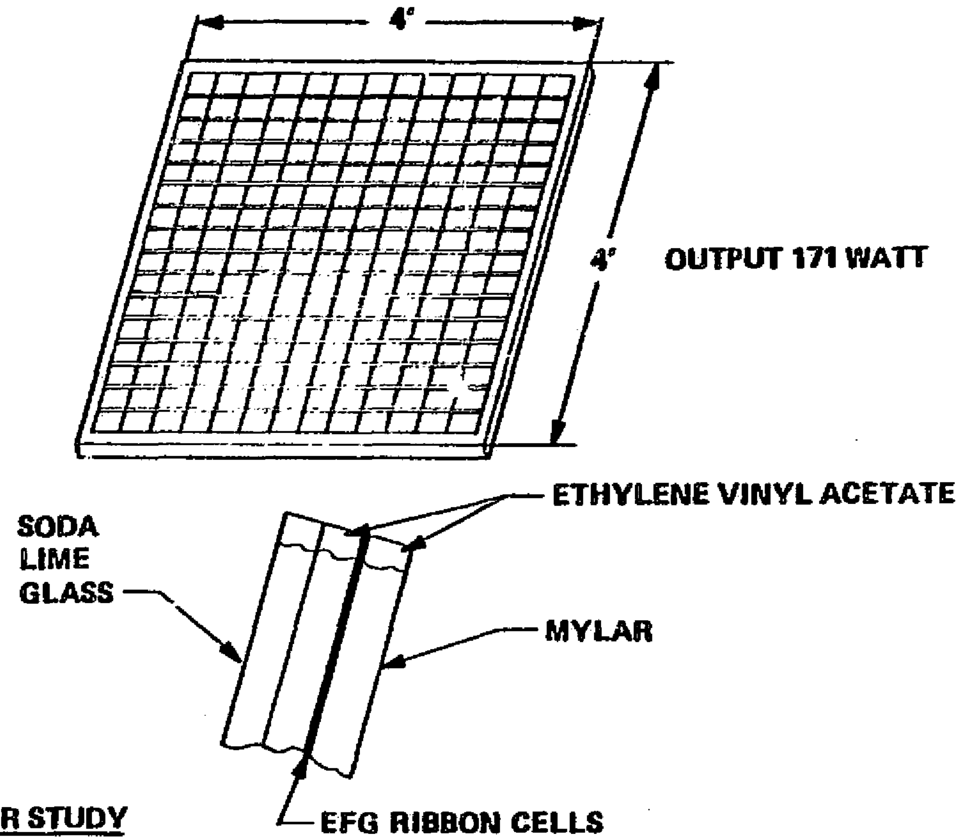
< $ 500/KW(p) STRAWMAN FACTORY

PRODUCT DESIGN

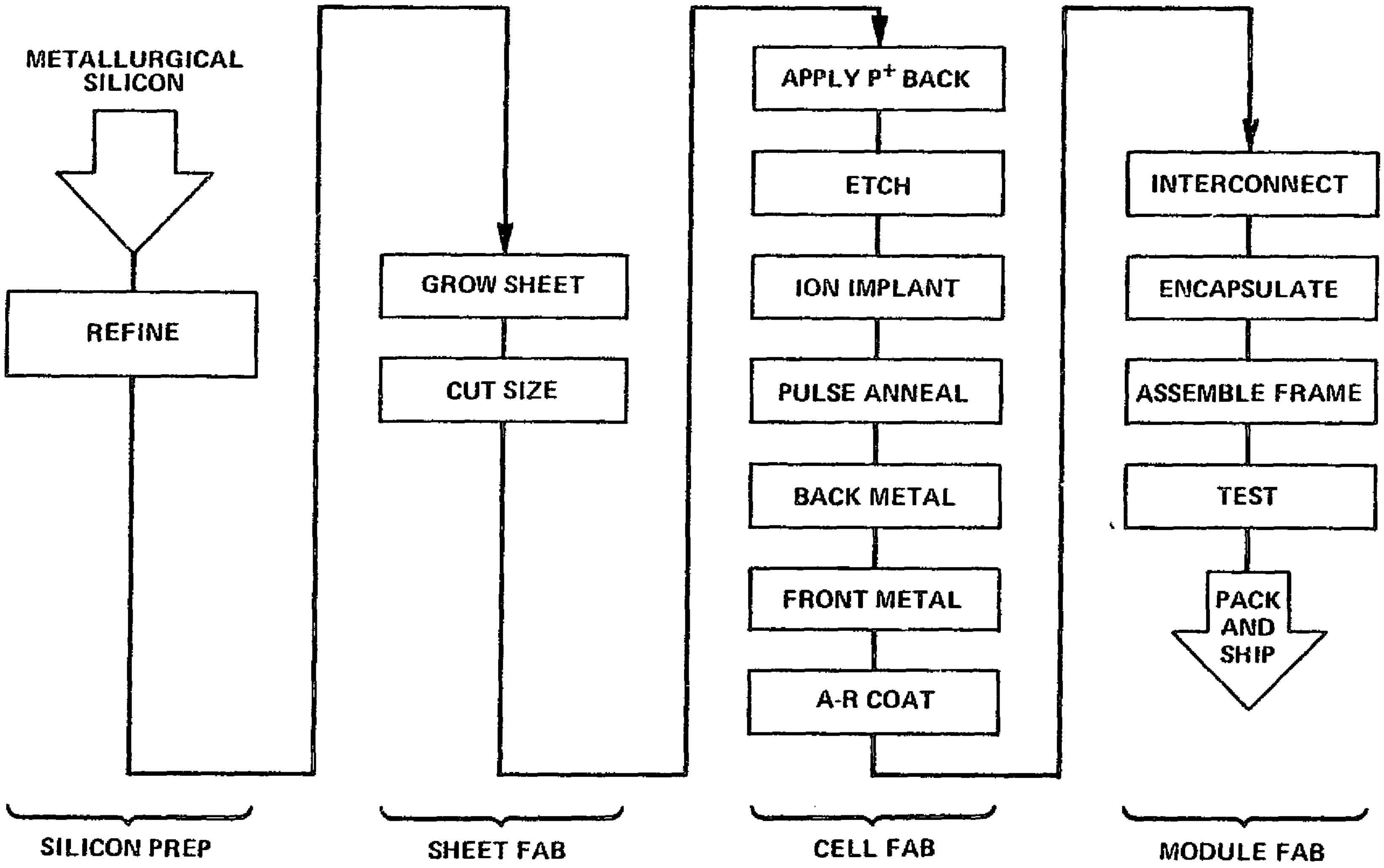


NOMINAL TECHNOLOGIES SELECTED FOR STUDY

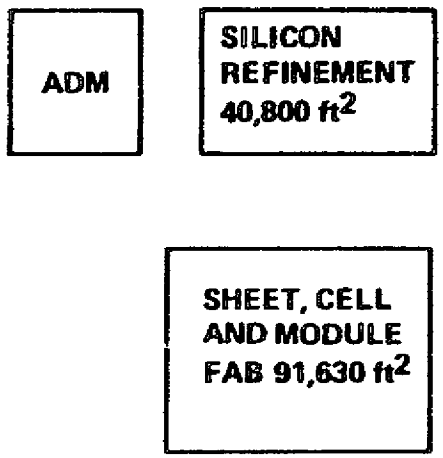
TECHNICAL AREA	NOMINAL APPROACH
POLYSILICON PRODUCTION	LOW COST SILANE AND FREE SPACE REACTOR (U.C.)
SILICON SHEET PRODUCTION	EDGE-DEFINED, FILM FED GROWTH (MOBIL TYCO)
SOLAR CELL AND ARRAY PRODUCTION	ION IMPLANTATION, ETC.
ENCAPSULATION	GLASS - ETHYLENE VINYL ACETATE | CELLS | ETHYLENE VINYL ACETATE- MYLAR

LOW-COST SOLAR ARRAY PROJECT

$0.50/WATT CANDIDATE MANUFACTURING SEQUENCE



LSA
$500.00/KW CANDIDATE PLANT LAYOUT



PRODUCTION RATE	250,000,000 WATTS/YEAR
LABOR FORCE (ALL SHIFTS)	1,152 DIRECT 529 INDIRECT
FACTORY AREA	
SILICON REFINEMENT	40,800 ft^2
SHEET GROWTH	19,550
CELL FABRICATION	27,600
MODULE FABRICATION	13,800
WAREHOUSE	9,779
MISC (AISLES, SHOPS, CAFETERIA, ETC.)	20,901
CAPITAL EQUIPMENT	
SILICON REFINEMENT	1,940,000*
SHEET GROWTH	14,820,000
CELL AND MODULE FABRICATION	8,219,000

*UNION CARBIDE

ENERGY PAYBACK TIME SHEET & CELL & MODULE — 0.179 YEARS

LOW-COST SOLAR ARRAY PROJECT

ANNUAL COSTS (IN 1975 $/Wpk)

	VALUE ADDED	CAPITAL COSTS	DIRECT LABOR	MATERIALS/ SUPPLIES	UTILITIES	INDIRECT EXPENSES	YIELDS YIELDS
SILICON PREP*	0.043			(0.0428)			–
SHEET FAB	0.134	0.0545	0.0308	0.0134	0.0048	0.0311	0.800
P+BACK	0.002	0.0010	0.0004	0.0002	0.0000	0.0005	0.998
ETCH	0.010	0.0032	0.0018	0.0033	0.0003	0.0018	0.994
ION IMPLANT.	0.011	0.0055	0.0018	0.0000	0.0003	0.0032	0.998
PULSE ANNEAL	0.018	0.0099	0.0004	0.0000	0.0015	0.0057	0.992
BACK METAL	0.035	0.0095	0.0013	0.0203	0.0005	0.0030	0.980
FRONT METAL	0.035	0.0098	0.0013	0.0199	0.0005	0.0030	0.980
A-R COAT	0.008	0.0032	0.0018	0.0014	0.0002	0.0015	0.990
INTERCON	0.042	0.0121	0.0053	0.0178	0.0000	0.0070	0.999
ENCAPSULATE & ASSEMBLE	0.120	0.0314	0.0061	0.0712	0.0001	0.0115	0.999
TEST	0.001	0.0003	0.0002	0.0000	0.0000	0.0002	0.980
PACKAGE	0.001	0.0002	0.0001	0.0002	0.0000	0.0001	0.9999
TOTALS	0.460	0.1406	0.0513	0.1905	0.0079	0.0686	–

* BASED ON 10 $/kg SILICON

LOW-COST SOLAR ARRAY PROJECT

PROJECT ANALYSIS AND INTEGRATION

- RELEASE OF SAMIS III COMPUTER CODE
- ECONOMIC INFORMATION SUMMARY - $0.50/W$_{pk}$ "STRAWMAN"
- LIFETIME, COST AND PERFORMANCE (LCP) MODEL

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LOW-COST SOLAR ARRAY PROJECT

0.50 $/Wpk TECHNOLOGY

	30 MEGAWATT CAPACITY	50 MEGAWATT CAPACITY	250 MEGAWATT CAPACITY
PRICE	0.487 $/$W_{pk}$	0.479 $/$W_{pk}$	0.465 $/$W_{pk}$
INITIAL INVESTMENT	5.8×10^6 $	9.5×10^6 $	42×10^6 $

SENSITIVITY TO SCALE (1975 DOLLARS)

BASED ON:

- 12% ENCAPSULATED CELL EFFICIENCY
- $10/kg SILICON

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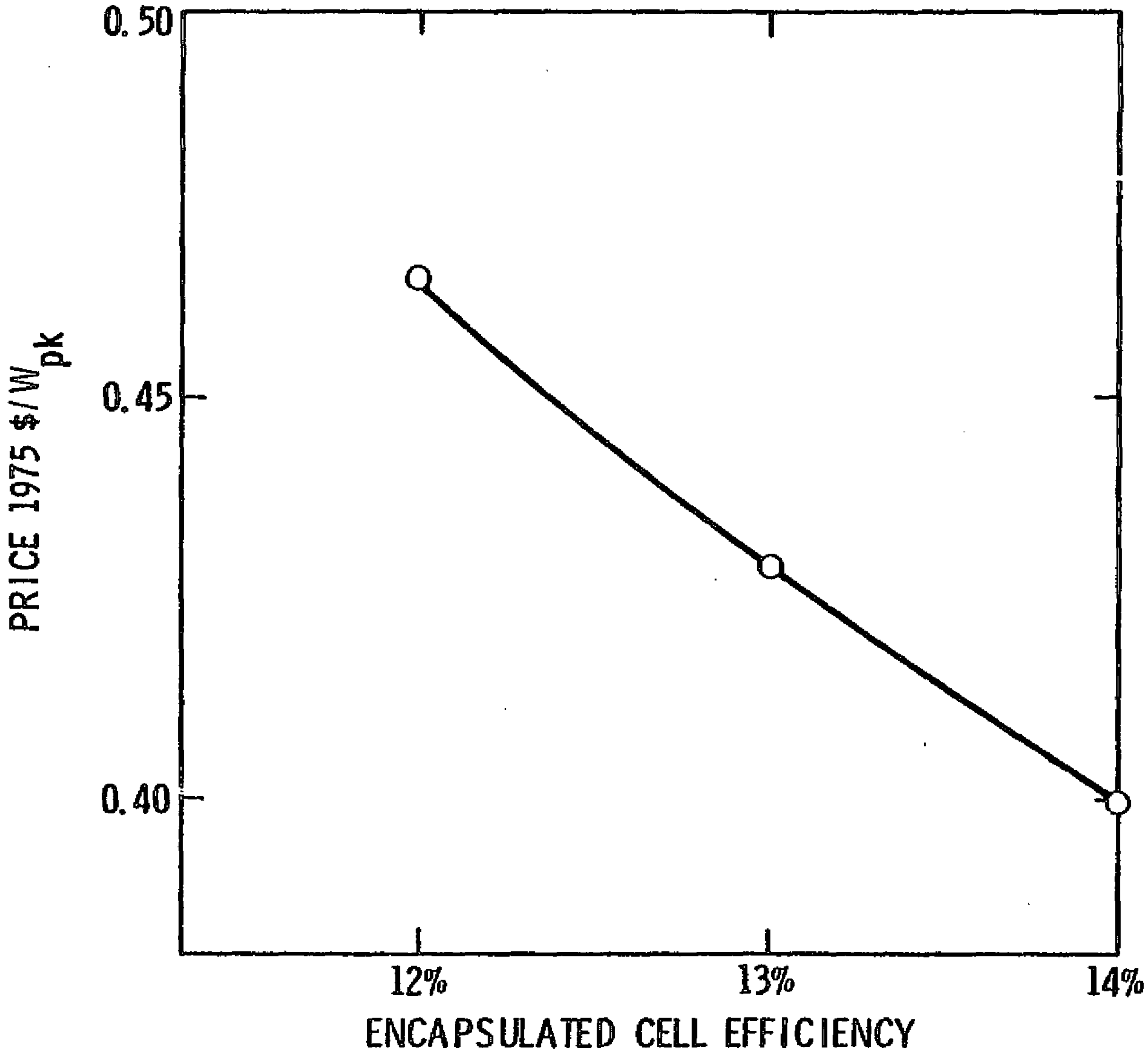
LOW-COST SOLAR ARRAY PROJECT

0.50 $/Wpk TECHNOLOGY PRICE vs CELL EFFICIENCY



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LOW-COST SOLAR ARRAY PROJECT

LIFETIME COST AND PERFORMANCE (LCP) MODEL

- RIGOROUS APPROACH TO DETERMINE ECONOMIC CONSEQUENCES OF OPERATIONS AND MAINTENANCE POLICY VARIATION MODEL
- MODEL CONSIDERS
  - POWER CALCULATION (INCL MISMATCH CONSIDERATIONS)
  - FAILURE RATE
  - CLEANING POLICY
  - REPLACEMENT POLICY
  - FINANCIAL ENVIRONMENT
- MODEL YIELDS ECONOMIC DECISIONS
- LCP WILL BE DISCUSSED IN WORKSHOP SESSION II ON COST/ECONOMICS

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LOW-COST SOLAR ARRAY PROJECT

LSA ENGINEERING STATUS

R. ROSS

LSA ENGINEERING MANAGER

NOVEMBER 7, 1978

RGR
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LOW-COST SOLAR ARRAY PROJECT

ENGINEERING AREA ACTIVITIES

MODULE ENGINEERING ACTIVITIES

- MODULE STRUCTURAL OPTIMIZATION - BECHTEL
- TRANSPARENT ENCLOSURE TRADEOFFS - BOEING
- SERIES/PARALLEL MISMATCH ANALYSES
- MODULE GLASS STRUCTURAL ANALYSIS
- CELL RELIABILITY - CLEMSON UNIV
- CELL FRACTURE MECHANICS
- MODULE THERMAL TESTING

ENVIRONMENTAL TESTING R&D

- MODULE HAIL TESTING AND TEST DEVELOPMENT
- BIAS-HUMIDITY TESTING
- DIRT ADHERENCE TESTING
- UV-HUMIDITY (DELAMINATION) TESTING

MODULE REQUIREMENT GENERATION

- SERI STANDARDS PARTICIPATION
- FLAT PLATE PRDA SPECIFICATION
- BLOCK IV PROCUREMENT SPECIFICATIONS

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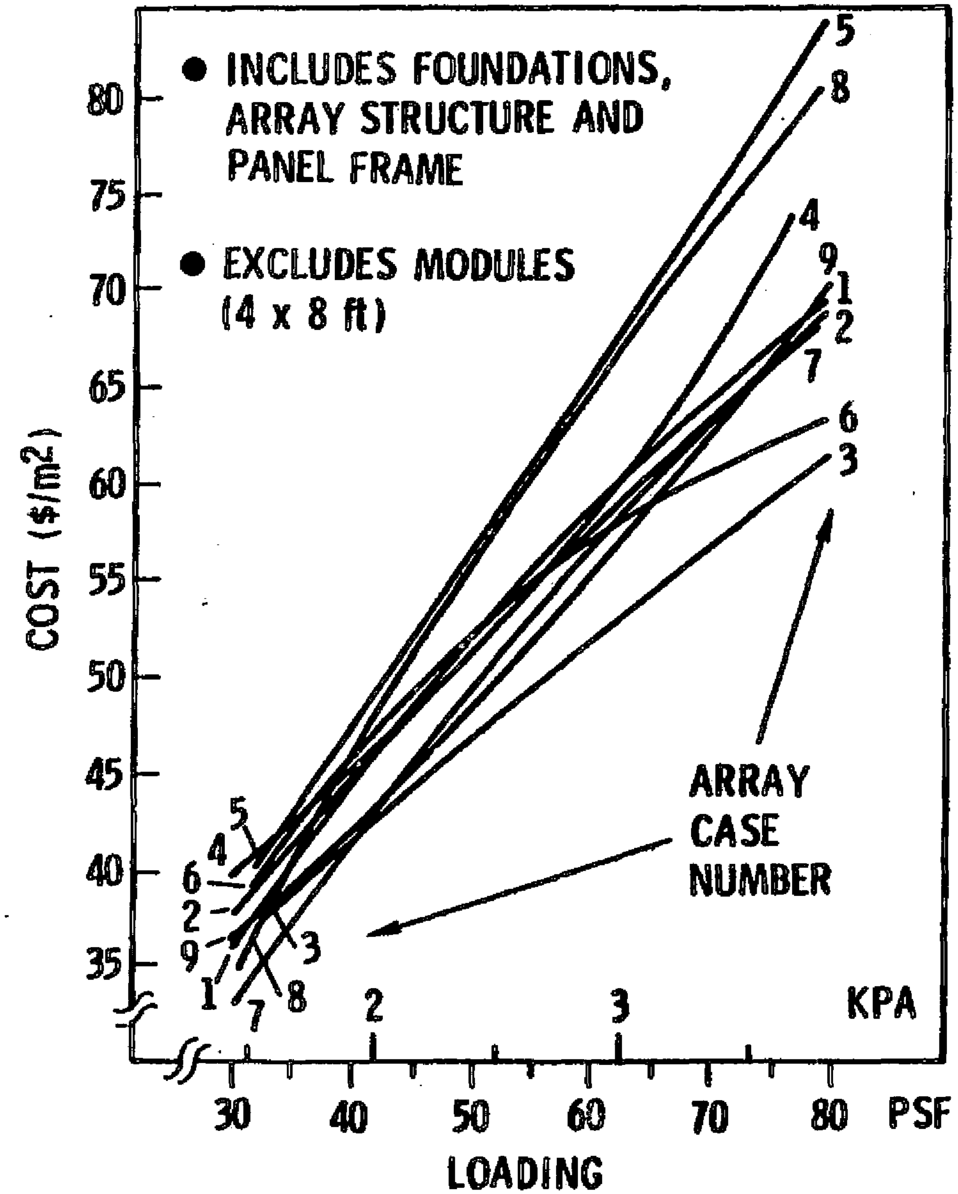
LOW-COST SOLAR ARRAY PROJECT

STRUCTURES COST

(1975 $'s)



PS
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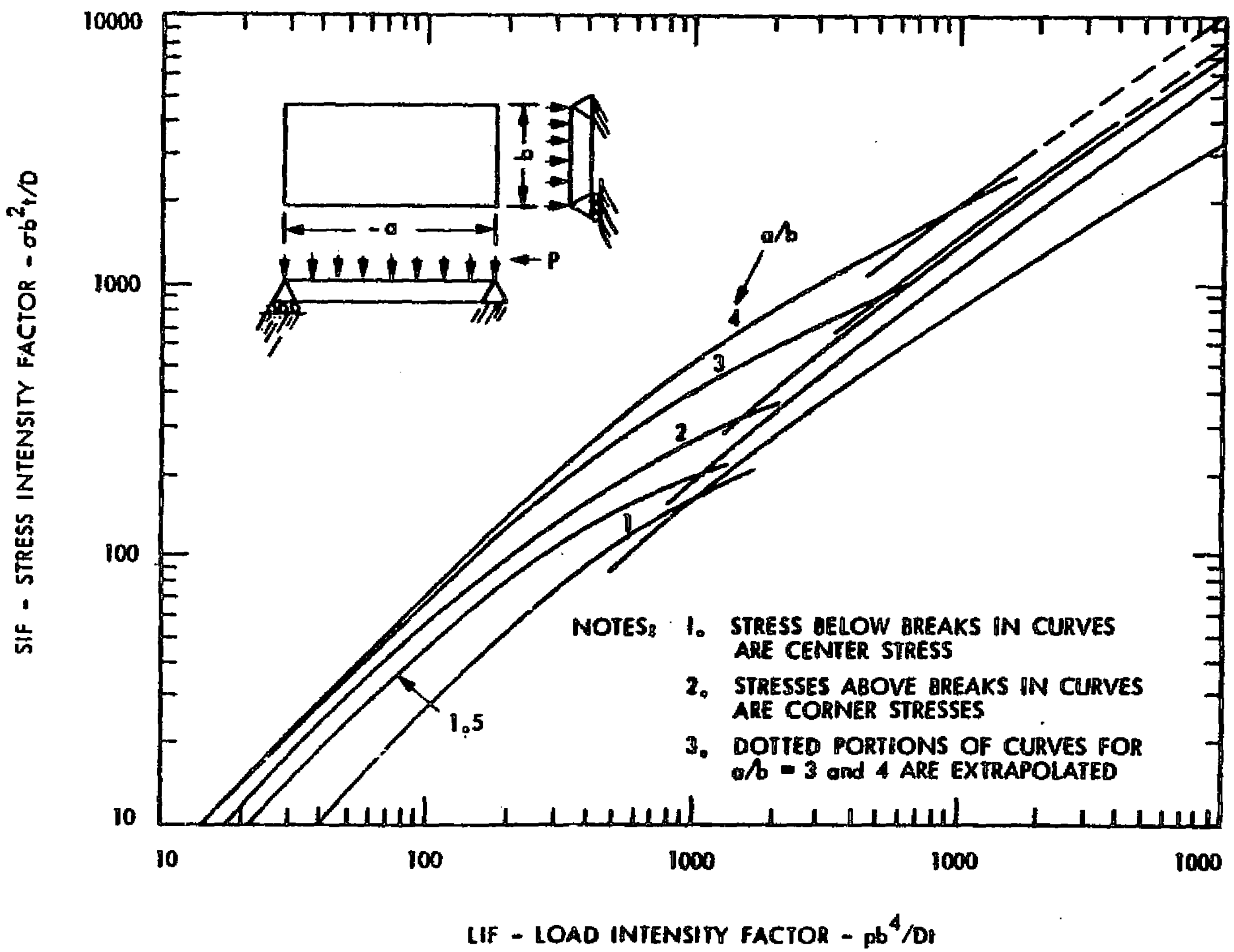
LOW-COST SOLAR ARRAY PROJECT

DESIGN CURVES

UNIFORMLY-LOADED, SIMPLY SUPPORTED, RECTANGULAR PLATES



RR/DM
8-16-78

LOW-COST SOLAR ARRAY PROJECT

EFFECTS OF FIELD SOILING ON MODULE PERFORMANCE

MANUFACTURER (COVER)	BLK	RANGE OF POWER CHANGE FROM INITIAL (%)	
		AFTER SOILING*	AFTER SOILING AND CLEANING
V (SILICONE RUBBER)	I	11 to 39	2 to 18
W (FLOAT GLASS)	I	2 to 7	0 to 2
Y (SILICONE RUBBER)	I	8 to 36	2 to 12
Z (SEMIFLEXIBLE SILICONE CONFORMAL COATING)	I	6 to 32	2 to 17

*EXPOSURE DURATION IS FROM 161 DAYS TO 1 YEAR (FROM NASA LEWIS)

LOW-COST SOLAR ARRAY PROJECT
30-DAY SOILING TESTS
PASADENA, CALIFORNIA

TEST PERIOD	AVERAGE % DECREASE IN Isc*	RANGE OF % DECREASE IN Isc*	NUMBER OF MODULES
5/25 - 6/15	3.8	3.0 - 5.6	213
6/5 - 7/10	6.5	5.8 - 7.5	23
6/30 - 7/31	6.7	6.1 - 7.1	213
7/11 - 8/7	6.4	5.9 - 7.0	23
8/9 - 9/5	6.2	5.0 - 7.6	23

*ALL RESULTS LINEARLY NORMALIZED TO 30-DAY PERIOD

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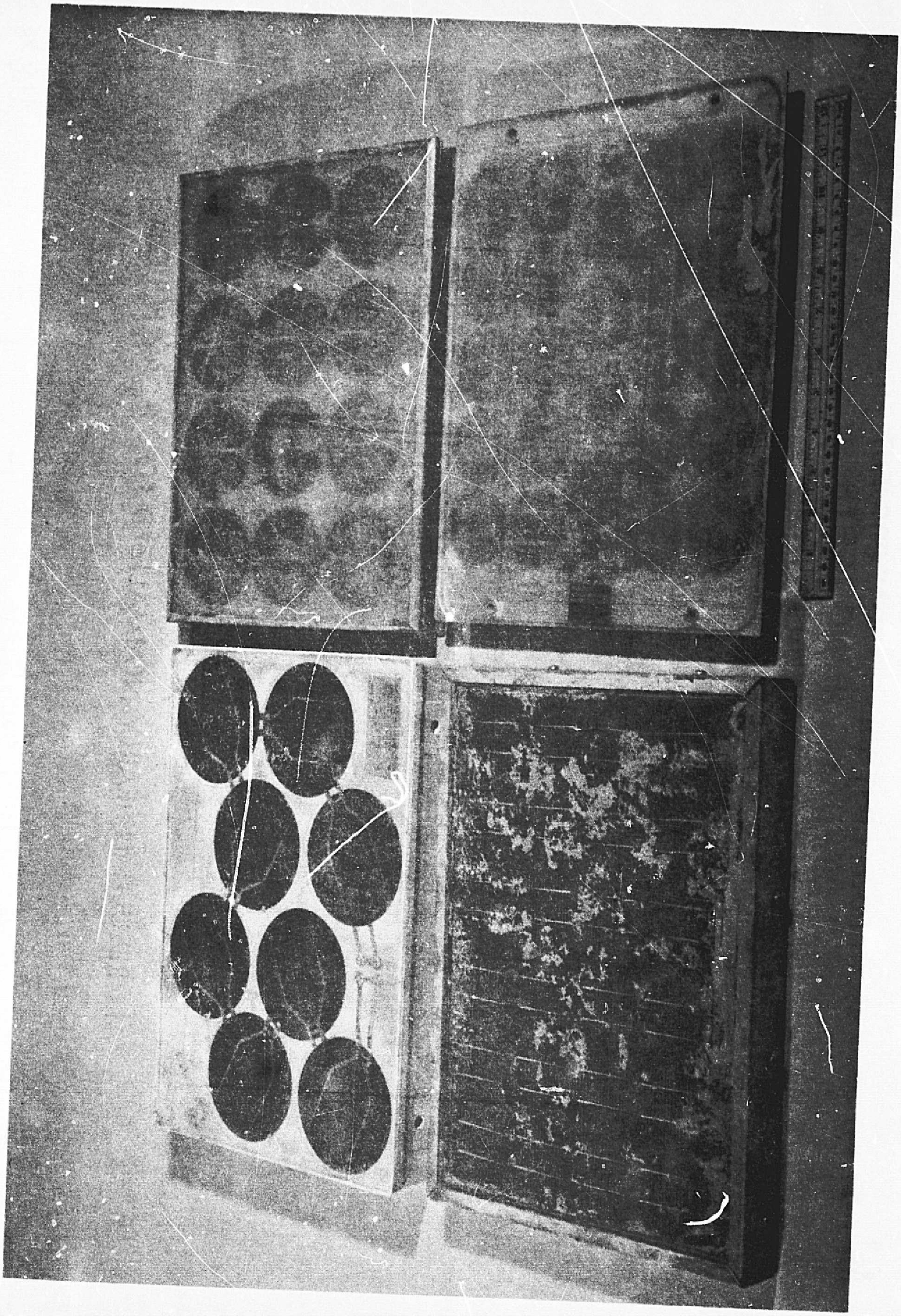


LOW-COST SOLAR ARRAY PROJECT

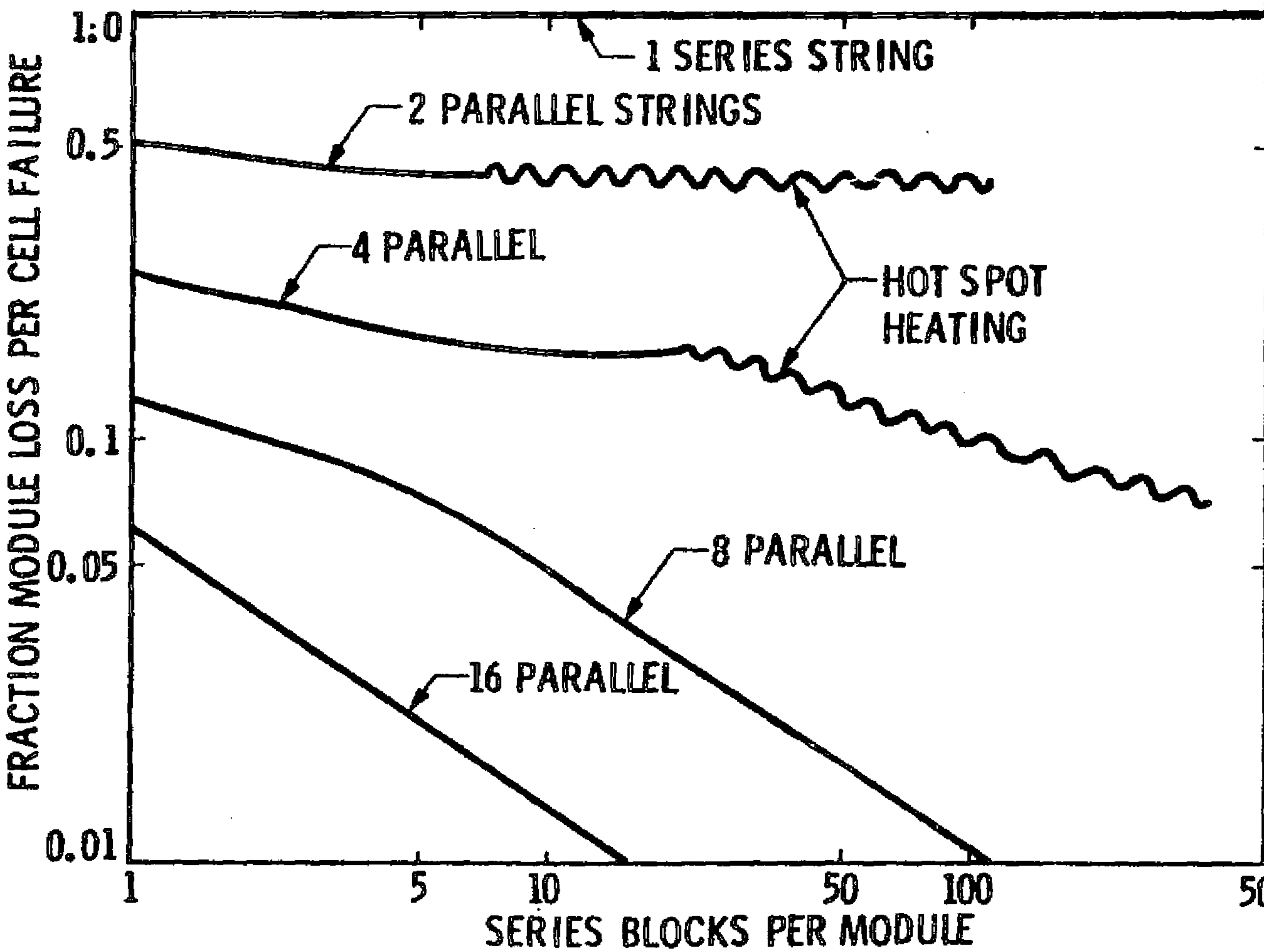
PRELIMINARY DUST TEST RESULTS

MINIMODULE ENCAPSULANT EXTERIOR SURFACE	OUTPUT POWER DEGRADATION (%)		
	DRY	FOGGED	FIELD DATA
FLOAT GLASS	2	66	2 to 7
SEMIFLEXIBLE SILICONE CONFORMAL COATING	4	49	6 to 32
SILICONE RTV RUBBER COMPOUND TYPE I	64	68	11 to 39
SILICONE RTV RUBBER COMPOUND TYPE 2	46	52	8 to 36

LOW-COST SOLAR ARRAY PROJECT

MANUFACTURING YIELD VERSUS MODULE SERIES/PARALLELING

(1 CELL FAILURE PER 1000)



MFG YIELD (%)		
MODULE SIZE (ft)		
1 x 2	2 x 4	4 x 8
97	90	75
100	100	100

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LOW-COST SOLAR ARRAY PROJECT

FUTURE ENGINEERING ACTIVITIES

MODULE ENGINEERING ACTIVITIES

- ARRAY WIND LOADING STUDY - BOEING
- ARRAY STRUCTURAL OPTIMIZATION
- SERIES/PARALLEL CIRCUIT ANALYSIS
- RESIDENTIAL MODULE REQUIREMENTS - BURT HILL
- ELECTRICAL TERMINATION DEVELOPMENT (PROPOSALS IN)
- MODULE VOLTAGE ISOLATION STUDY
- CELL RELIABILITY - CLEMSON UNIV
- CELL FRACTURE MECHANICS
- MODULE RELIABILITY STUDIES

ENVIRONMENTAL TESTING R&D

- DIRT ADHESION/CLEANABILITY
- DELAMINATION QUAL TEST DEVELOPMENT
- VOLTAGE ISOLATION DURABILITY

MODULE REQUIREMENT GENERATION

- ARRAY PERFORMANCE CRITERIA AND STANDARDS IN SUPPORT OF SERI

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LOW-COST SOLAR ARRAY PROJECT

OPERATIONS STATUS: MODULE PROCUREMENT, TEST AND EVALUATION

LARRY DUMAS
OPERATIONS MANAGER

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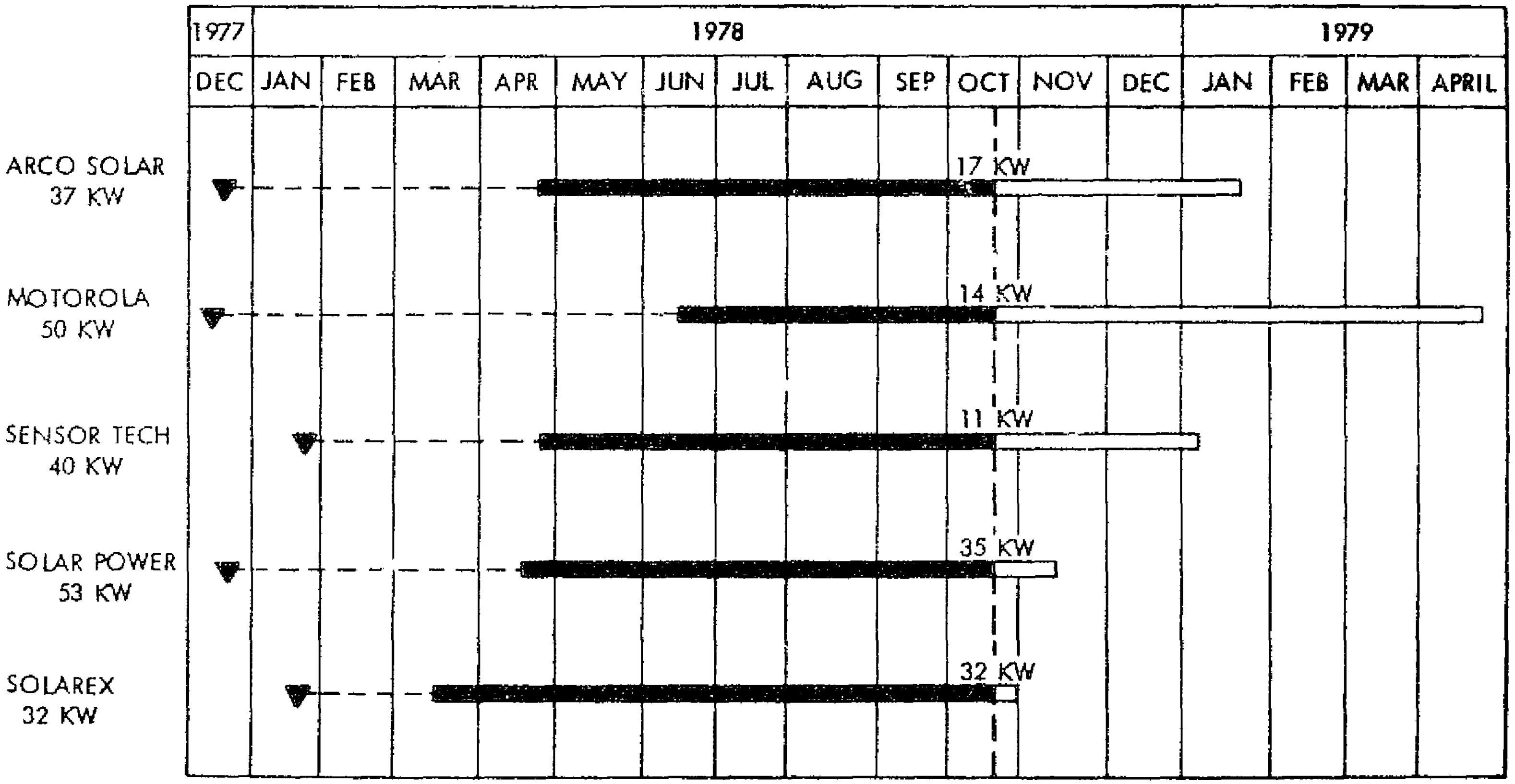
LOW-COST SOLAR ARRAY PROJECT

BLOCK III MODULE PRODUCTION SCHEDULE



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jpl

LOW-COST SOLAR ARRAY PROJECT

BLOCK III MODULE UTILIZATION (KW)

USER \ MFR.	ARCO	MOTOROLA	SENSOR TECH	SOLAR POWER	SOLAREX
MIT/LL					
NATURAL BRIDGES	33.4	48.8	–	–	–
HYBRID APPLN	–	–	10.0	–	–
DISTRIB APPN	–	–	9.4	–	20.5
LeRC					
APPLICATIONS	1.7	–	–	–	–
SYST TEST FAC	–	–	19.7	–	–
DOD	–	–	–	48.8	9.0
JPL	1.3	1.5	1.1	1.2	0.8

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LOW-COST SOLAR ARRAY PROJECT
EARLY BLOCK III MODULES QUALIFICATION-TYPE TESTS

SUPPLIER (NUMBER TESTED)	CELL CRACKS	ENCAPSULANT			COLLECTOR DISCOLORATION
		BUBBLES	DELAMINATION	LEAKS	
R (8)		●		●	
U (5)					
V (16)					
Y (12)			●		●
Z (9)	○		○		

● TEMPERATURE CYCLING

○ HUMIDITY CYCLING

⦶ WIND SIMULATION

NOTE: NO ELECTRICAL DEGRADATION OBSERVED TO DATE

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LOW-COST SOLAR ARRAY PROJECT

BLOCK II PRODUCTION SAMPLE QUALIFICATION-TYPE TESTS

SUPPLIERS	CELL CRACKS	ELECTRICAL DEGRADATION	DELAMINATION
V (EARLY)	● ○ ◐	● ◐	●
V LATER)	●		
W	● ○	○ ◐	
Y	● ◐	◐	
Z	● ◐	●	● ○

● TEMPERATURE CYCLING

○ HUMIDITY CYCLING

◐ WIND SIMULATION

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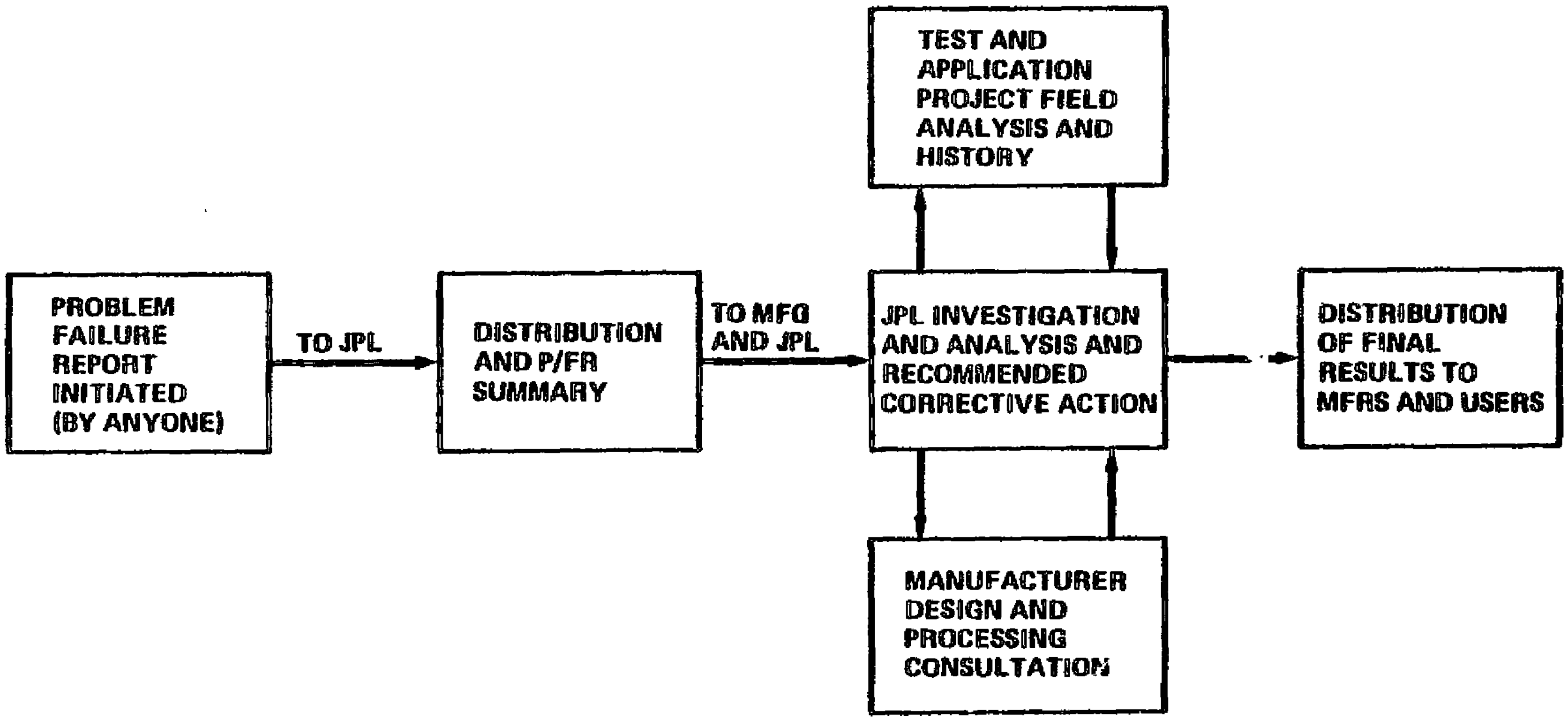
LOW-COST SOLAR ARRAY PROJECT

P/FR FLOW PLAN



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JPL

LOW-COST SOLAR ARRAY PROJECT

PROBLEM/FAILURE REPORT STATUS

MODULE TYPE	NO. P/FR'S	NO. CLOSED	PROBLEM/FAILURE ORIGIN		
			ENVIRONMENTAL TEST	JPL FIELD TEST	APPLICATION PROJECTS
BLOCK I	152	133	90	31	31
BLOCK II	137	89	107	1	29
BLOCK III	42	1	42		
DEVEL/ COMM	71	39	71		
TOTALS	402	262	310	32	60

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11/7/78

D6

N79-25491

STATUS OF THE DOE PHOTOVOLTAIC CONCENTRATOR DEVELOPMENT PROJECT

D. G. Schueler

Sandia Laboratories

STATUS OF THE DOE PHOTOVOLTAIC CONCENTRATOR DEVELOPMENT PROJECT*

D. G. Schueler
Sandia Laboratories
Albuquerque, NM 87185

ABSTRACT

The overall objective of this project is to develop photovoltaic concentrator technology resulting in low-cost, long-life photovoltaic arrays at a price of less than $0.50 per peak watt by 1986.

The general approach is to identify and develop those concentrator concepts which have the highest potential for low-cost long life by supporting concept development and evaluation, improving solar array manufacturing technology and by increasing solar array production capacity and quantity. These efforts are being performed principally by industries and universities as a result of competitive solicitations. The principal criterion is to develop concentrating arrays that provide the lowest life cycle energy cost.

Considerable progress has been made in the development of high conversion efficiency solar cells for operation in concentrated sunlight and a number of prototype concentrator arrays in the 100-1000 W_p range have been built and evaluated. Project activities are now phasing from technology assessment and exploratory investigations to the narrowing and selection of the most promising candidates for engineering development. The feasibility of achieving $2/$W_p$ with state-of-the-art technology has been demonstrated by a number of related design and manufacturing cost studies. Facilities for routine testing of concentrator arrays have been established.

*This work supported by the Department of Energy, Division of Solar Technology

PRESENTATION TOPICS

- TECHNOLOGY GOALS AND REQUIREMENTS
- MANUFACTURING COST ANALYSIS
- CURRENT DEVELOPMENT STATUS
- FUTURE PLANS

PHOTOVOLTAIC CONCENTRATOR TECHNOLOGY DEVELOPMENT

OBJECTIVE -

- REDUCE THE COST OF PHOTOVOLTAIC ARRAYS BY REPLACING SOLAR CELL AREA WITH LOWER COST REFLECTIVE OR REFRACTIVE MATERIALS

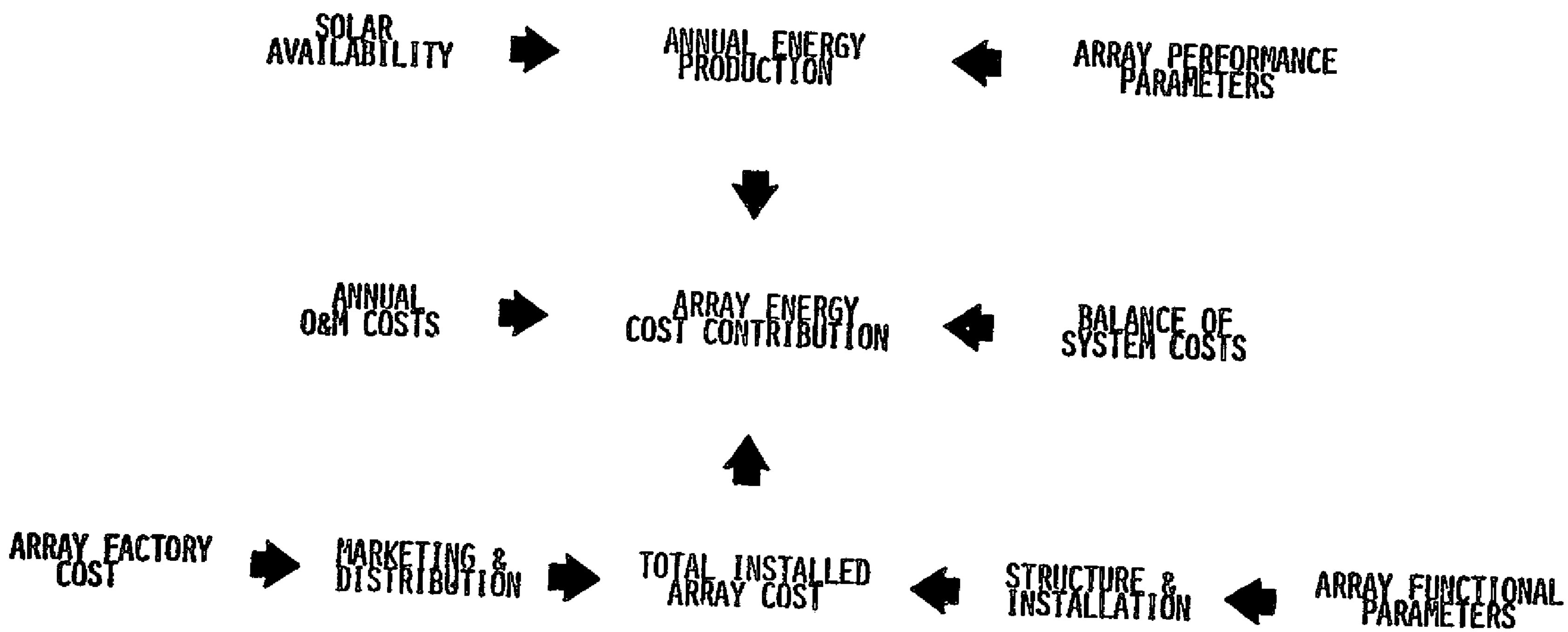
APPROACH -

- ANALYZE SOLAR ENERGY AVAILABLE TO CONCENTRATING COLLECTORS
- DEVELOP HIGH PERFORMANCE SOLAR CELLS FOR CONCENTRATED SUNLIGHT APPLICATIONS
- DEVELOP LOW COST SOLAR CONCENTRATORS FOR PHOTOVOLTAIC APPLICATIONS
- PERFORM SYSTEM ANALYSIS AND DESIGN TRADEOFF STUDIES
- EVALUATE PERFORMANCE AND RELIABILITY OF PROTOTYPE ARRAYS

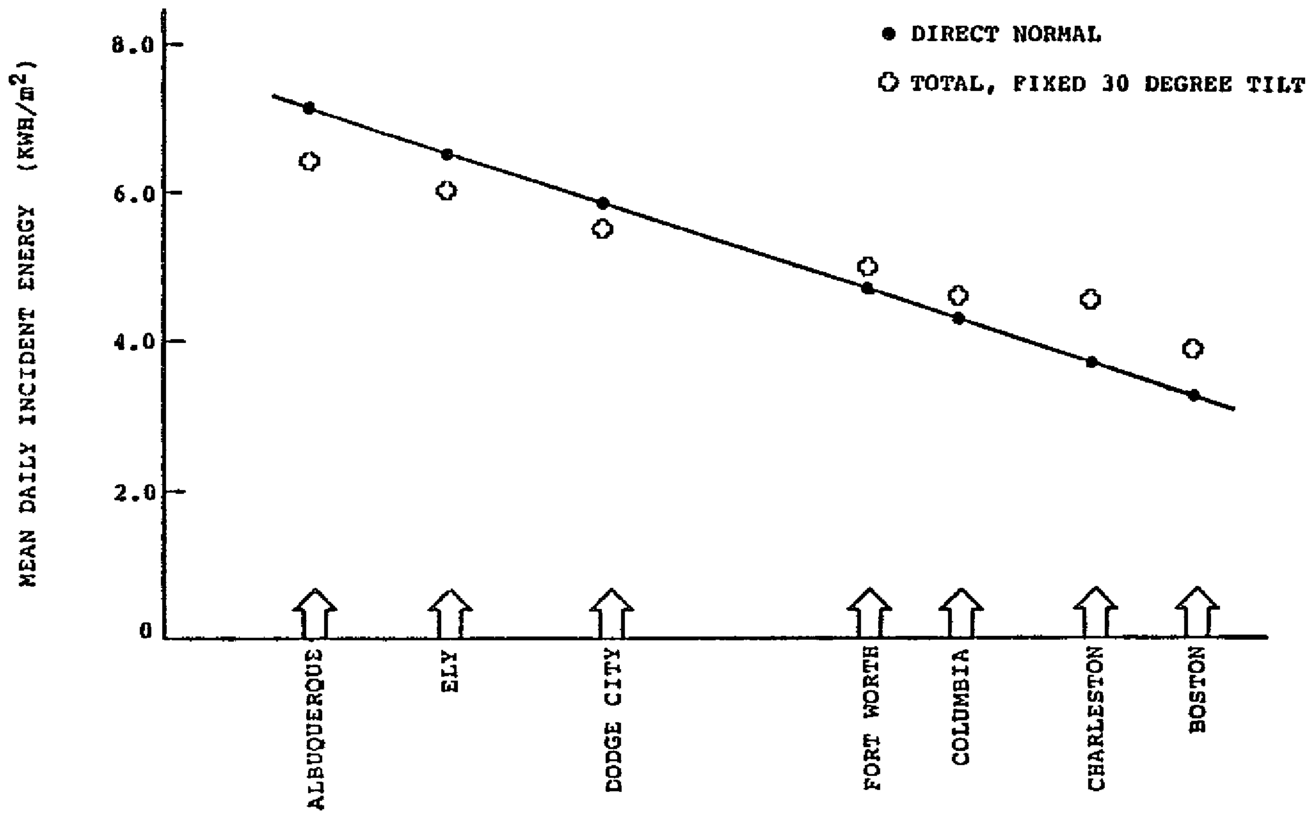
MAJOR MILESTONE SCHEDULE - PHOTOVOLTAIC CONCENTRATOR TECHNOLOGY DEVELOPMENT

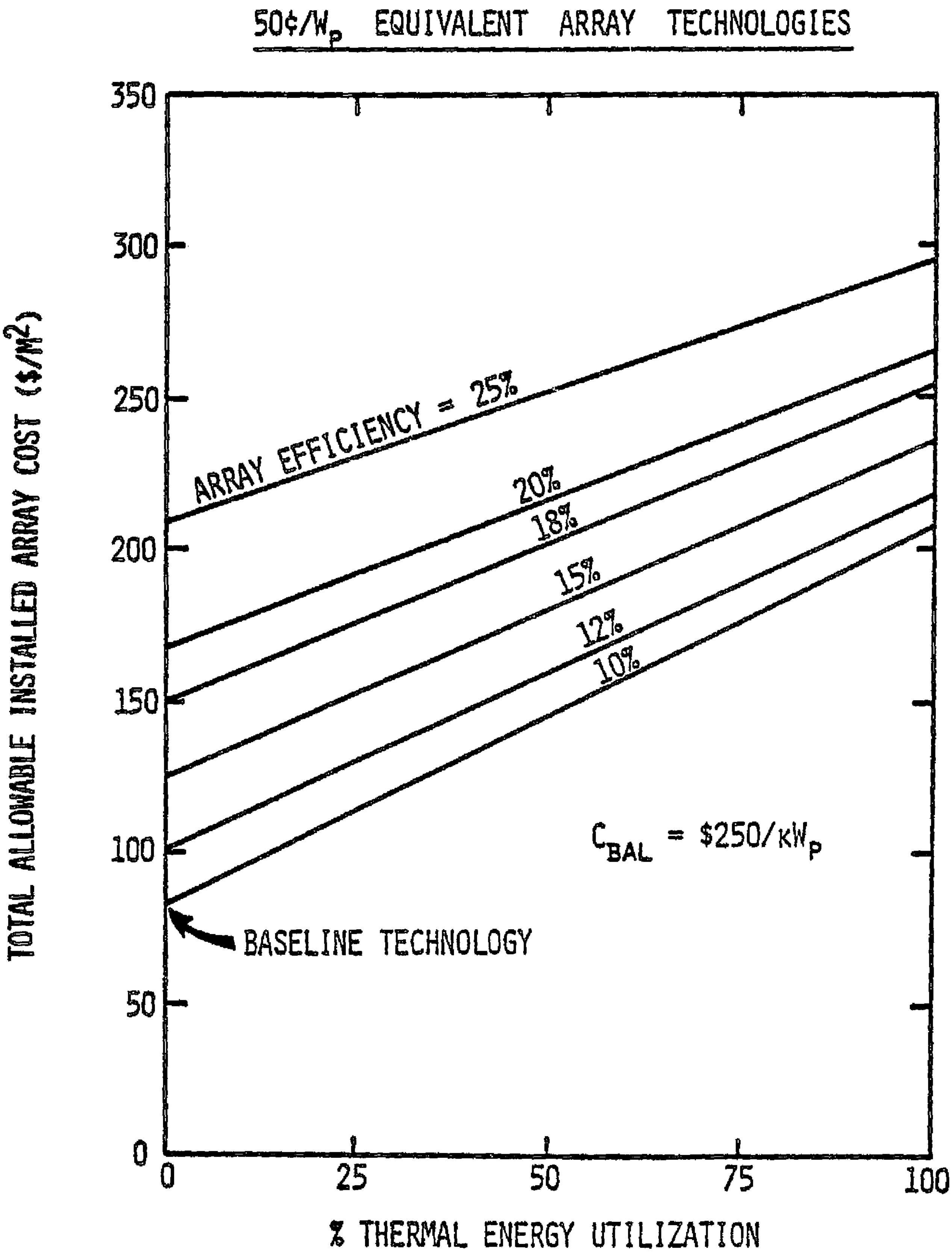
ACTIVITY	FISCAL YEAR										
	76	77	78	79	80	81	82	83	84	85	86
PROJECT PHASE		TECHNOLOGY ASSESSMENT		⇨	ENGINEERING DEVELOPMENT		⇨		INCREMENTAL IMPROVEMENT		⇨
TECHNOLOGY FEASIBILITY			$2/W_p$			$0.5/W_p$					
TECHNOLOGY READINESS					$2/W_p$			$0.5/W_p$			
COMMERCIAL READINESS							$2/W_p$				$0.5/W_p$
PILOT PLANTS					1-10 MW/YR ⇨						
PRODUCTION PLANTS								10-100 MW/YR ⇨			
PROJECT FUNDING ($M)	1.3	2.5	5.2	8.0							

ARRAY TECHNOLOGY COMPARISON ON THE BASIS OF EQUIVALENT ENERGY COST CONTRIBUTION

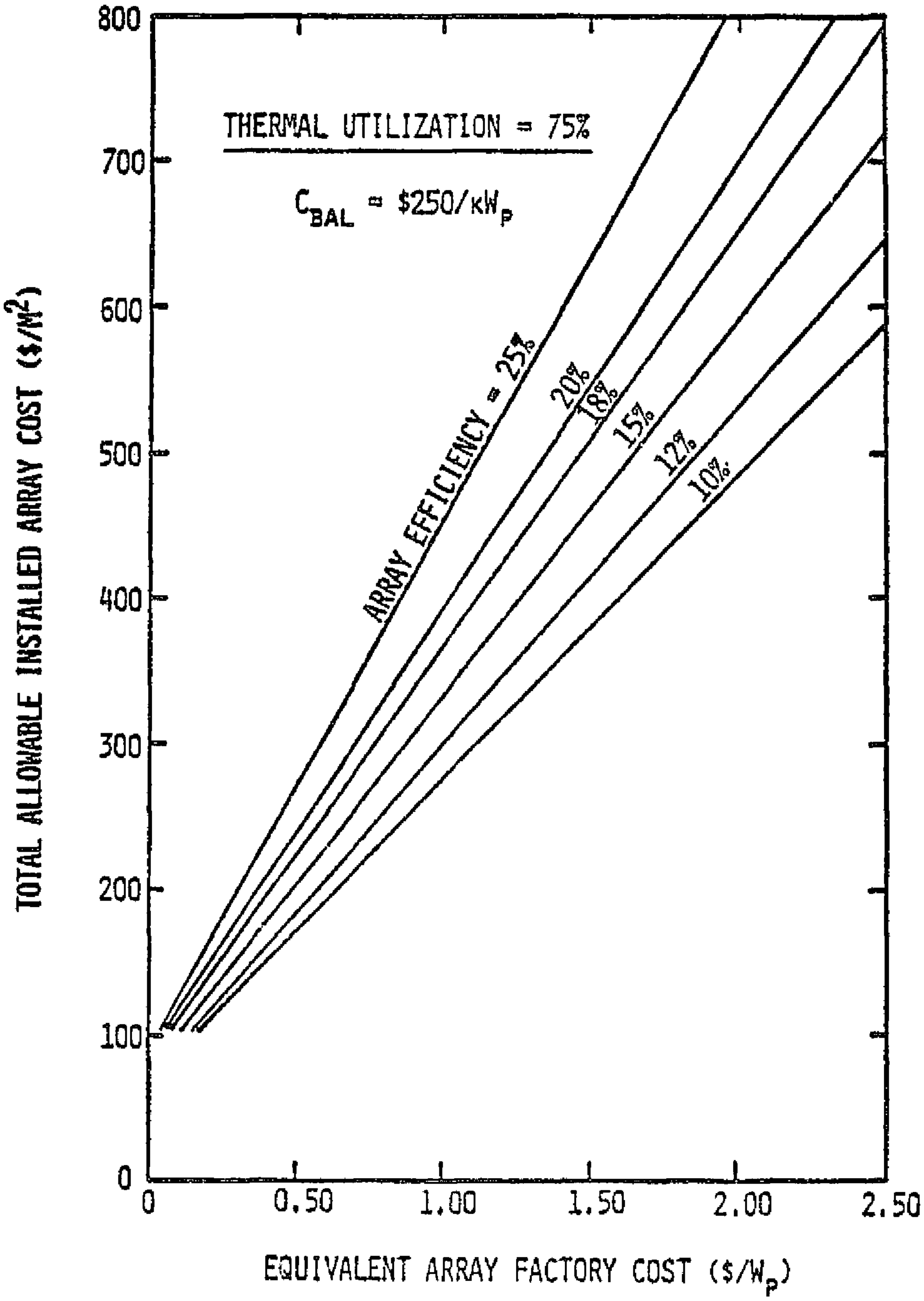


SOLAR AVAILABILITY FOR VARIOUS LOCATIONS




50¢/Wp EQUIVALENT ARRAY TECHNOLOGIES
TOTAL ALLOWABLE INSTALLED ARRAY COST ($/M2)
ARRAY EFFICIENCY = 25%
20%
18%
15%
12%
10%
BASELINE TECHNOLOGY
CBAL = $250/KWp
% THERMAL ENERGY UTILIZATION
0
50
100
150
200
250
300
350
0
25
50
75
100

EQUIVALENT ARRAY TECHNOLOGY COMPARISION



CONCENTRATING ARRAY PRODUCTION PROCESS DESIGN

OBJECTIVES:

- PROVIDE INSIGHT INTO HOW ARRAY COSTS VARY WITH PRODUCTION PROCESSES, LEVELS, ARRAY CATEGORY AND DESIGN
- GENERATE "REALISTIC" PRODUCTION AND LIFE CYCLE COSTS
- IDENTIFY PROMISING ARRAY DESIGNS IN TERMS OF LOW COST PRODUCTION POTENTIAL

SCOPE:

- REMOTE POWER STATION APPLICATION
- EXISTING CONCENTRATOR CONCEPTS
- 20 YEAR LIFE CYCLE COSTS

GENERAL ELECTRIC

SELECTED CONCEPTS

CONCENTRATING PHOTOVOLTAICS

CATEGORY	PHOTOVOLTAIC CONCENTRATOR CONCEPTS
I PARABOLIC TROUGHS	• SPECTROLAB'S PARABOLIC TROUGH WITH CEC (25X) • GE'S PONTOON PARABOLIC TROUGH (26X) • GE'S TURNTABLE-MOUNTED PARABOLIC TROUGH (35X) • GE'S REFLECTOR AUGMENTED AZIMUTH TRACKER CONCENTRATOR (57X)
II CIRCULAR FRESNELS	• SANDIA'S 1KW CIRCULAR FRESNEL CONCENTRATOR (60X) • MARTIN-MARIETTA'S CIRCULAR FRESNEL CONCENTRATOR (39X) • RCA'S EXPERIMENTAL 300W FRESNEL CONCENTRATOR (424X)
III PARABOLOIDAL DISHES	• BOEING'S ENCLOSED PARABOLOIDAL CONCENTRATOR (200–500X) • MIT'S CASEGRAIN CONCENTRATOR (200–1000X)
VI CPC	• ARGONNE'S COMPOUND PARABOLIC CONCENTRATOR (7X) • ARGONNE'S DIELECTRIC COMPOUND PARABOLIC CONCENTRATOR (7X)
VII HELIOSTATS	• AAI'S MULTIPLE HELIOSTAT ARRAY CONCENTRATOR (200X) • VARIAN'S MULTIPLE MIRROR CONCENTRATOR (1146X)

GENERAL ELECTRIC

SELECTED SOLAR THERMAL DESIGNS

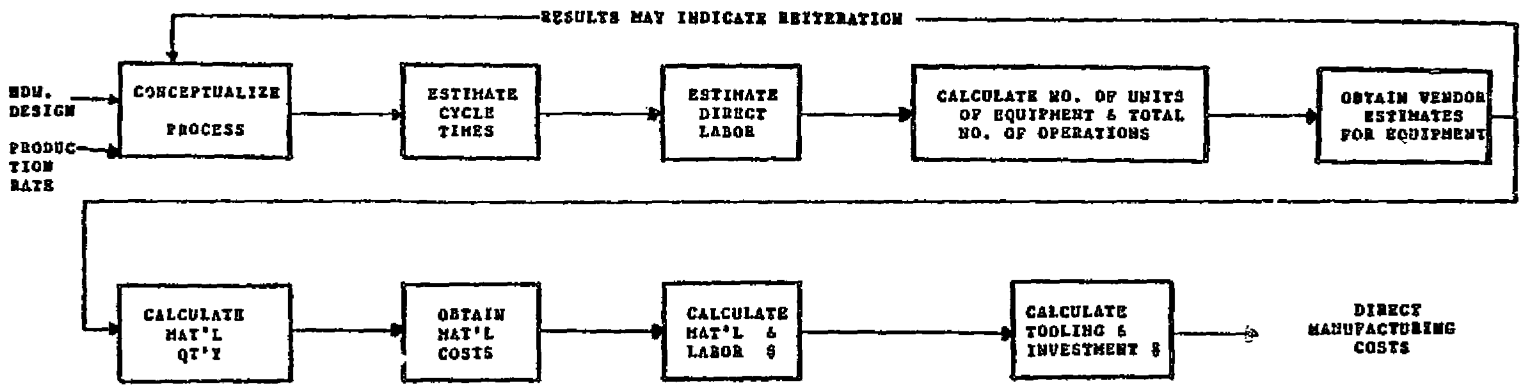
CONCENTRATING PHOTOVOLTAICS

CATEGORY	PERTINENT SOLAR THERMAL CONCENTRATOR CONCEPTS
I PARABOLIC TROUGHS	1. HEXCEL'S PARABOLIC TROUGH COLLECTOR (36X) 2. SANDIA'S PARABOLIC TROUGH COLLECTOR (30–35X) 3. SOLAR KINETICS, INC. PARABOLIC TROUGH COLLECTOR 4. DEL MFG. CO. STEEL-SAGGED GLASS PARABOLIC TROUGH COLLECTOR 5. ACUREX CORP. PARABOLIC TROUGH COLLECTOR 6. BOEING'S AIR SUPPORTED CYLINDRICAL COLLECTOR 7. SCIENTIFIC ATLANTA FIXED SEGMENTED MIRROR MOVING COLLECTOR 8. GENERAL ATOMIC CO. FIXED MIRROR MOVING COLLECTOR 9. GE'S SUN-TRAK SEGMENTED MIRROR VARIABLE TILT COLLECTOR 10. SHELDAHL'S SLATS TRACKING SEGMENTED MIRROR FIXED TILT COLLECTOR
II CIRCULAR FRESNEL	11. McDONNELL DOUGLAS CORP. CIRCULAR FRESNEL COLLECTOR
III PARABOLOIDAL DISHES	12. RAYTHEON MOSAIC PARABOLIC DISH COLLECTOR 13. GE/SA PARABOLOIDAL DISH COLLECTOR
IV SLOTTED LINEAR ARRAYS	14. GE'S TC-101 "CUSP-LIKE" COLLECTOR (1.1X) 15. GE'S TC-300 "CUSP-LIKE" COLLECTOR (2.9X) 16. CHAMBERLAIN CUSP COLLECTOR (2.7X) 17. ARGONNE NATIONAL LABS. CUSP COLLECTOR (1.5X)
V LINEAR FRESNELS	18. McDONNELL DOUGLAS CORP. LINEAR FRESNEL COLLECTOR 19. NORTHRUP'S LINEAR FRESNEL LENS COLLECTOR (10X) 20. FMC CORP., CYLINDRICAL FRESNEL BELT COLLECTOR

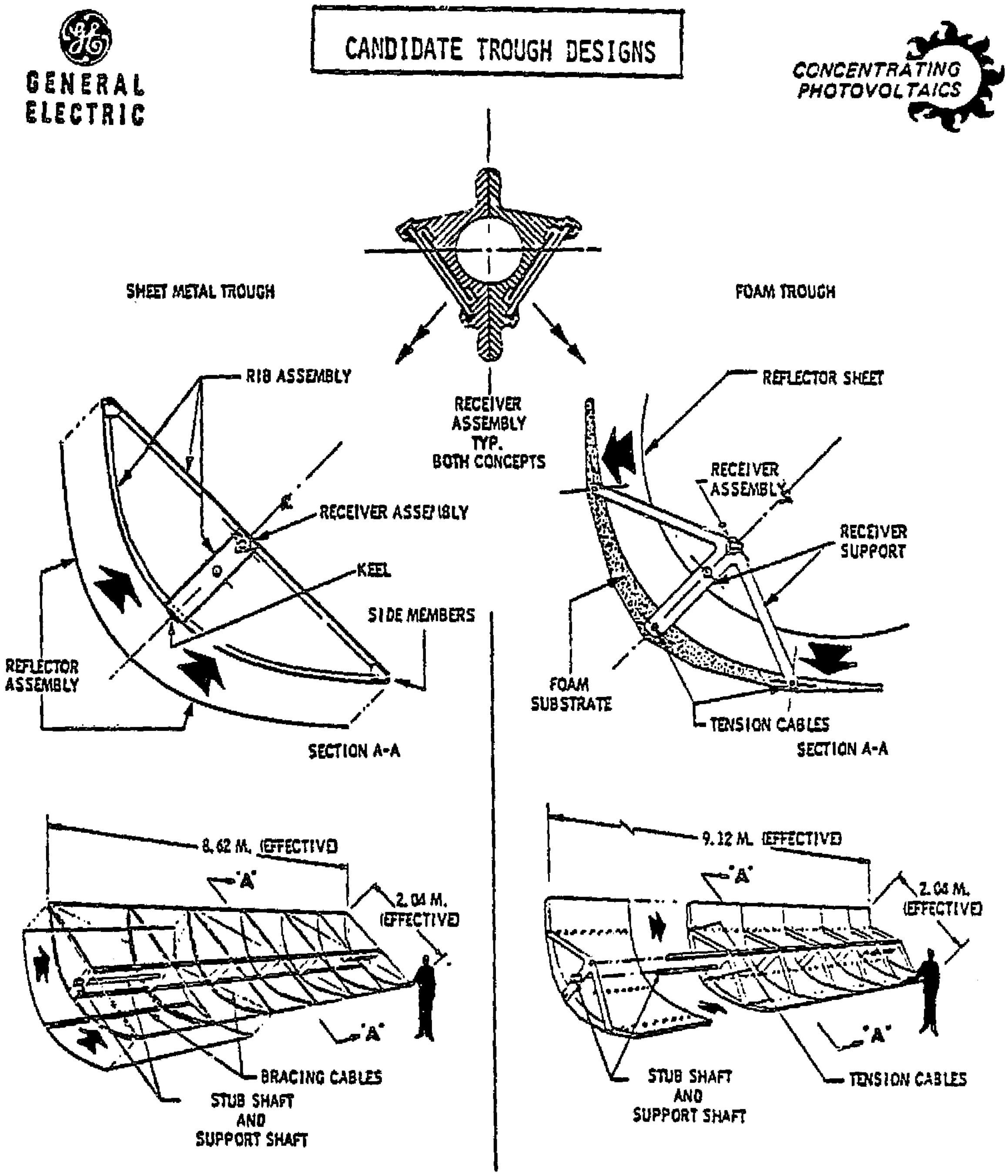
GENERAL ELECTRIC

CONCENTRATING PHOTOVOLTAICS

MANUFACTURING COST METHODOLOGY



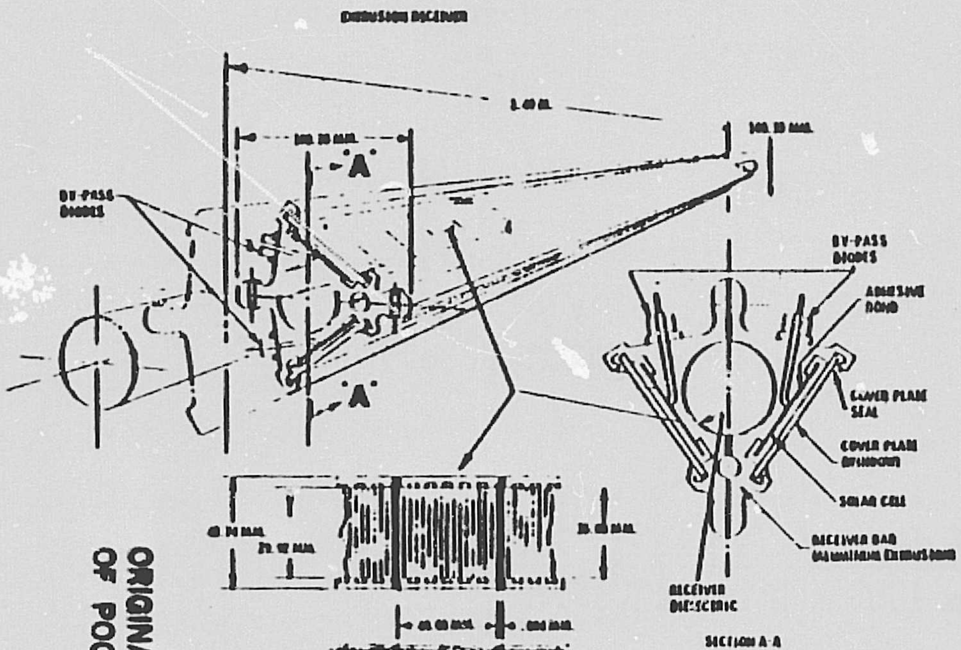
CANDIDATE TROUGH DESIGNS

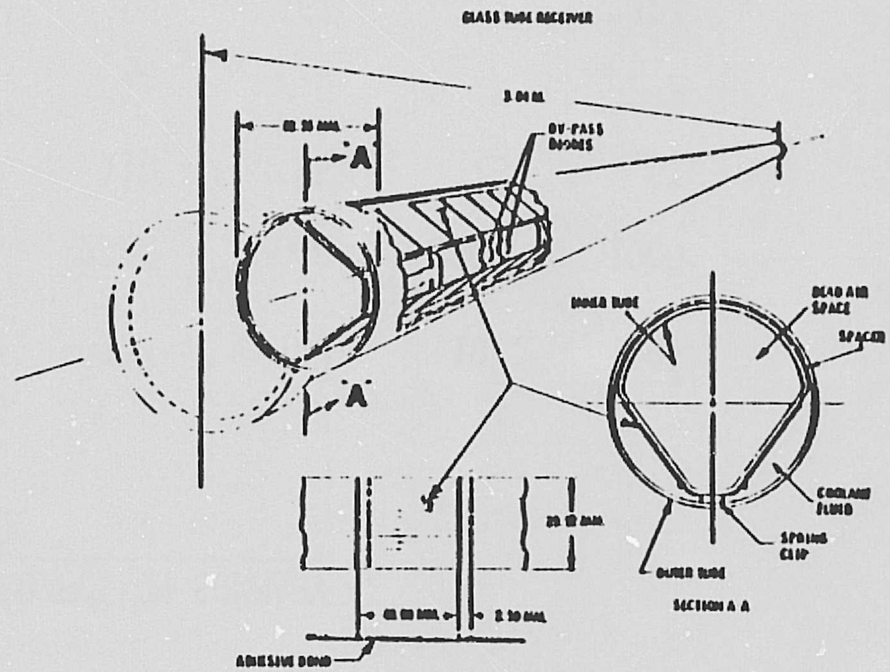


GENERAL ELECTRIC

CELL RECEIVER OPTIONS

CONCENTRATING PHOTOVOLTAICS





PARABOLIC TROUGH COST PROJECTION SUMMARY

(1975$)

ANNUAL PRODUCTION LEVEL M^2/YR	10^4	10^5	10^6	10^7
SOLAR CELL COST $/$M^2$	2500	2000	1500	1000
DIRECT MATERIAL COST $/$M^2$	110	95	75	61
APPLIED LABOR $/$M^2$	13	7.5	3	2
SELLING PRICE $/$M^2$	200	167	127	103
SHIPPING $/$M^2$	3	3	3	3
INSTALLATION $/$M^2$	72	65	56	48
TOTAL INSTALLED COST $/$M^2$	275	235	186	154

CONCENTRATOR PROJECT ORGANIZATION

CONCENTRATOR SOLAR CELL TECHNOLOGY

- SILICON CELL DEVELOPMENT
- ADVANCED DEVICES
- MANUFACTURING PROCESS DEVELOPMENT
- CELL ASSEMBLY DESIGN
- TESTING

SOLAR CONCENTRATOR TECHNOLOGY

- LENS DEVELOPMENT
- REFLECTOR DEVELOPMENT
- CONCENTRATOR DESIGN AND ANALYSIS
- ARRAY STRUCTURE DEVELOPMENT
- TRACKING AND CONTROLS
- CONCENTRATOR MANUFACTURING PROCESS DEVELOPMENT

CONCENTRATOR ARRAY SUBSYSTEMS

- ARRAY DESIGN AND ANALYSIS
- ARRAY FABRICATION
- ARRAY EVALUATION

CONCENTRATOR SOLAR CELL TECHNOLOGY

SILICON CELL DEVELOPMENT

- BSF CELLS - SANDIA
- HLE CELLS - SANDIA
- IBC CELLS - PURDUE
- PROPOSALS IN REVIEW

GALLIUM ARSENIDE CELLS

- VARIAN AND HUGHES

MULTIPLE JUNCTION DEVICES

- MONOLITHIC STACK - RESEARCH TRIANGLE
- BEAM SPLITTING - VARIAN

SILICON CELL MANUFACTURING

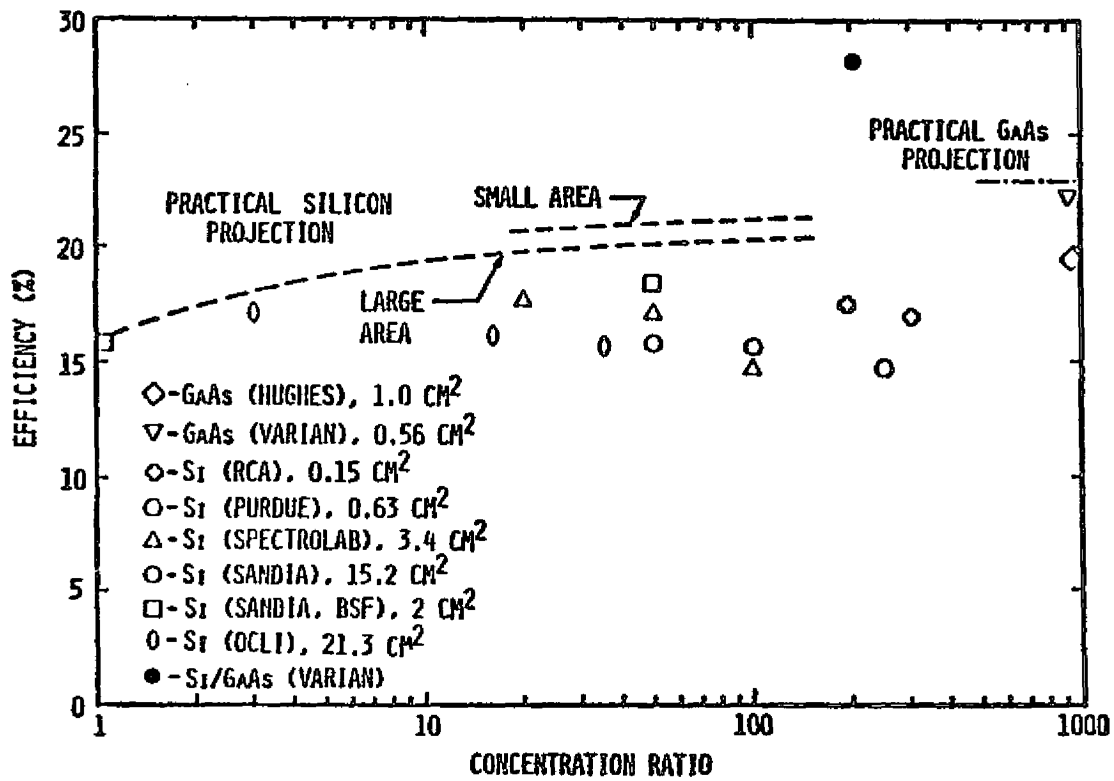
- MOTOROLA AND SOLAREX

ENCAPSULATION

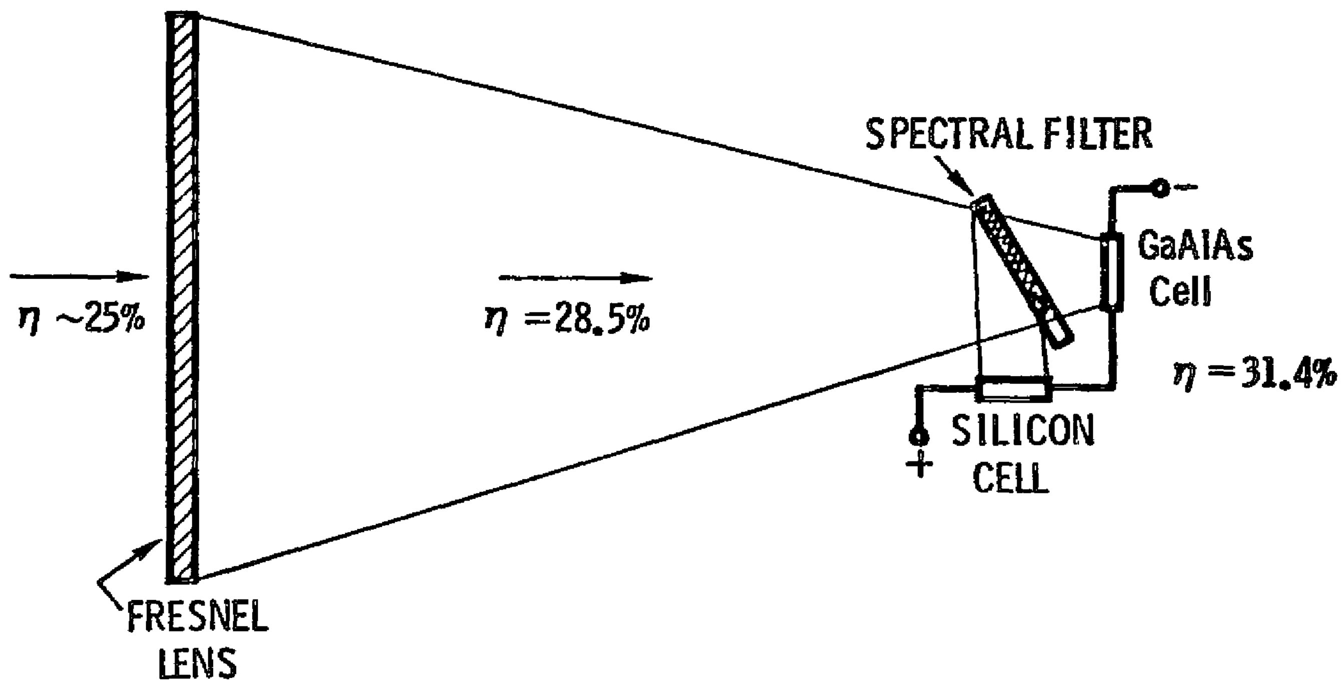
- BATTELLE

DENSE ARRAY ASSEMBLY

- ROCKWELL


PRACTICAL SILICON PROJECTION
SMALL AREA
LARGE AREA
PRACTICAL GaAs PROJECTION
◇-GaAs (HUGHES), 1.0 CM2
▽-GaAs (VARIAN), 0.56 CM2
O-Si (RCA), 0.15 CM2
O-Si (PURDUE), 0.63 CM2
△-Si (SPECTROLAB), 3.4 CM2
O-Si (SANDIA), 15.2 CM2
□-Si (SANDIA, BSF), 2 CM2
0-Si (OCLI), 21.3 CM2
●-Si/GaAs (VARIAN)
EFFICIENCY (%)
0
5
10
15
20
25
30
1
10
100
1000
CONCENTRATION RATIO

VARIAN HIGH-EFFICIENCY MULTIPLE CELL



SOLAR CONCENTRATOR TECHNOLOGY

FRESNEL LENS CONCENTRATORS

- CAST ACRYLIC LENSES - SWEDLOW
- 60 X ARRAY - SANDIA
- 400 X ARRAY - RCA
- LAMINATED LENSES - RCA

REFLECTIVE CONCENTRATORS

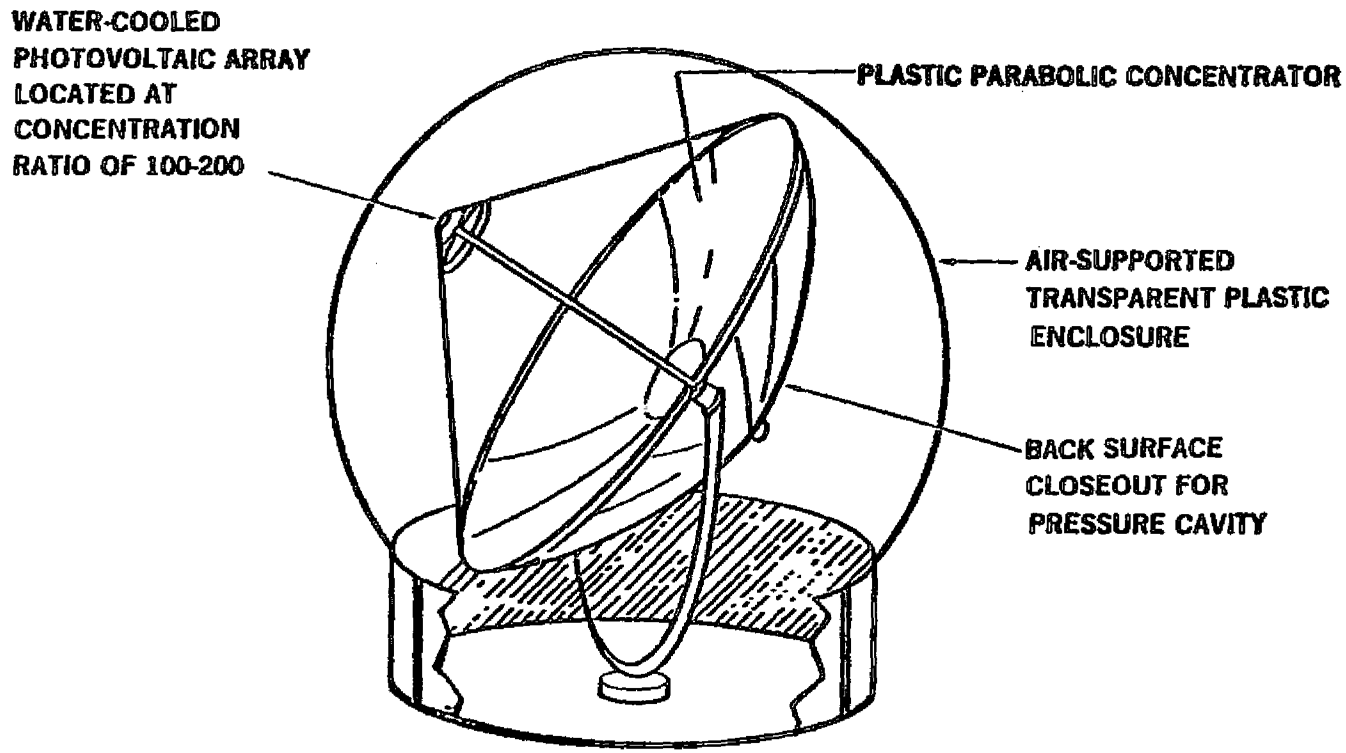
- PARABOLIC TROUGH, ACTIVE - ACCUREX
- PARABOLIC TROUGH, PASSIVE - SPECTROLAB
- PRESSURE SUPPORTED DISH - BOEING
- SEALED GLASS DISH - ACCUREX

COMPOUND PARABOLIC CONCENTRATORS

- LINE FOCUS REFRACTIVE - ARGONNE
- LINE FOCUS REFLECTIVE - ARGONNE
- POINT FOCUS, 116 X - SUN TRAC

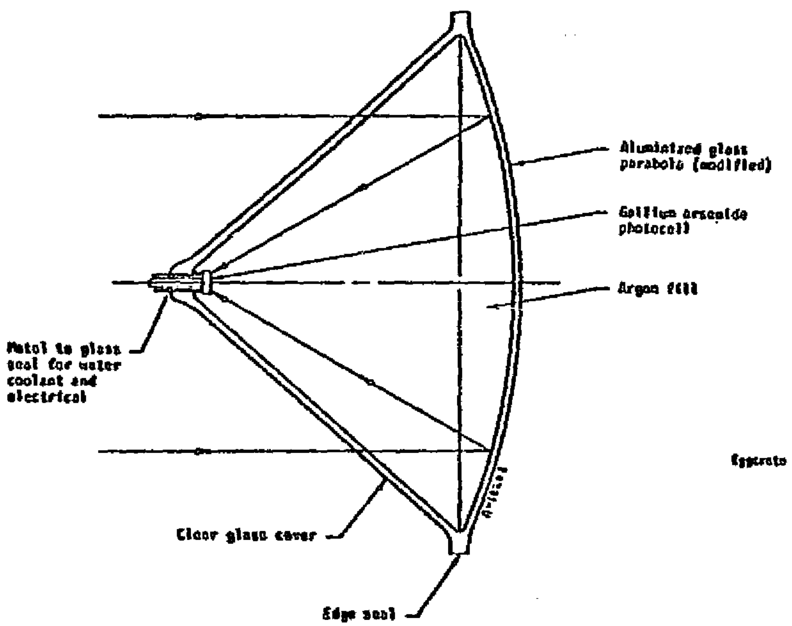
LUMINESCENT CONCENTRATORS

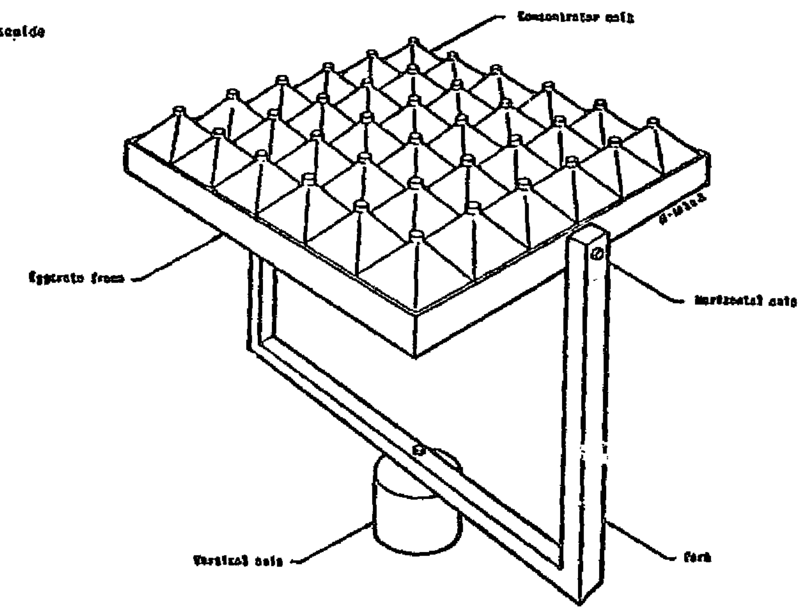
- OWENS-ILLINOIS AND CAL TECH



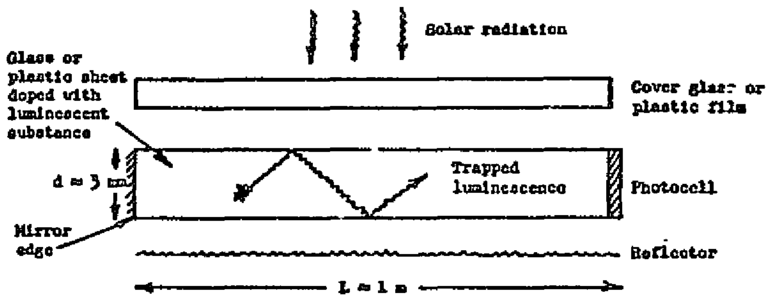
Boeing's Concentrating Photovoltaic Array System Concept

A NOVEL APPROACH FOR A LOW-COST PHOTOVOLTAIC CONCENTRATOR

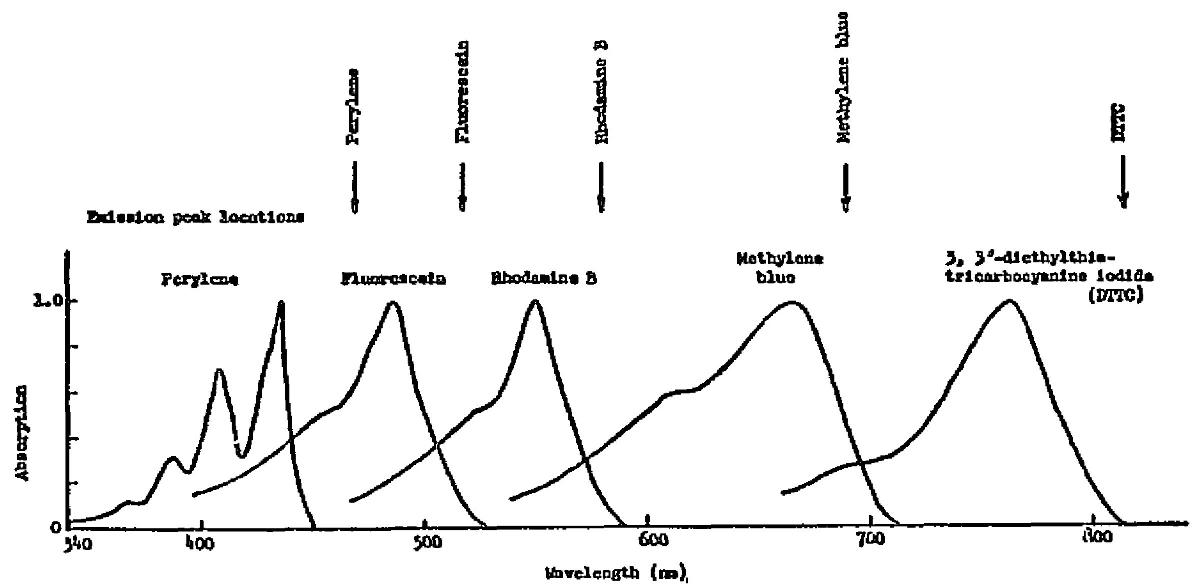




LUMINESCENT SOLAR COLLECTORS



Absorption spectra of four dyes potentially suitable for use together in an LSC converter. The emission peak locations are indicated by the arrows.



SOLAR CONCENTRATOR TECHNOLOGY (CONT)

CONCENTRATOR ANALYSIS, EVALUATION

- SANDIA AND ARIZONA STATE

MANUFACTURING PROCESSES

- GENERAL ELECTRIC

NOVEL CONCENTRATOR DEVELOPMENT

- DIRECTED TOWARD $0.50 TO $1 PER PEAK WATT
- 14 PROPOSALS UNDER REVIEW

PRODUCTION COST REDUCTIONS

- DIRECTED TOWARD $2 PER PEAK WATT IN NEAR FUTURE
- 24 PROPOSALS UNDER REIVEW

CONCENTRATOR ARRAY SUBSYSTEM

10 kW ARRAYS

- OFF-AXIS PARABOLIC ARRAY, CEC SECONDARY - SPECTROLAB
- FRESNEL LENS ARRAY - MARTIN MARRIETTA
- CENTRAL RECEIVER ARRAY - AAI
- ACTIVELY COOLED ARRAY - HONEYWELL

ENGINEERING DEVELOPMENT OF ARRAYS

- PARABOLIC TROUGH
- POINT FOCUS FRESNEL
- DESIGN OPTIMIZATION
- MANUFACTURING PROCESS DEVELOPMENT VIA CONTRACT

ACTIVITIES - NEXT SIX MONTHS

- INITIATE NEW WORK RESULTING FROM RFP's
  - Production Cost Reduction
  - Advanced Silicon Concentrator Cells
  - Novel Low Cost Concentrators
- CONTINUE EXPERIMENTAL EVALUATION OF ARRAY HARDWARE
- PUBLISH RESULTS OF COMPLETED WORK
  - Manufacturing Cost Analysis
  - Silicon Cell Manufacturing Processes
  - Enclosed Concentrating Arrays
  - Fresnel Lens Development
- DEVELOP AND ISSUE RFP's FOR NEW WORK

N79-25492

DEPARTMENT OF ENERGY
PHOTOVOLTAIC TESTS AND APPLICATIONS PROJECT

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

PRESENTED AT THE

DOE PHOTOVOLTAICS TECHNOLOGY DEVELOPMENT AND APPLICATIONS PROGRAM REVIEW

NOVEMBER 7-9, 1978

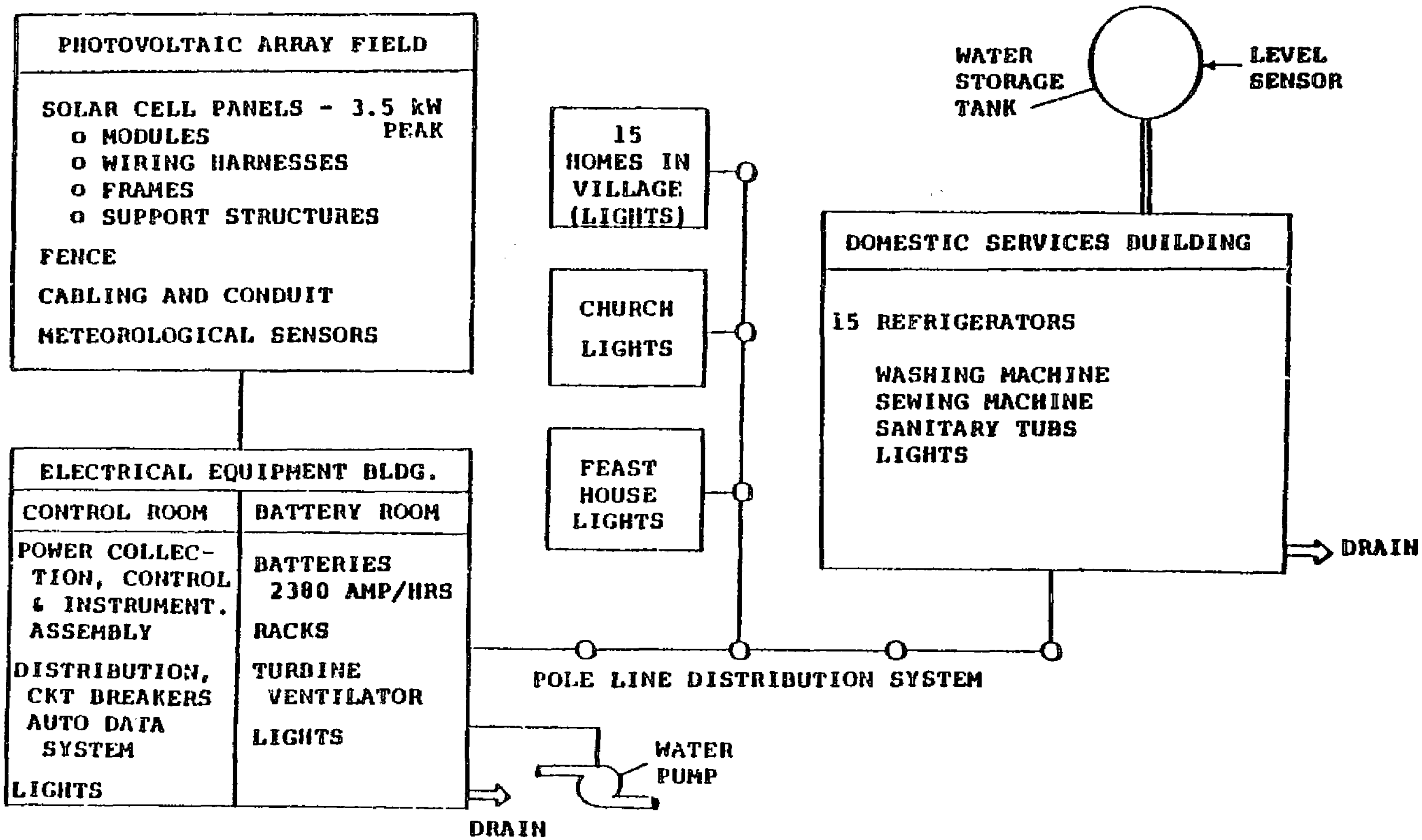
ARLINGTON, VIRGINIA

NASA-LERC/DOE APPLICATIONS STATUS

APRIL - OCTOBER 1978

INSTALL DATE	SYSTEM/LOCATION	W_{ARRAY}/AH_{BATT}	REMARKS
	REFRIGERATORS		
JUL 76	SIL NAKYA, AZ	300/600	o 1 OPEN CIRCUIT MODULE
JUN 78	ISLE ROYALE NP, MI	220/600	o >3880 VISITORS
	USFS FOREST LOOKOUTS, CA		
OCT 76	ANTELOPE PEAK	300/3015	o DEDICATION: 66 PUBS., 2.6 MILLION CIRC. o 900 VISITORS DURING SEASON
OCT 76	PILOT PEAK	300/3015	o 130 VISITORS, NO VEHICLE ACCESS
APR 77	DOT HIGHWAY SIGN IS 10, AZ	116/200	o OPERATIONS: ACTUAL 72, 46-1/2 HRS. PREDICTED 48, 144 o PROJECTILE DAMAGE TO ONE MODULE
MAY 77	USDA INSECT TRAPS, TX		
	FLUORESCENT (2)	163/400	o BATTERIES DISCHARGED ALL 4 TRAPS MID-SEPTEMBER: UNUSUALLY LOW INSOL. AND DAYTIME OPERATION DUE TO STORMS
	CHARGED GRID (2)	23/100	
APR-AUG 77	NOAA WEATHER STATIONS NY, FL, NM, HI, AK	74-184/80-1085	o NY: WINTER STORM DAMAGE & MODULE THEFT
SEPT 77	WATER COOLER LONE PINE, CA	500/150	o REGULATOR FAILURE o >30,500 VISITORS

BLOCK DIAGRAM OF SCHUCHULI VILLAGE POWER SYSTEM



SCHUCHULI VILLAGE POWER PROJECT STATUS

POLE LINE DISTRIBUTION SYSTEM COMPLETE

BATTERIES DELIVERED

PV PANELS COMPLETE

ARRAY SUPPORT STRUCTURE AND GROUND GRID INSTALLED

ARRAY FIELD FENCE INSTALLED

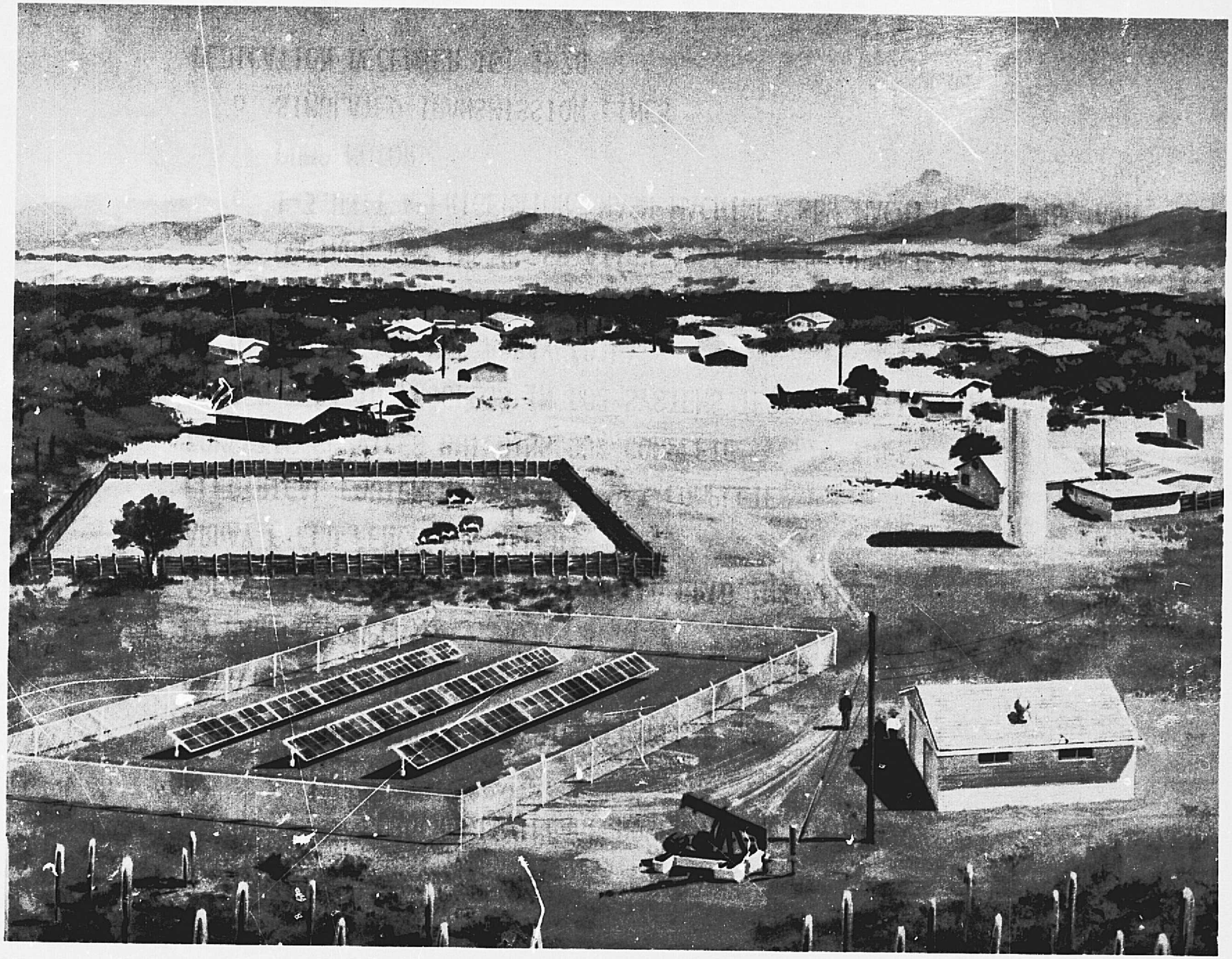
ELECTRICAL EQUIPMENT BUILDING 95% COMPLETE

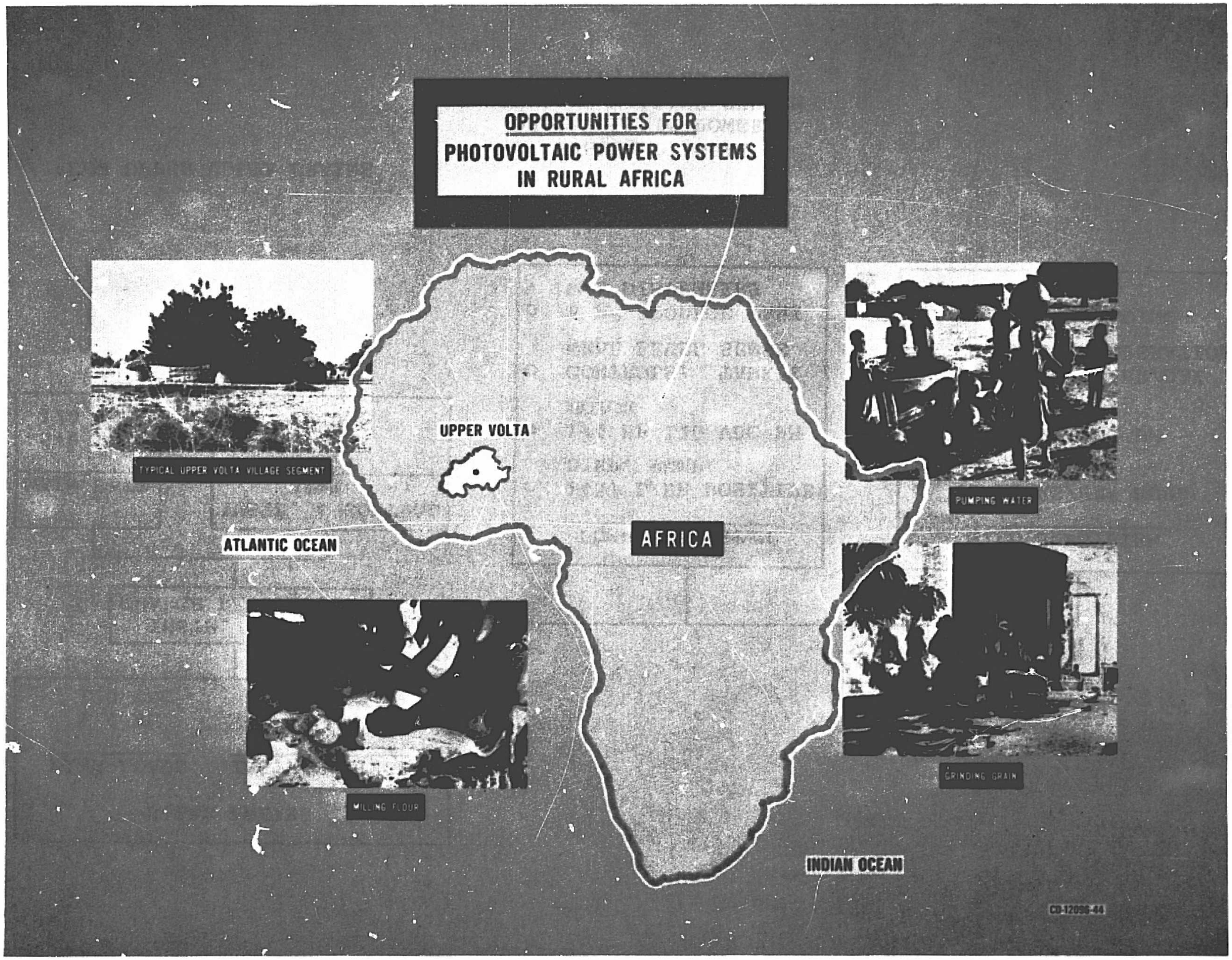
DOMESTIC SERVICES BUILDING 90% COMPLETE

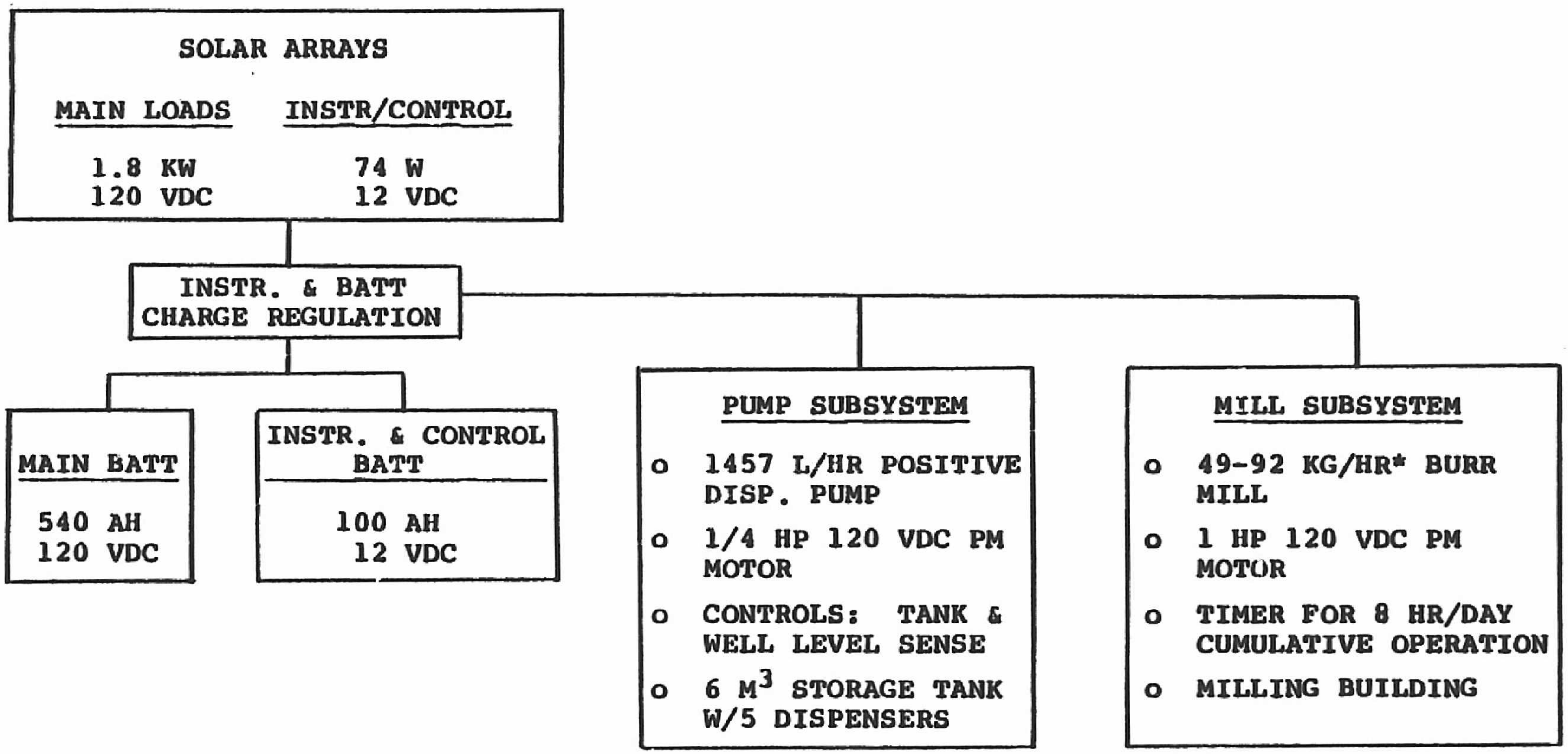
SYSTEM TEST IN PROGRESS IN DOE SYSTEMS TEST FACILITY (STF) AT LERC

- o 3.9 KW 120 VDC ARRAY (STF)
- o 440 AH 120 VDC BATTERY (STF) WITH 50 AH PILOT CELLS
- o CONTROL AND INSTRUMENTATION ASSEMBLIES CONNECTED
- o 1-3 UNIT REFRIGERATOR, WASH MACHINE, SEW MACHINE, LIGHTS, AND PUMP MOTOR
- o SIMULATED TRANSMISSION LINES

DEDICATION DECEMBER 16, 1978

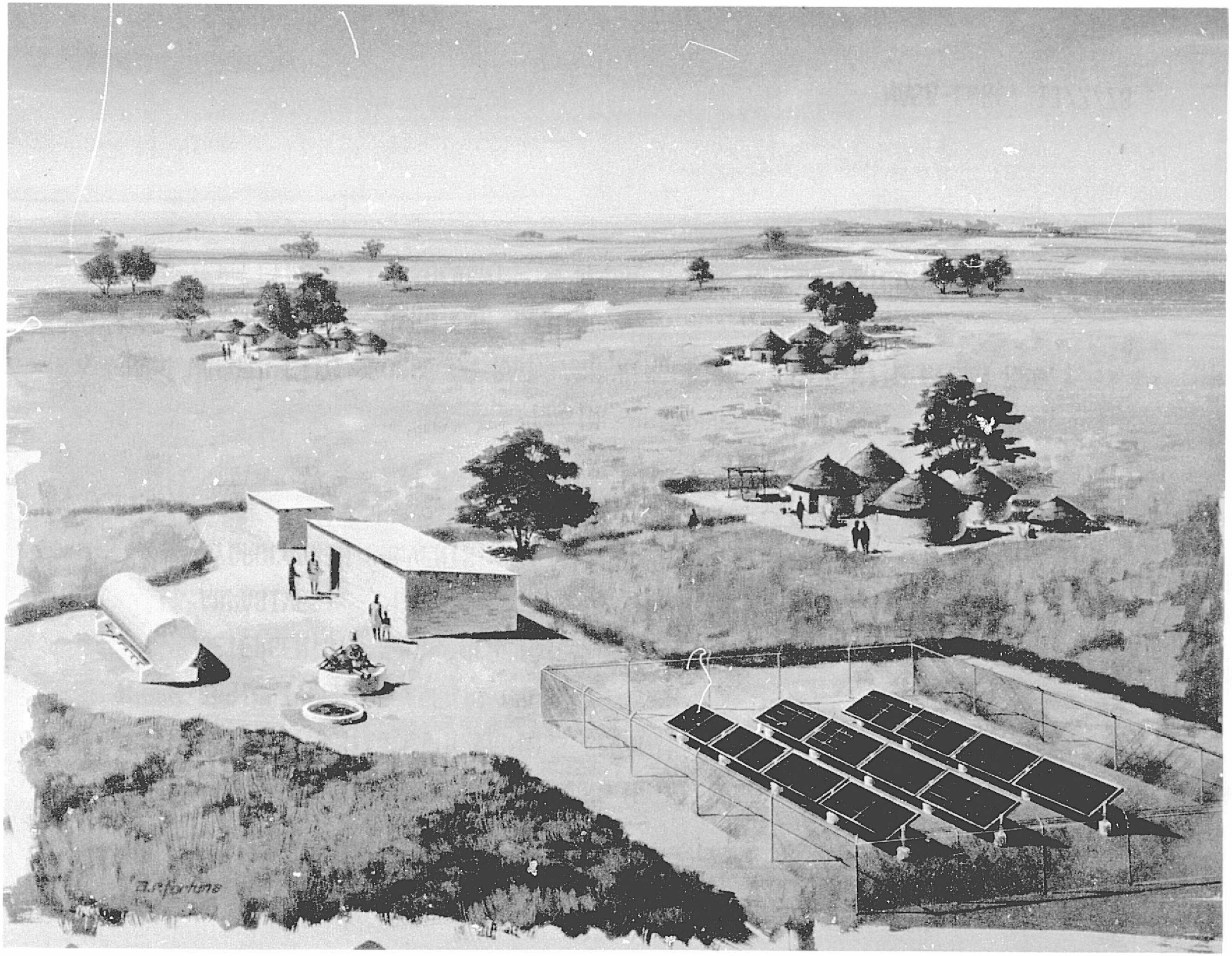



OPPORTUNITIES FOR
PHOTOVOLTAIC POWER SYSTEMS
IN RURAL AFRICA
TYPICAL UPPER VOLTA VILLAGE SEGMENT
UPPER VOLTA
ATLANTIC OCEAN
AFRICA
PUMPING WATER
GRINDING GRAIN
MILLING FLOUR
INDIAN OCEAN
CD-12096-44



*FOR UPPER VOLTA GRAINS

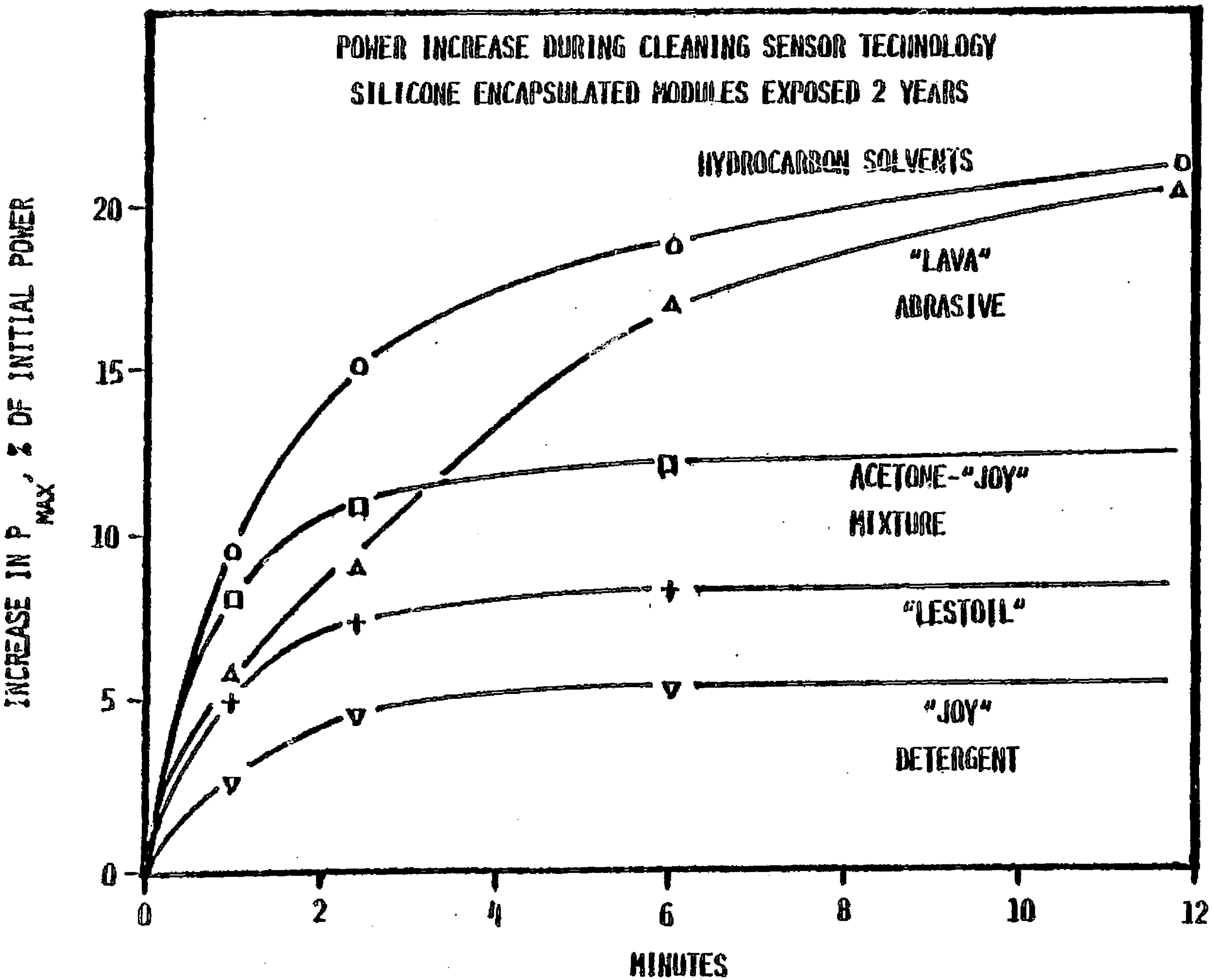
SYSTEM DIAGRAM
PHOTOVOLTAIC POWERED
PUMPING/MILLING SYSTEM
TANGAYE, UPPER VOLTA



CLEANING OF BLOCK I MODULES WITH VARIOUS CLEANERS

- SCHEDULED WASHING WITH DETERGENT AND WATER RECOVERED ONLY ≈ 3% OF POWER (1978).
- INVESTIGATE CLEANING WITH VARIOUS CLEANING AGENTS.
- THREE BASIC TYPES OF AGENTS CHOSEN:
  - DETERGENTS: "JOY," LESTOIL"
  - ABRASIVES: "LAVA"
  - HYDROCARBON SOLVENTS: TRICHLOROETHANE
    ACETONE
    TOLUENE
    "ENGINE SHAMPOO"
- HAND WASHED WITH SPONGE OR RAG, AND RINSED AND DRIED WITH CLEAN RAG.
- FIXED TIME PERIODS USED FOR WASHING.
- LONG-TERM EFFECTS OF SOLVENTS ON MODULES NOT INVESTIGATED.

NASA-LeRC, 11/7/78



NASA-LeRC, 11/7/78

PV SYSTEM REGULATORS

o DISSIPATIVE:

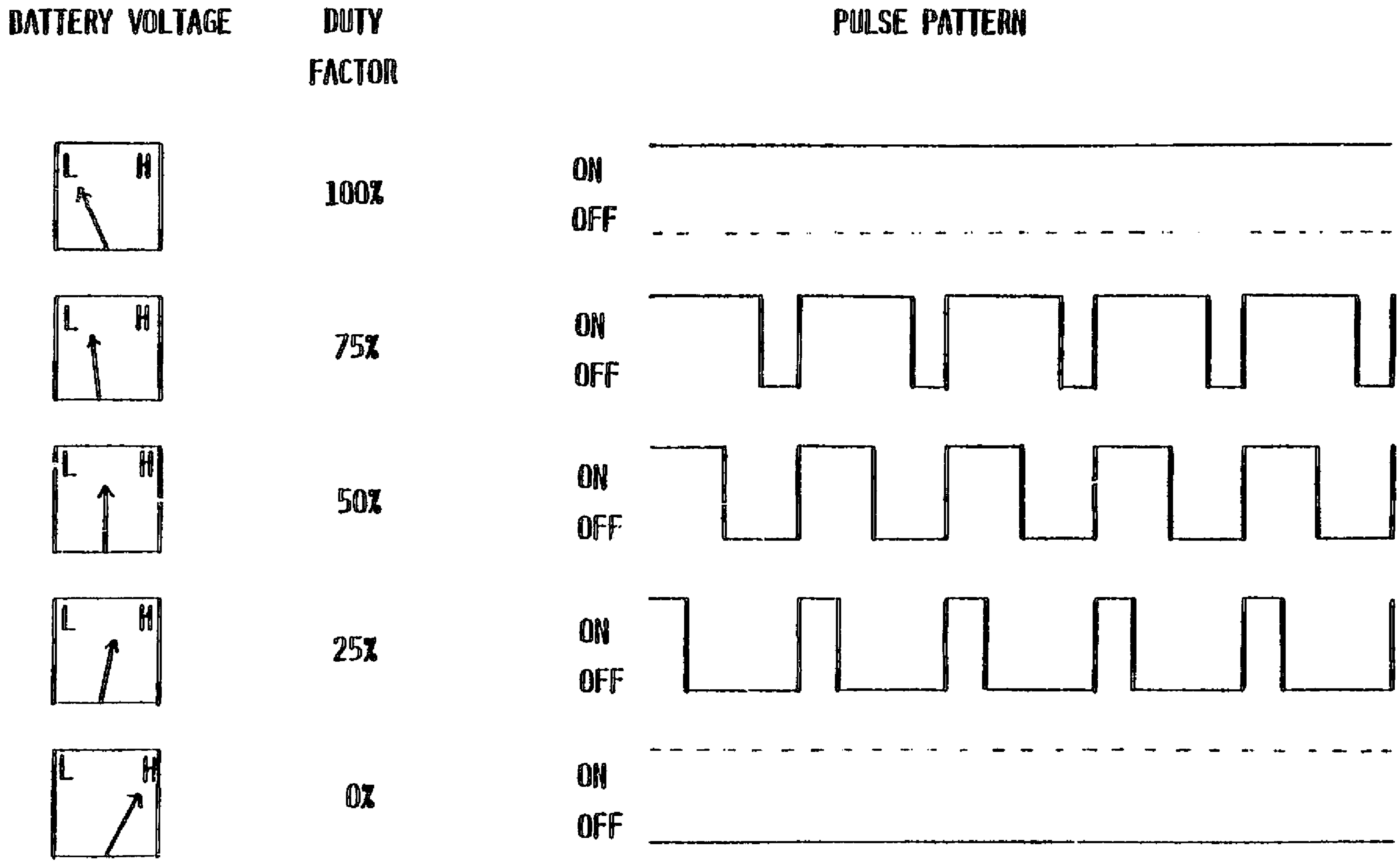
- ZENER DIODES
- "ELECTRONIC LOAD"
- COMPONENTS RATED FOR TOTAL ARRAY POWER
- NEED TO REMOVE HEAT FROM POWER COMPONENTS
- SIMPLE TO COMPLEX

o SWITCHING:

- ELECTROMECHANICAL OR SOLID STATE SWITCHING ELEMENTS
- COMPONENTS RATED FOR ARRAY CURRENT AND VOLTAGE
- NON-DISSIPATIVE
- MORE COMPLEX

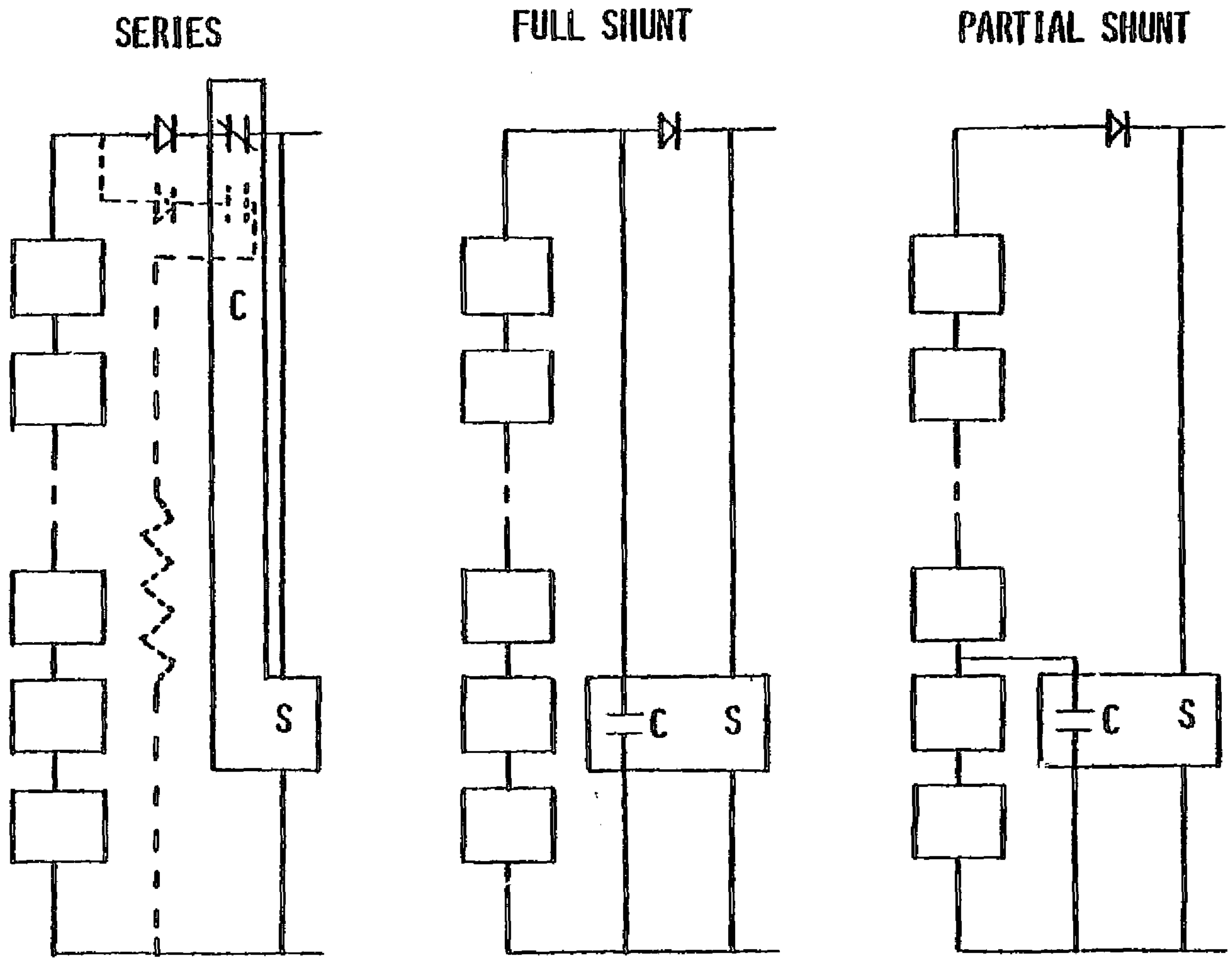
NASA-LeRC, 11/7/78

DUTY CYCLE REGULATOR



NASA-LeRC, 11/7/78

DUTY CYCLE REGULATOR ARRAY CONFIGURATIONS



NASA-LeRC, 11/7/78

SWITCHING REGULATOR ATTRIBUTES

- NONDISSIPATIVE
- SMALL
- LOW COST
- INTEGRATABLE WITH MODULES
- REDUNDANT
- MODULAR

NASA-LeRC, 11/7/78

SOLAR PHOTOVOLTAIC FIELD TESTS
AND APPLICATIONS PROJECT

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY
LEXINGTON, MASSACHUSETTS 02173

7 NOVEMBER 1978

C-B

MIT Lincoln Laboratory

Solar Photovoltaic Field Tests and Applications Project

Under funding from DOE, MIT Lincoln Laboratory is in its third year of field testing PV power systems. A variety of both large and small experimental PV systems have been and are being built for use in several application areas. These systems are summarized in the accompanying figure. In keeping with the engineering character of the FT&A Project, the test systems are heavily instrumented and are periodically inspected to detect changes induced by exposure to the elements and to the operating environment. Wherever possible, the field test systems emphasize flexibility in order to permit easy and rapid reconfiguring of the experimental PV system.

One of the most challenging problems which the FT&A Project addresses is that of reducing the currently high balance of system costs (i.e., costs for items other than PV modules) for photovoltaic power systems. These costs presently are in the range $5 to $15 per peak watt. Therefore, they require as much cost reduction as do the PV modules in order for widespread usage of photovoltaics to become economically practical. In view of the importance of the balance of system costs, the FT&A Project will emphasize construction and evaluation of new approaches for structures, foundations, power system control, inverters and storage units in a systems context and in representative environments from which useful data can be obtained concerning reliability, maintenance, and lifetime.

During FY-79, in addition to the continuing operation and/or completion of the test projects indicated above, field tests in the residential demand sector will be initiated. MIT Lincoln Laboratory will formulate a national residential field test plan in collaboration with the MIT Energy Laboratory under the guidance of DOE. This activity will coordinate the testing of prototype residential PV power systems using typical residential loads at the Lincoln Laboratory PV Systems Test Facility (LL/STF), the initiation of regional residential flexible test beds, specific residential field tests, followed by much larger groups of residential test units.

During the past six months, progress has been made in all of the FT&A areas. In particular, the integration contract for the 100 kW pk Natural Bridges National Monument system is about to be issued which will lead to project completion in the fall 1979. A 15 kW pk daytime only AM radio station project has been initiated and plans are for it to be completed by the end of next summer. Finally, the planned expansion of the Lincoln Laboratory residential test facility by an additional 25 kW pk is well underway and is due to be completed by this coming winter. A summary of the progress on these projects is given in the accompanying figures.

MIT LINCOLN LABORATORY -
FIELD TESTS AND APPLICATIONS PROJECT

- ESTABLISH TECHNICAL CREDIBILITY OF SOLAR CELL POWER SYSTEMS.
- IMPLEMENT SELECTED FIELD TEST EXPERIMENTS.
  - 100 kW PK - LOAD CENTER IN UTAH
  - 15 kW PK - AGRICULTURAL TEST SITE IN NEBRASKA
  - 15 kW PK - AM RADIO STATION IN OHIO
- PREPARE NATIONAL RESIDENTIAL FIELD TEST PLAN.
- INITIATE RESIDENTIAL FIELD TEST EXPERIMENTS.
- ASSESS AND DEVELOP POWER CONDITIONING AND STORAGE DEVICES FOR SOLAR CELL POWER SYSTEM USAGE.

R. W. MATLIN

1 NOVEMBER 1978

MIT/LL SOLAR PHOTOVOLTAIC FIELD TESTS AND APPLICATIONS PROJECT

- PLENARY SESSION
  - OVERALL PROGRAM STATUS.................R. W. MATLIN
    - REVIEW OF MAJOR FIELD TESTS
  - FLYWHEEL STORAGE FOR PV................A. R. MILLNER
  - OPTICAL GLINT FROM PV ARRAYS...........S. B. SACCO
- TOPICAL SESSIONS
  - NEBRASKA OPERATIONAL EXPERIENCE........R. F. HOPKINSON
L. L. BUCCIARELLI
  - ARRAY LIFE/PERFORMANCE.................E. B. MURPHY
  - SYSTEM CONTROL.........................J. H. HELFRICH
  - POWER HANDLING/STORAGE.................E. E. LANDSMAN
  - BALANCE OF SYSTEM COSTS................B. E. NICHOLS

RWM/11/2/78

PV FIELD TESTS CONDUCTED BY MIT/LL FOR DOE

Purpose/Usage	Size	Site(s)	Status
• Prototype PV Load Center System with Stand-Alone Capability	100 kW PK	Natural Bridges National Monument, Utah	Integration contract to be awarded; operational Fall '79
• Dispersed System -- Power for AM Radio Station	20 kW PK	Bryan, Ohio	Specs being prepared; to be operational Summer '79
• Lincoln Laboratory PV Systems Test Facility -- Test Prototype Residential System	25 kW PK	Lexington, MA	9 kW Installed & Operating: remainder to be completed Fall '78
• Micro-Irrigation PV Powered Pumping System	250 watts	Lexington, MA Mead, Nebraska	Prototype under construc.; to be Operational Feb '79
• Agricultural Test Facility -- Large & Small Scale Irrigation, Crop Drying, Fertilizer Mfg. etc.	25 kW PK	Mead, Nebraska	Operational since July '77
• Public Education -- Electric Power for Museum Exhibit	1.6 kW PK	Chicago, ILL	Operational since August '77
• Real Time Endurance Testing of PV Arrays & Structures	Less than 100 W PK Each	New York City (2 sites) MIT Cambridge, MA Mt. Washington, NH	Operational since Fall '77

R. W. Matlin
1 November 1978

A 100 kW PEAK PV POWER SYSTEM FOR THE NATURAL BRIDGES NATIONAL MONUMENT

Array

- 100 kW PEAK (48.4 kW MOTOROLA BLOCK III, 19.5 kW SPECTROLAB BLOCK II, 32.1 kW ARCO SOLAR BLOCK III - ALL MODULES GLASS COVERED)
- 4,716 MODULES, 266,028 CELLS, 1,712 m^2 TOTAL AREA
- 48 BRANCH CIRCUITS (2.08 kW)
- NOMINAL BUS VOLTAGE 220 VDC
- 1.4 ACRE ARRAY FIELD SITE

Battery Subsystem

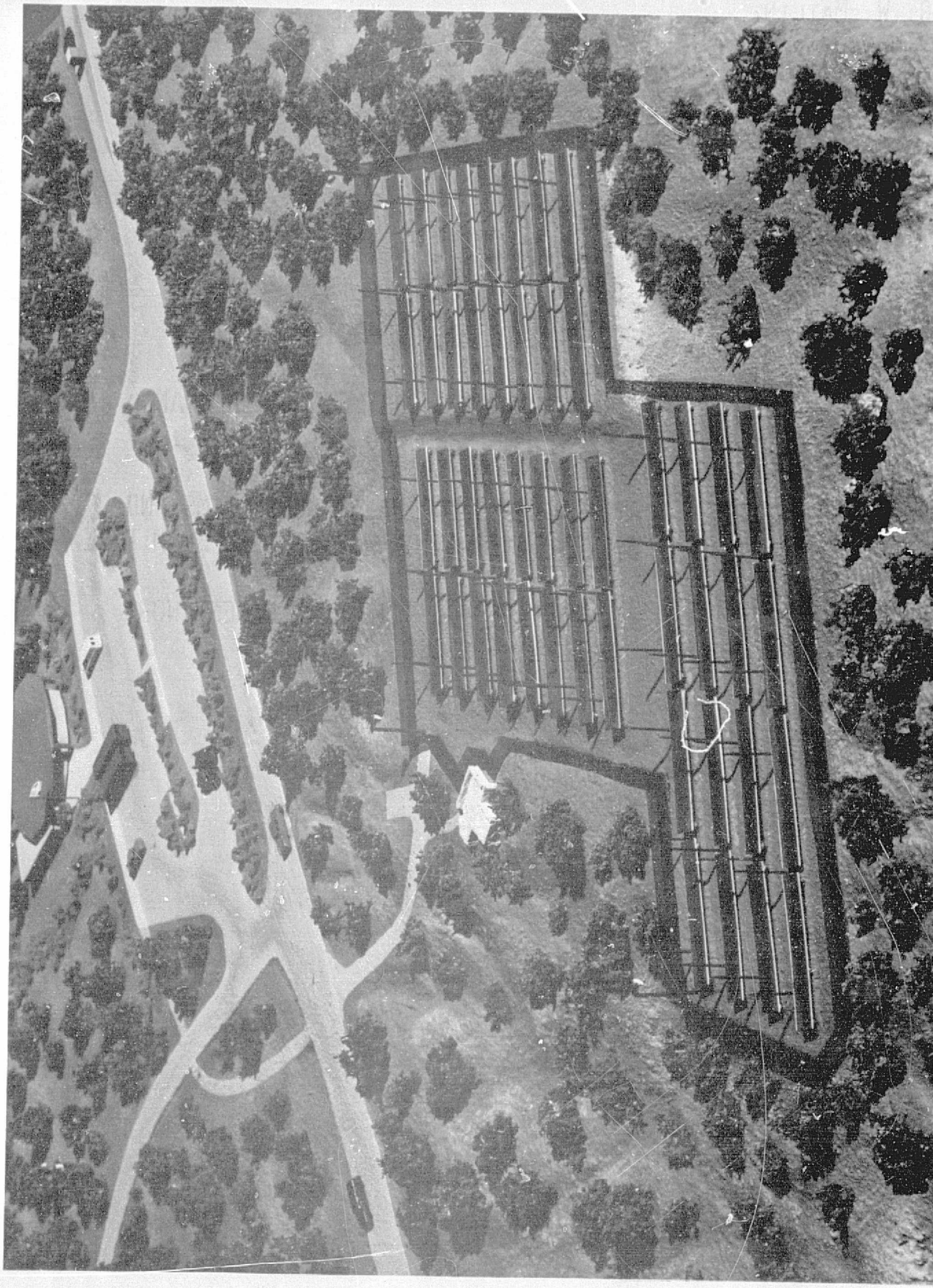
- 700 kWh (TOTAL CAPACITY) C&D LEAD CALCIUM BATTERIES, 600 kWh USABLE CAPACITY - (3,130 AH TOTAL)
- BATTERY COST $124/kWh (TOTAL CAPACITY, NOT INSTALLED)

Power Conditioning

- 50 kVA CYBEREX MAIN INVERTER ($360/kVA)
- 40 kW CONTROLLED FERRORESONANT BATTERY CHARGER

Site

- 6,500 FT. ELEVATION
- 13.4 IN. ANNUAL PRECIPITATION
- AVERAGE TEMPERATURE RANGES FROM 16°F to 91°F



R. W. MATLIN
2 NOVEMBER 78

STATUS UPDATE

MARCH, 1978	-	PRELIMINARY DESIGN REVIEW (MIT/LL)
MARCH, 1978	-	FORMAL AGREEMENT BETWEEN DOI/NPS AND DOE/DST FOR NBNM PROJECT
MAY/JUNE, 1978	-	BID PACKAGES FOR MAJOR SUBSYSTEMS AND SYSTEM INTEGRATION WORK ISSUED BY MIT/LL
AUGUST, 1978	-	BID PACKAGE FOR SITE DEVELOPMENT WORK ISSUED BY NPS/DSC

2 November 1978
R. Matlin

FUTURE MILESTONES

NPS/DSC

- BID PACKAGE FOR SITE DEVELOPMENT WORK REVISED AND REISSUED - RESPONSES DUE 8 NOVEMBER 1978
- PLANNED CONSTRUCTION START 1 DECEMBER 1978
- PLANNED CONSTRUCTION COMPLETION 1 JUNE 1979

MIT/LL

- SYSTEM INTEGRATION CONTRACT:

  PLANNED ISSUANCE - 1 DECEMBER 1978

  COMPLETION - 1 OCTOBER 1979
- COMPONENT PROCUREMENT (BATTERIES, BATTERY CHARGER, INVERTERS)

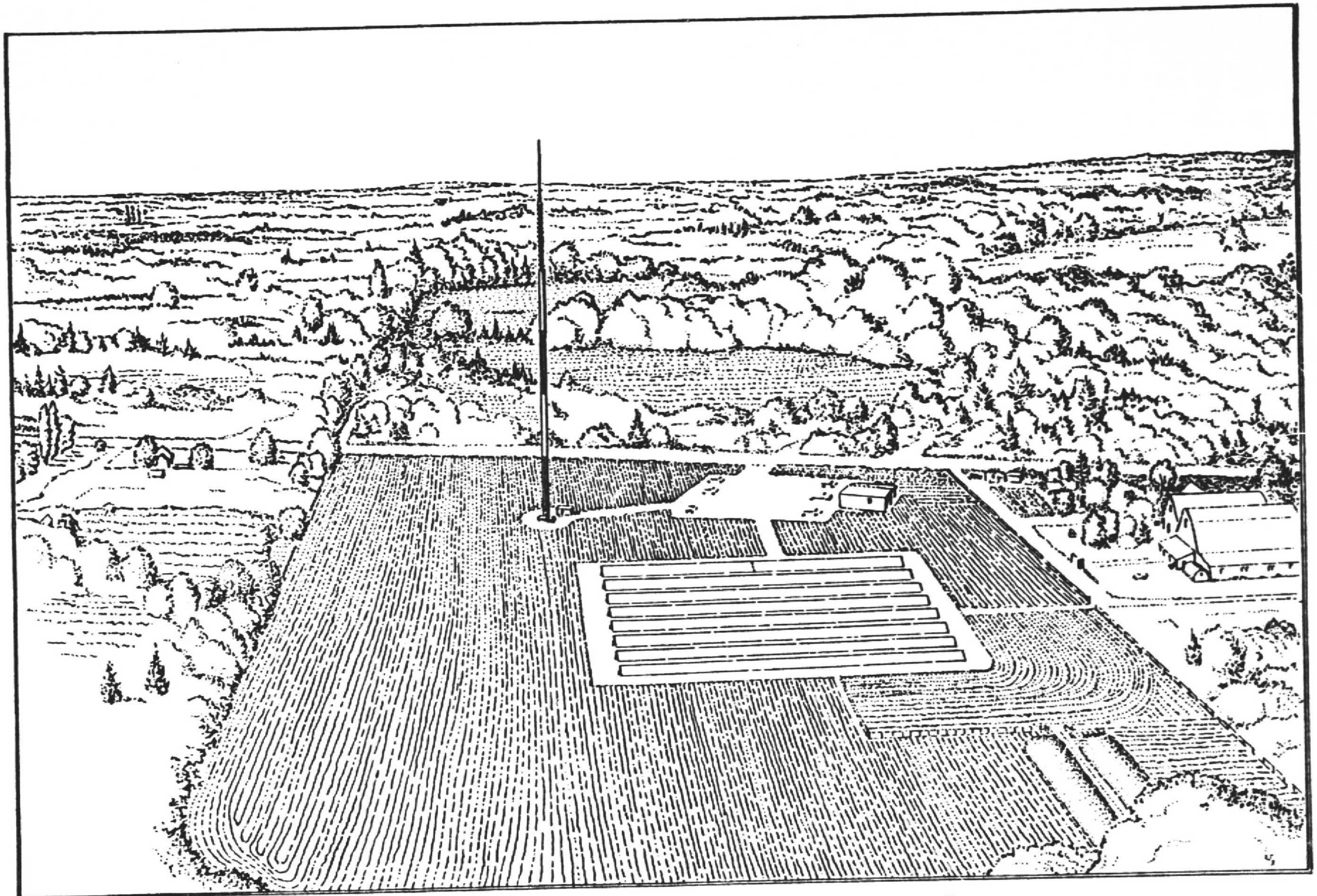
  DELIVERY - 1 MARCH 1979
- FINAL DESIGN REVIEW: JANUARY 1979
- SYSTEM DEDICATION: NOVEMBER 1979

2 November 1978
R. Matlin

SMALL DISTRIBUTED SYSTEM
(< 25 kW PK)

- CONCEPT:
  - FLAT PLATE ARRAY
  - LIMITED BATTERY STORAGE
  - DC LOAD
  - MINIMUM SITE PREPARATION
  - STANDARD DESIGN - MODULAR
  - LOW COST
- POSSIBLE APPLICATIONS:
  - REMOTE, ISLAND, DESERT, MOUNTAIN, ARCTIC SITES
  - RADIO, RADAR, NAVAID STATIONS
  - FACTORY DC PROCESSING
  - BATTERY CHARGING

  NOT: UTILITY FEED OR AC LOADS
- SELECTED APPLICATION: DAYTIME AM RADIO STATION:
  - 1000 TV
  - 3800 FM
  - 4400 AM (2000 DAYTIME ONLY)



CONCEPT OF PV ARRAY AT RADIO STATION

2 November 1978
R. W. Matlin

DAYTIME AM RADIO STATION

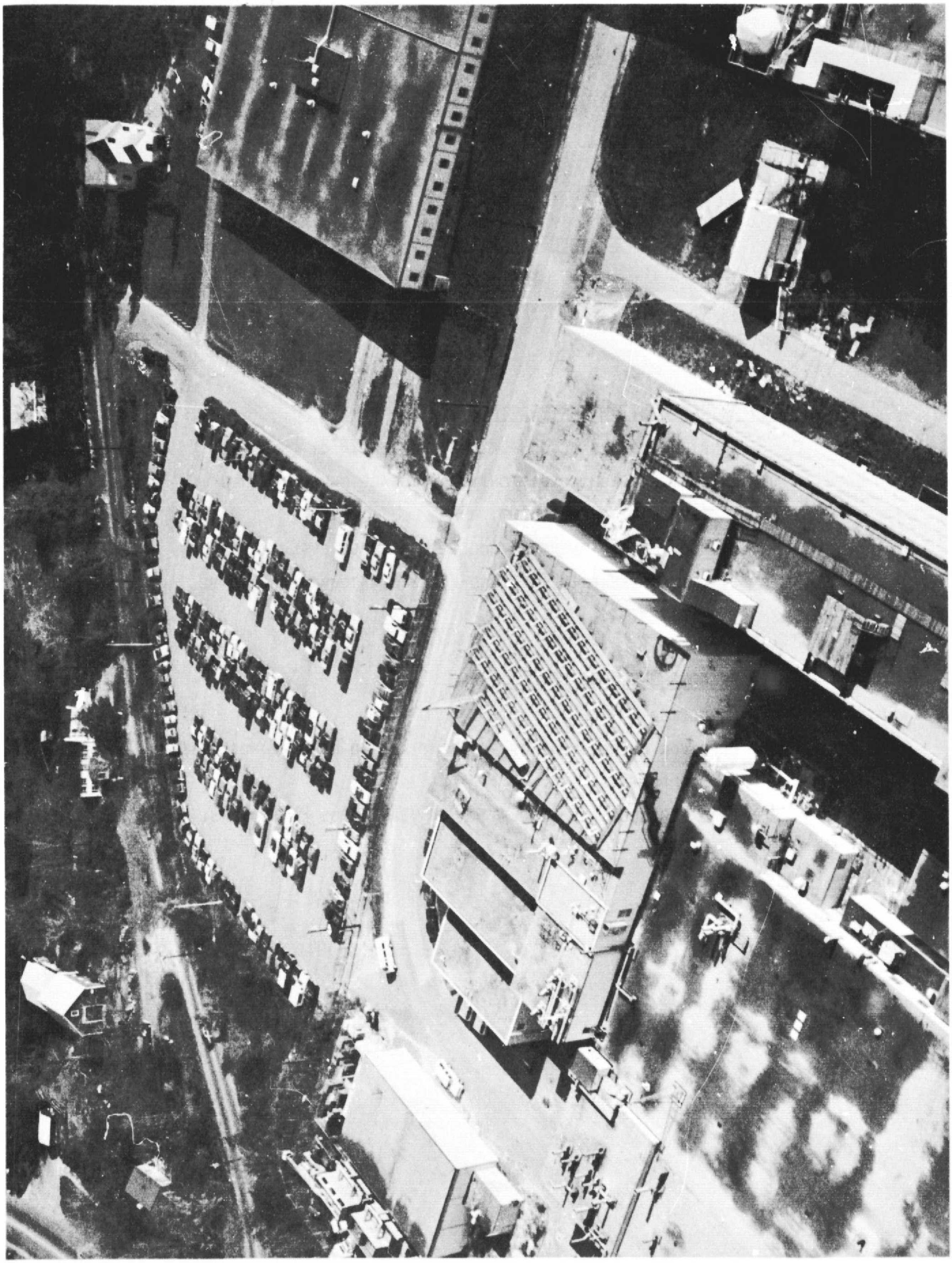
- LOCATION: WBNO BRYAN, OHIO
- SYSTEM PARAMETERS:
  - ARRAY - 15 kW PK
  - BATTERIES - 40 kWh
  - LOAD - 4 kW DC
- PROJECT STATUS:
  - SYSTEM DESIGN - COMPLETE
  - RADIO STATION - SELECTED
  - SYSTEM INTEGRATION RFP - DECEMBER 1978
  - SYSTEM OPERATIONAL - SUMMER 1979

11/1/78

LINCOLN LABORATORY PV SYSTEMS TEST FACILITY - TEST PROTOTYPE RESIDENTIAL SYSTEMS

- 25 kW PK RESIDENTIAL TEST FACILITY
  - CONSTRUCTION TO BE COMPLETE BY WINTER 1978.
  - EXTENSIVE POWER CONDITIONING & STORAGE DEVELOPMENT & EVALUATION EQUIPMENT.
  - HYBRID (PV AND THERMAL) COLLECTORS TO BE EVALUATED.
  - UTILITY INTERACTIVE & STAND-ALONE CONFIGURATIONS TO BE TESTED.

- 10 kW PK COMPONENT TEST FACILITY
  - COMPLETED.
  - USED FOR DEVELOPMENT OF RESIDENTIAL AND OTHER POWER SYSTEM COMPONENTS.
  - USED FOR SUBSCALE SIMULATION OF VERY LARGE PV SYSTEMS.



N79-25494

MILITARY APPLICATIONS OF PHOTOVOLTAIC SYSTEMS

US DEPARTMENT OF ENERGY

INTERAGENCY AGREEMENT NO. E(49-26)-1031

Period of Agreement: 1 November 1975 - 31 December 1978

DONALD D. FAEHN
Development Project Officer
US Army Mobility Equipment Research and Development Command
DRDME-ES
Fort Belvoir, Virginia 22060

Presented at the Semi-Annual Review Meeting
Photovoltaic Branch
7-9 November 1978
Arlington, Virginia

MILITARY APPLICATIONS OF PHOTOVOLTAIC SYSTEMS

A number of applications are being designed for installation at military facilities under the sponsorship of Defense agencies. In addition, we are completing the 60kW installation at Mount Laguna Air Force Station. This is part of the cooperative DoE/DoD demonstration which began in FY76.

The US Army Test and Evaluation Command is sponsoring two significant applications of solar cell power at their remote field testing facilities at Dugway, Utah and Yuma, Arizona. Both of these power systems are expected to advance the applications engineering experience in p/v systems. At Dugway Proving Ground, a remote, unmanned meteorological data station will be powered by a solar cell system rated at 4500 peak watts. The electrical demand (single-phase, 115 v a.c.) consists of a 600 watt continuous electronic load, plus an intermittent 1200 watts for air-conditioning in the summer months. Fifteen high density solar cell panels producing approximately 300 watts each will interface with the system controller, which will track the maximum power point of the array. The controller will also regulate the battery charge rate and float voltage, and will also include the paralleling and monitoring functions, along with a dual output, 60 Hz inverter. The 230kWh, 144 volt, lead-calcium battery will be housed in a 10 x 20 foot building, which will also contain the control equipment in a separate section.

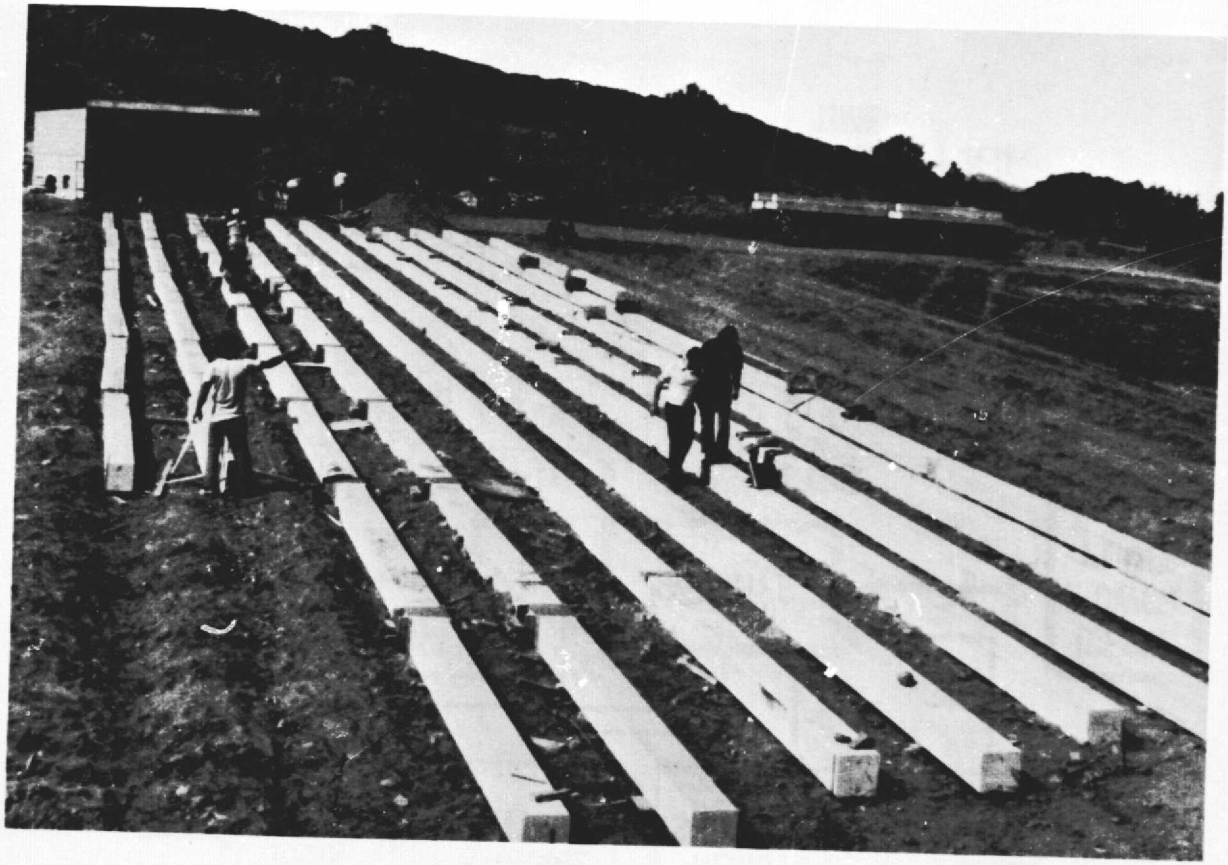
For Yuma Proving Ground, another power system is being developed which could have widespread application throughout the military testing community. This will be a general purpose, mobile photovoltaic power system rated at 1000 peak watts. Initially, this system will be used with portable video surveillance equipment, but is expected to be used also for a variety of equipment which is within the daily energy capability of the power system. The high density solar cell array will be trailer-mounted, along with the battery, regulator, and dc/ac power conditioning equipment.

A solar cell array is also being built for a radio repeater in the UAR which is being used by the peacekeeping forces in the Sinai Peninsula. The array will be added to existing wind/battery power system to improve the system reliability during periods of calm weather.

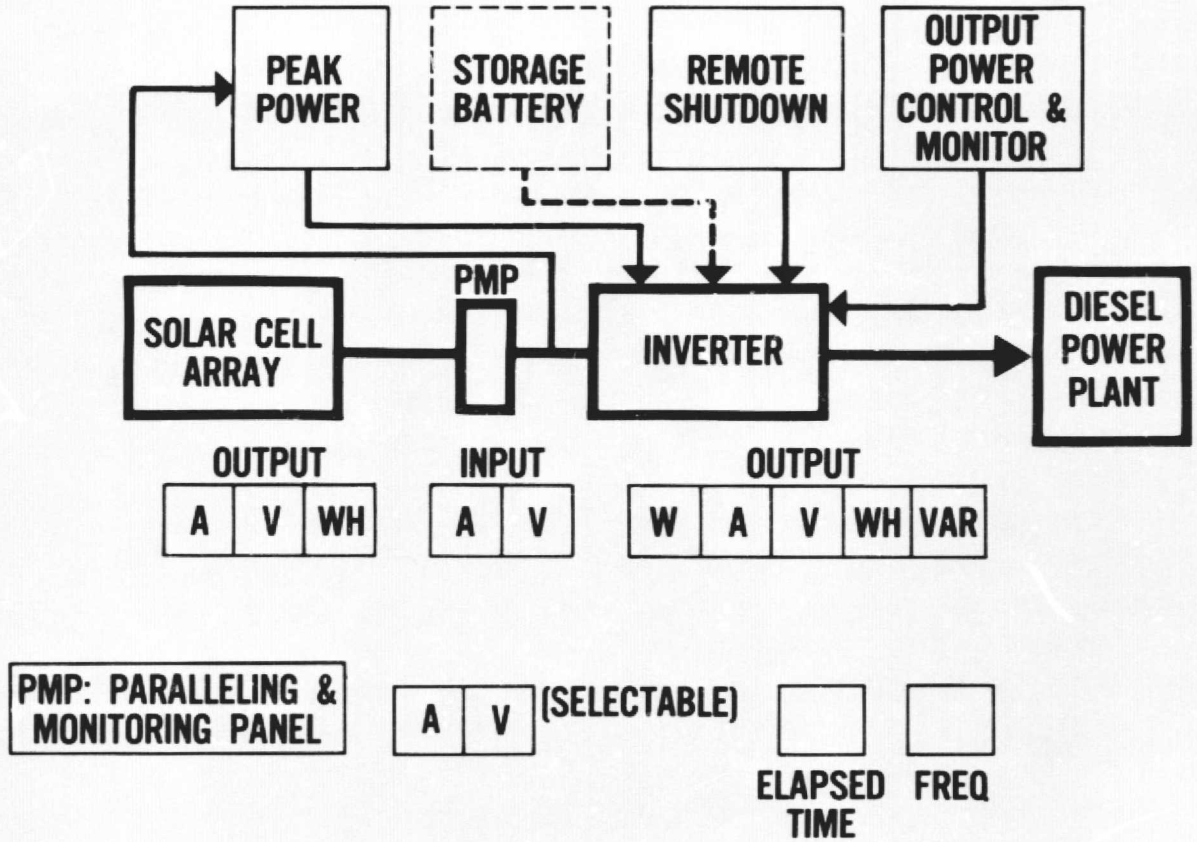
Fork lift truck battery charging has been identified as a potential military market sector, especially in areas where above ground power lines are prohibited. We are restructuring the array which was formerly used for a water purification demonstration at Fort Belvoir for this purpose. The battery charging demonstration will be located at Tobyhanna Army Depot, Pennsylvania and will utilize peak power tracking dc/dc power conversion in the battery charge controller. The controller is being funded by the Army.

Construction work is well underway for the 60kW installation at Mount Laguna Air Force Station in southern California. This is the last remaining application to be completed under the cooperative DoE/DoD demonstration program. Concrete footings have been installed in the array field and a building has been installed for containing the power conditioning equipment which will interface the array with the local utility grid. Meanwhile, the array panels are being assembled and wired at the contractor's plant and the inverter and other control components are being constructed and tested. Under the component test program, the inverter was successfully interfaced with the public utility, and d.c. loads up to 70kW were fed into the utility system. The peak power tracking capability of the inverter was also verified.

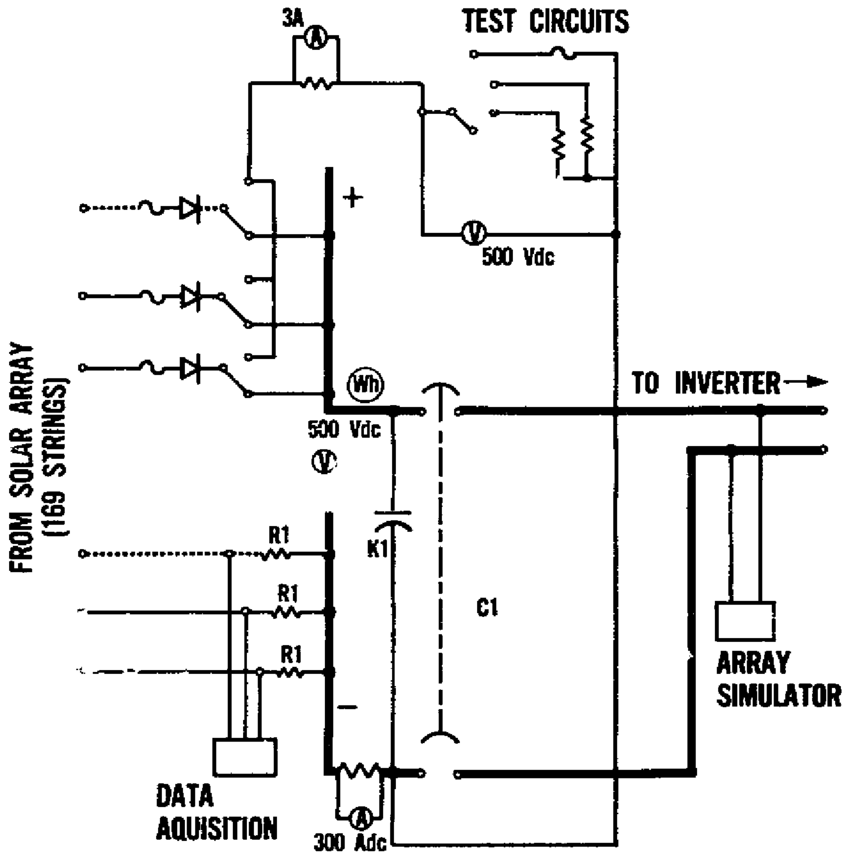
Site Preparation for 60kW Installation at Mount Laguna AFS



Array Foundations being Emplaced at Mount Laguna AFS



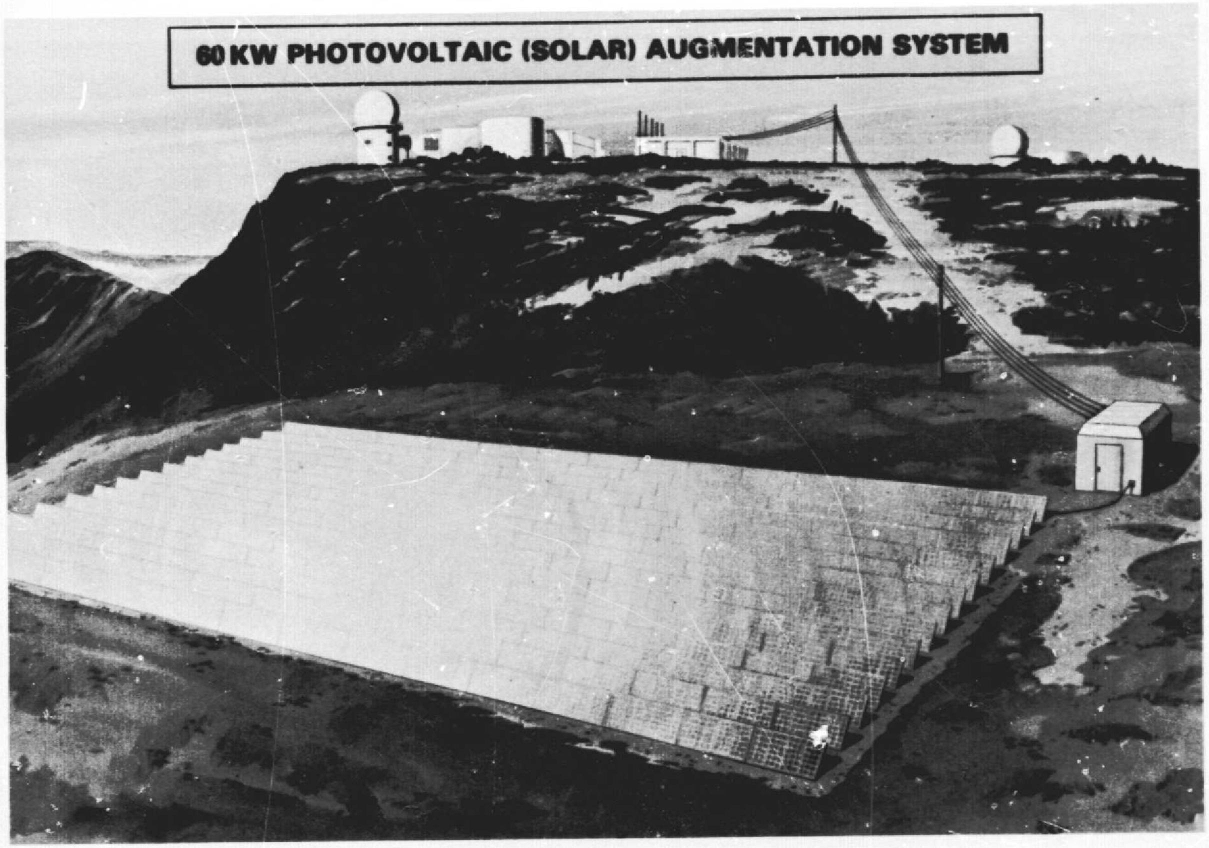
Block Diagram of 60kW System



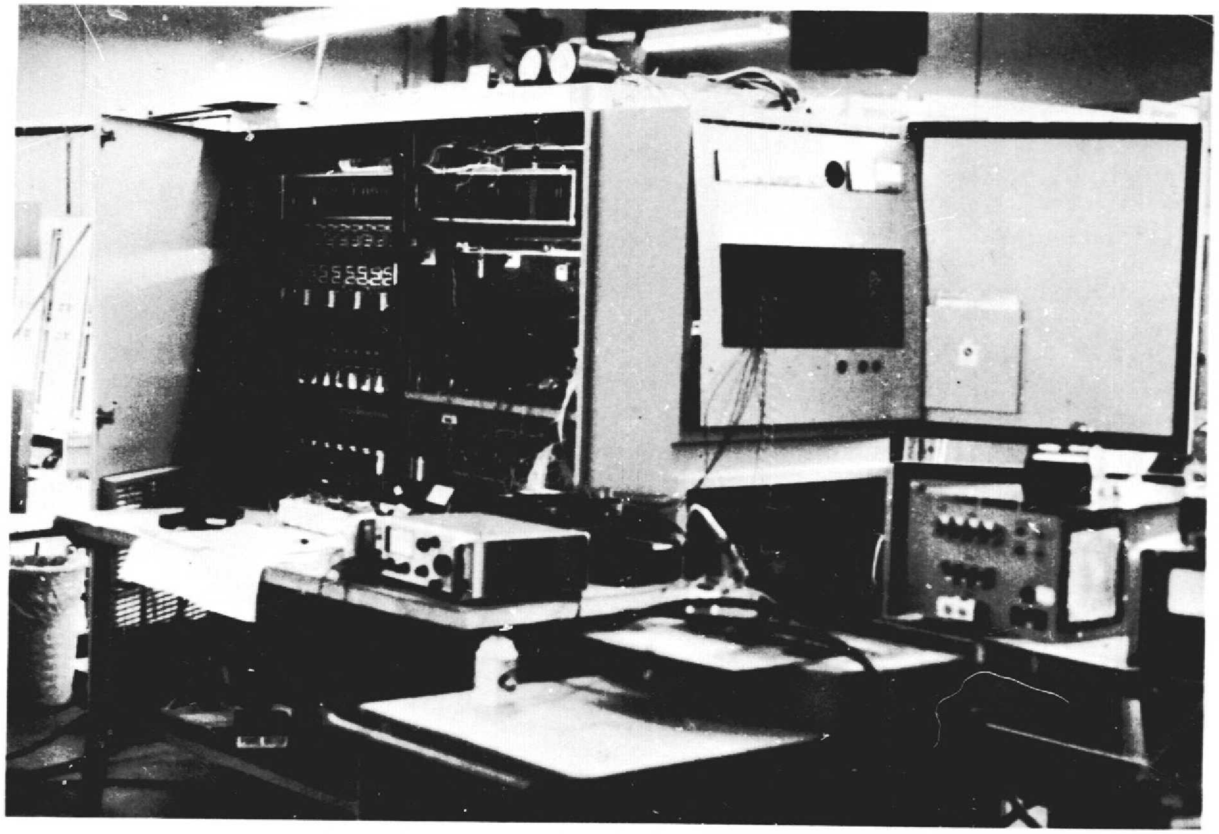
Paralleling and Monitoring Schematic

SOLAR CELL ARRAY	POWER [UW]	60
	VOLTAGE [Vdc]	230
	CURRENT [Adc]	261
	CELL TEMP. [°C]	50
	PANELS PER STRING	14
	NUMBER OF SOLAR PANELS	756
	NUMBER OF SOLAREX PANELS	1610
	NUMBER OF PARALLEL STRINGS	169
POWER CONDITIONER	POWER [KVA]	75
	FREQUENCY	60Hz
	OUTPUT VOLTAGE [V]	277/480, 3 PHASES
	EFFICIENCY, F.L. [%]	90
	TOTAL HARMONIC DISTORTION	LESS THAN 3%
	PHASE ANGLE	120° ± 1%
	OPERATION	AUTOMATIC STARTUP AND SYNCHRONIZATION PEAK POWER TRACKING
	MODES	CONNECTED TO UTILITY GND

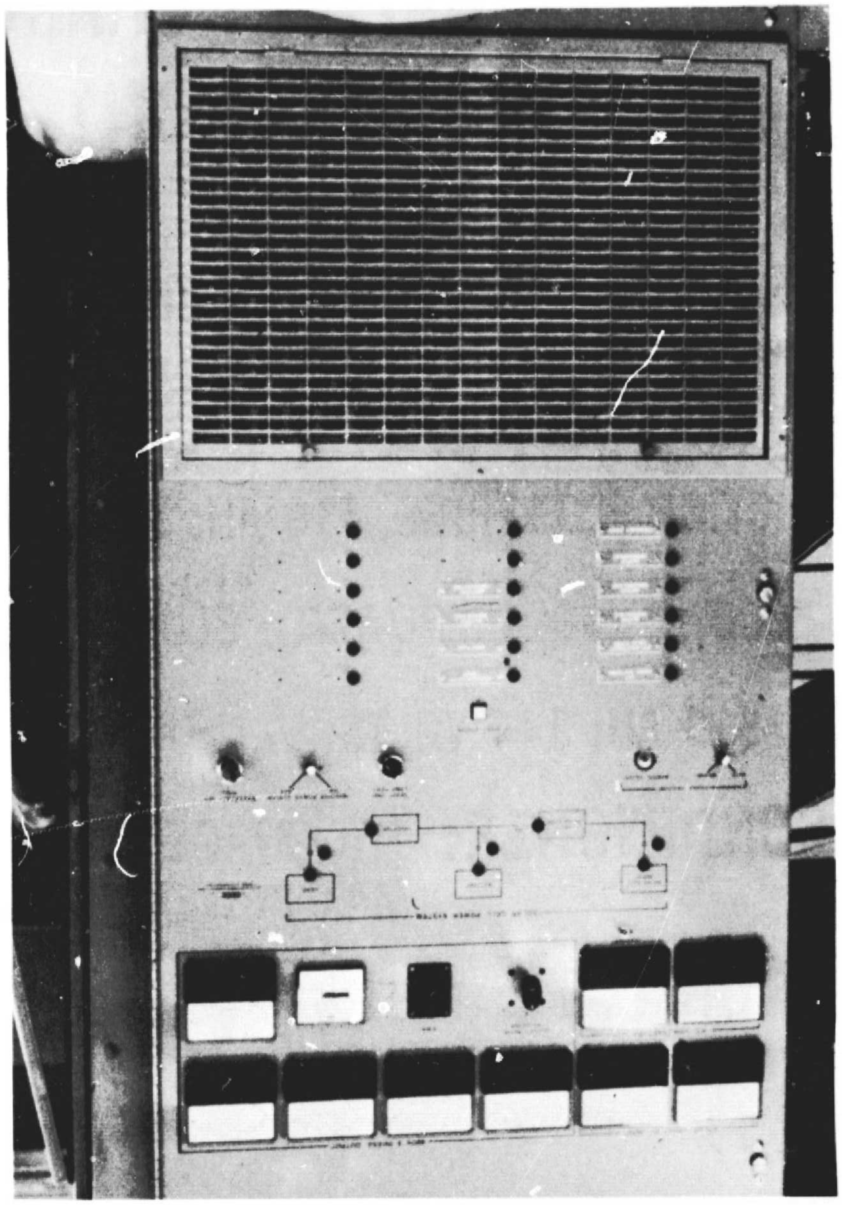
System Parameters



Artist's Concept of Mount Laguna Installation



60kW Inverter Undergoing Tests



Main System Control Panel

LIFT TRUCK BATTERY CHARGER (DEMONSTRATION)

MARKET SECTOR: BATTERY CHARGING

LOCATION: TOBYHANNA ARMY DEPOT, PA

LOAD: TRACTION BATTERIES, 510 AH; 36 VOLTS

ARRAY: 5000WP (SOLAR POWER), BLOCK I

BATTERY: 510 AH; 144 VOLTS

POWER CONDITIONER: TWO STAGE DC/DC CONVERTER, MAX POWER TRACKING

INSTALLATION DATE: FEB 79

VOICE/DATA REPEATER

MARKET SECTOR: COMMUNICATIONS

LOCATION: UAR

LOAD: ELECTRONICS

ARRAY: 1800WP, HIGH DENSITY (ARCO SOLAR)

BATTERY: (EXISTING)

INSTALLATION DATE: FEB 79

SATELLITE METEOROLOGICAL STATION

MARKET SECTOR: FIELD INSTRUMENTATION

LOCATION: DUGWAY PROVING GROUND, UT
(REMOTE, UNMANNED)

LOAD: ELECTRONICS AND AIR CONDITIONER

POWER REQUIRED: 1800 W MAX; 600 W NOMINAL

ARRAY: 4500WP HIGH DENSITY (ARCO SOLAR)

BATTERY: 230KWH, 144 VOLTS (C&D)

INVERTER: DUAL OUTPUT SECTIONS (1&2 KW)
115V 60HZ 1PH (DECC)

SHELTER: 10 x 20 FT BUILDING

INSTALLATION DATE: FEB 79

GENERAL PURPOSE P/V POWER UNIT

MARKET SECTOR: FIELD INSTRUMENTATION

LOCATION: YUMA PROVING GROUND, AZ
(PORTABLE; TRAILER MOUNTED)

LOAD: VARIOUS

ARRAY: 1000WP, HIGH DENSITY (SOLAREX)

BATTERY: 30KWH, 48 VOLTS

INVERTER: 1.5KW, 115V, 60HZ, 1PH (TBD)

INSTALLATION DATE: APRIL 79

PHOTOVOLTAIC RESEARCH AND DEVELOPMENT STATUS

D. L. Feucht

SERI

N79-25495

PHOTOVOLTAIC R&D STATUS

D.L.Feucht - Manager
Photovoltaic Program Office
SERI
Golden, Colorado 80401

The Solar Energy Research Institute has been designated by DOE as a lead center for the Photovoltaic R&D Program. This Program at SERI is divided into two efforts. One, which is conducted in the Photovoltaic Research Branch headed by Sigurd Wagner, does in-house photovoltaic research. The second is concerned with the funding and management of external contracted research and is handled through the Photovoltaic Program Office.

The goals of the Photovoltaic R&D Program are 1) to develop thin film semiconductor and novel photovoltaic conversion concepts, 2) to demonstrate the feasibility of producing these cells for a price of $100 - $300 per peak Kw electric output (in 1975 $) by FY1985. The approaches being used to determine which research should be funded are formal solicitations, an innovative concepts program which will be launched in FY79 and the review of unsolicited proposals. The Photovoltaic R&D Program, as outlined on the chart labelled Photovoltaic R&D Strategy, has an FY79 budget of approximately $33M. The materials listed as Advanced Materials are those materials which we believe have the best chance of reaching the stated goals. The programs listed as High Risk Research include materials which we believe merit investigation, but which have a much higher risk for satisfying the long term goals. Research Support and Fundamental Studies includes those areas which we believe need investigation because they may effect the success of the overall program. Technical Issues include such things as the availability of In, Ga and Ge, the environmental effects associated with large scale production of Cd or As containing compounds, the reliability and stability of thin film cells, the problem of nucleating large grains in thin films etc. Early efforts to move selected advanced materials into the Exploratory Development stage will be conducted under Development Initiatives. The research activities carried out by the Photovoltaic R&D Branch are summarized on the chart labelled SERI Photovoltaic R&D Branch.

The Photovoltaic R&D Program held its Annual Review Meeting in Vail, Colorado from October 24th - 26th, 1978. At that meeting some 37 Contractors reported on their progress and the research to be conducted by some 38 new Contractors was outlined. The following Charts indicate the status of research in the Program as reported at that meeting.

The final two charts summarize the Electrochemical Photovoltaic Cell Program and the Innovative Concepts Program which will be initiated during FY79.

Photovoltaic R&D Strategy

Advanced Material/Cell Research:

- Cu_2S/CdS and Cu Ternary/CdS Cells
- GaAs Cells
- Polycrystalline Silicon Cells
- Amorphous Silicon Materials/Cells

High Risk Research:

- Emerging Materials
- Amorphous Materials
- Advanced Concentrator Cells and Concepts
- Electrochemical Photovoltaic Cells
- Innovative Concepts

Research Support & Fundamental Studies:

- Basic Mechanisms
- Material/Cell Evaluation Techniques
- Technical Issues
- Development Initiatives

SERI Photovoltaic Research

SERI — Photovoltaic R&D Branch

Branch Chief: Sigurd Wagner

Research Areas:

- III-V Alloy Systems for High Efficiency Concentrator cells
- Understanding and Improvement of the Conversion Mechanism in Amorphous Silicon
- Continuous Growth and Processing for Thin Silicon Cells
- Theoretical Understanding of Metal-Oxide-Semiconductor Cell Structures
- Characterization of Surfaces, Interfaces and Grain Boundaries of Photovoltaic Cells
- Development of New Measurement Techniques for Thin Film Materials
- Development of a National Photovoltaic Research Measurement Facility

Cu_2S/[CdZn]S Cell Research

- 9.15% Cu_2S/CdS Textured Cell Obtained by Dipping Process (Voc = 0.52v, Jsc = 24.8 ma/cm², A = 0.9 cm²)
- 7.1% Planar Junction CdS/Cu_2S Cells Obtained (Voc = 0.56v, Jsc = 19 ma/cm², A = 1.0 cm²)
- 7.6% $Cd_{.93}Zn_{.07}S/CU_2S$ Cells Obtained by Planar Processes (Voc = 0.60, Jsc = 19.4 ma/cm², A = 1.0 cm²)
- Investigating Multiple Cathode Reactive Sputtering for Thin Film Cu_2S/CdS Cell Fabrication
- Investigating Structural Characteristics of the Cu_2S/CdS Interface

Participants: University of Delaware, Westinghouse, Lockheed/Telic, Lawrence Livermore Lab., Lawrence Berkeley Lab

Cu Ternary/CdS Research

- Fabricated 5.7% (no AR) $CdS/CuInSe_2$ Thin Film Cell on Glass by Co-evaporation Process. (Voc. = 0.34, Jsc = 31 ma/cm^2, A = 1.0 cm^2); Grain Size 1 μm

- 9% CdS/CuInSeTe Small Area Cell Obtained in Pressed Pellets.

- Investigating Sputtering & Multi-source Evaporation to Deposit $CuInSe_2$ Films on CdS

Participants: Boeing Aerospace Corporation, Brown University, Sperry Univac

GaAs Cell Research

- Fabricated 20% n^+/p GaAs Cell by $AsCl_3$-CVD on Single Crystal Ge (V_{oc} = .97, J_{sc} = 25.6 ma/cm^2, A = .5 cm^2)
- Fabricated 6.7% Au MIS Cells on CVD Deposited GaAs on W. Coated Graphite (V_{oc} = .52v, J_{sc} = 23 ma/cm^2, A = 9 cm^2)
- Using Anodic Oxidation to Mask Grain Boundaries, Fabricated 5.5% (No AR) Au MIS Cell on MO CVD Thin Film GaAs on Ge.
- Investigating Laser Recrystallization to Produce Large Grains & Transport across Grain Boundaries.

Participants: MIT-Lincoln Labs, Rockwell Electronic Research and Science Centers, Rennselear, SMU, and JPL

Thin Film Polycrystalline Si Cell Research

- 9.5% CVD ($SiHCl_3$) p-n Si Cell on Recrystallized Metallurgical Grade Si on Graphite (Voc = .57v, Jsc = 23.5 ma/cm^2, A = 9 cm^2)
- 10.1% SnO_2/n-Si, Wacker poly (Voc = .56v, Jsc = 26.6 ma/cm^2, A = 1 cm^2)
- 9.5% ITO/p-Si, Monsanto poly (Voc = .48v, Jsc = 28 ma/cm^2, A = 20 cm^2)
- Cr-MIS Cells 12.2% on Single Crystal, 8.8% on Wacker Poly
- 70% Deposition Efficiency shown for Energy Beam Deposition using $SiHCl_3$; 1.9 × 20cm Films Separated from Subst.
- 1 Dimensional Recrystallization achieved using Pulsed Electron Beam

Participants: SMU, Exxon, Rutgers U., Motorola Inc., Westinghouse, Colo. St. Univ., Spire

Thin Film Polycrystalline Si Cell Research

New Efforts

- Electrodeposition from Nonaqueous Solvents and Molten Salt Electrolytes.
- Electron-Beam Evaporation on Low-Cost Glass Substrates.
- CVD Growth on Low Cost Substrates; Control of Nucleation
- Grain Boundary Effects & Passivation in Polycrystalline Si.
- Fundamental Studies of MS and MIS Solar Cells on Polycrystalline Si.

Participants: John Hopkins; Rockwell; EIC Corp; Sandia; RCA: Columbia U.

Amorphous Silicon Research

- Efficiency in Schottky Barrier Cells Limited to 6% by Minority Carrier Lifetime
- Electrolytic Contact Indicates Band Bending Equal to 90% of Eg

New Efforts

- Investigate growth conditions, substitution of impurities for Si and H and Defect States in Glow Discharged Silicon
- Investigate Reactive Sputtering and Resultant Film Properties for α-Si Cells
- Investigate the Electrodeposition of α-Si from Organic Solutions.

Participants: RCA, Mobil-Tyco, Xerox, U. of Delaware, Harvard, Lockheed, Penn. St. Univ., Battelle Columbus Labs, Univ. of S. California

Amorphous Materials Research

Amorphous Silicon:

Computer Modelling — Argonne Lab
Ion Plating Techniques — Duke Univ.
Hydrogen Implantation — Spire

Other Amorphous Materials Being Investigated:

Amorphous Boron — Duke Univ.
II-IV-V_2 Compounds — EIC Corp.
Amorphous GaAs — Harvard Univ.
Chalcogenide Glasses — M.I.T.

Emerging Materials Research

InP/CdS

- Achieved $\eta = 10\%$ (No AR) CdS on Single Crystal and Epitaxial InP
- Investigating InP Growth on CdS by Planar Reactive Deposition, MBE and Plasma Deposition

Participants: Hughes, Rockwell and Westinghouse

CdTe

- Electrochemical Deposition of 0.2 μm Grain CdTe; CdTe/ITO, $\eta = 2\%$
- Fabrication of p-n CdTe, MIS and ITO/CdTe Junctions by Vapor Deposition and Sputtering

Participants; Monosolar, Pennsylvania State Univ. Radiation Monitoring Devices and Southern Methodist Univ.

Zn_3P_2

- Single Crystal & Thin Film p-type material by Vapor Transport ($L_n = 8\mu$)
- 6.3% Mg Schottky Barrier Cell on Single Crystal Zn_3P_2 ($V_{oc} = .5v$, $J_{sc} = 19.8\ ma/cm^2$)

Participants: University of Delaware (IEC)

Electrochemical Photovoltaic Cells — RFP

Released SERI — October 23, 1978

Proposals Due — December 7, 1978

Objective: R&D for 10% efficient electrochemical PV Cells.
Includes — Fabrication studies, Understanding of Transport Mechanisms, Identification of Parameters Limiting Cell Performance, Laboratory Demonstration, and Analytical modeling of Device/Material Characteristics.

Funding $2m **Multiple Awards**

Innovative Concepts Program—Outline

- Objective: Support Innovative Concepts, Processes, Materials
- Proposals: Reviewed 2 Times/Year - Technical Panel
- Funding: 1 Year, Renewable for 2nd Year
- Annual Funding Level: Approximately $75K Max.
- For: Universities, Small Businesses, Private Inventors, Others
- Selection Criteria: Does Not Violate Physical Principles
  : Applicable to PV Program Goals
  : Not Currently Funded

PHOTOVOLTAICS AND ENVIRONMENTAL IMPACT CONSIDERATIONS

NOVEMBER 8, 1978

BY

ERIC R. WEBER
PROJECT MANAGER
AIRPORT SOLAR PHOTOVOLTAIC CONCENTRATOR PROJECT

ARIZONA PUBLIC SERVICE COMPANY
PHOENIX, ARIZONA

N79-25496

PHOTOVOLTAICS AND ENVIRONMENTAL IMPACT CONSIDERATIONS

The detailed analysis performed, together with the description of the project, have been prepared tofacilitate the evaluation of Arizona Public Service Company's (APS) proposed Airport Solar Photovoltaic Concentrator Project (ASPCP) as specified in Section 102 of the National Environmental Policy Act (NEPA) of 1969, and in accordance with specified task of the APS/Motorola Government Electronics Division Joint Proposal to the Department of Energy (DOE) dated January 13, 1978. The scope of the evaluation follows the Council on Environmental Quality Guidelines on Preparation of Environmental Impact Statements. In addition, problems of electromagnetic interference, eye hazard and distractive glint were evaluated.

A report was prepared, after detailed investigations by the APS Environmental Management Department, Motorola Government Electronics Division, and various independent environmental consultants; and it reflects numerous discussions with various governmental agencies. It is intended to provide DOE with sufficient information to effectively carry out its responsibilities as Lead Agency for Environmental Review and Consideration under all applicable legislation and regulations including, but not limited to, NEPA (P.L. 91-190).

The overall proposed project consists essentially of three separate portions: The Solar Array Field, a 12.6 KV underground transmission line and a Load Switch Center located in the Sky Harbor Airport Terminal Module Number 3. Since the Airport Terminal has been previously addressed in the 1973 Final Environmental Impact Statement for Expansion at Sky Harbor International Airport; and because the entire length of transmission line will be buried in existing airport concrete tunnels, the report is limited strictly to the array field.

To analyze the environment affected and the potential environmental impacts to both the site and potential facility, the factors of geology, soils, biology, archaeology, land use/zoning, waste disposal, air, radio serivce interference and eye hazards were evaluated.

Conclusions and recommended actions are presented that pertain to the initiation of construction of the proposed 500 KW peak capacity solar photovoltaic concentrator system.

PURPOSE/DESCRIPTION OF PROJECT

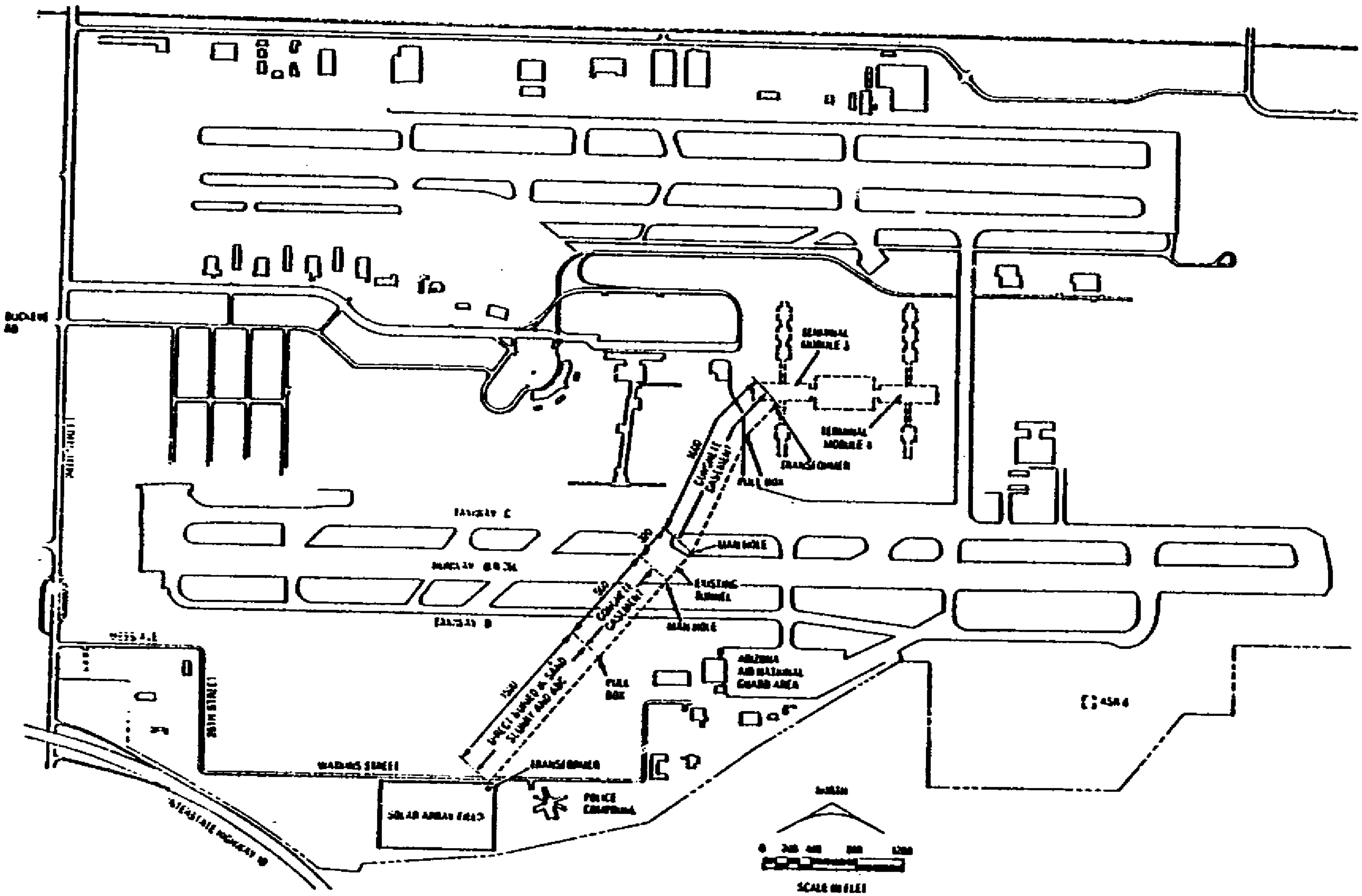
Arizona Public Service (Prime Contractor) and Motorola Government Electronics Division (Subcontractor)

- Design
- Construct
- Operate 500 KW peak capacity

  Airport Solar Photovoltaic Concentrator Project (ASPCP)

Objective

- Take a major and essential step toward reaching DOE goal of 2$ per watt



ASPCP Location Within Phoenix Sky Harbor International Airport Complex

ASPCP MAJOR SYSTEM ELEMENTS

OVERALL SYSTEM CONFIGURATION FIGURE 1

- FEEDER LINE FROM UTILITY GRID
- THREE-PHASE SOLID STATE SWITCH
- THREE-PHASE POWER INVERTER
- ARRAY FIELD - 59 ARRAYS
- ARRAY PARALLELING AND MONITORING PANEL
- MASTER CONTROL AND DATA ACQUISITION SYSTEM
- 12.6 KW UNDERGROUND TRANSMISSION LINE
- CONTROL AND FACILITIES BUILDING
- DISPATCH CONTROL THROUGH APS DISPATCH CENTER

MEINEL OPTICAL MODULE

- CASSEGRAIN TYPE OPTICAL CONCENTRATOR
- PEAK POWER OUTPUT 39 WATTS
- CONCENTRATION RATIO - 70
- SOLAR CELL EFFICIENCY - 14 PERCENT

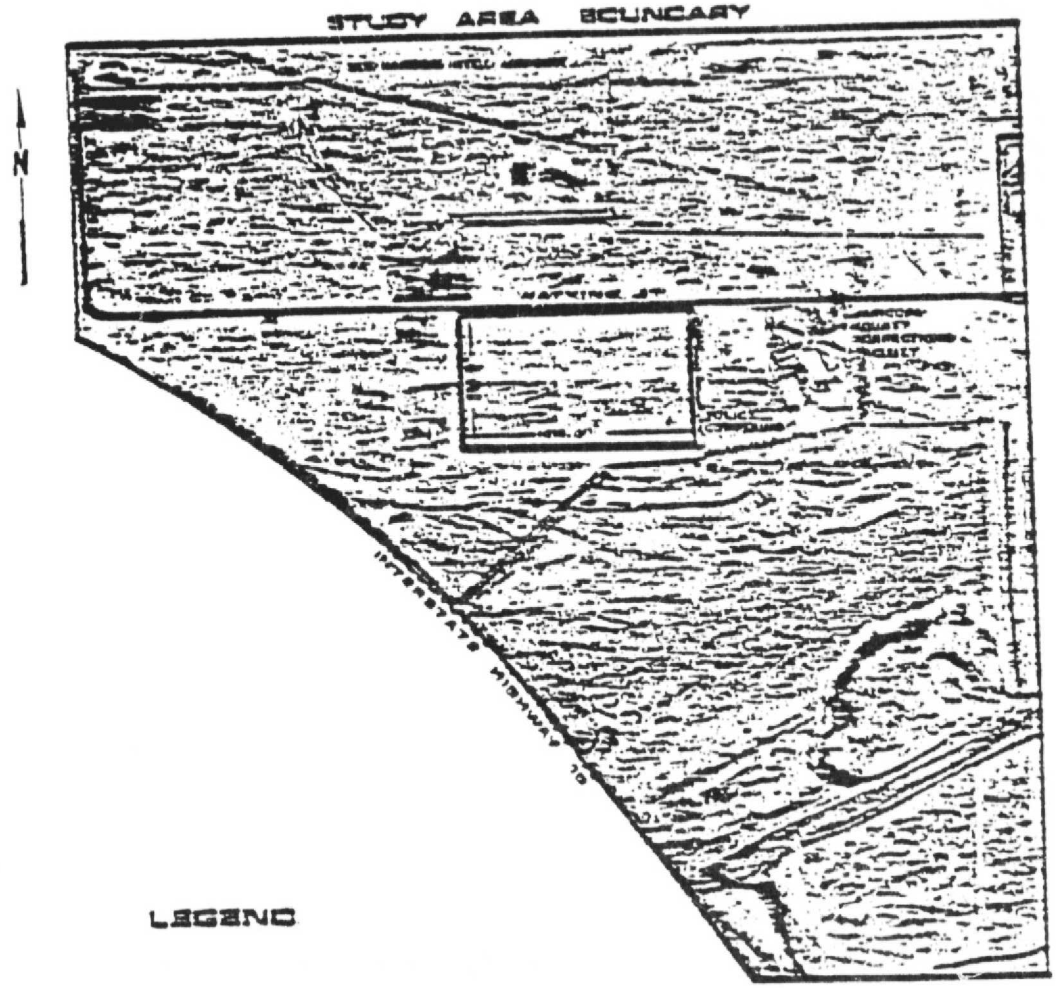
SITE AND STUDY DESCRIPTION

STUDY AREA AND SITE LOCATION

PLATE 1

AIRPORT
SOLAR PHOTOVOLTAIC CONCENTRATOR PROJECT

STUDY AREA & SITE LOCATION
1978



LEGEND

SOLAR ARRAY FIELD

SCALE IN FEET

PLATE 1

LAND USE STUDY

- EXISTING LAND USE
- INFRASTRUCTURE
- PROPOSED LAND USE
- EXISTING ZONING
- PROPOSED ZONING
- LAND OWNERSHIP

AIRPORT
SOLAR PHOTOVOLTAIC CONCENTRATOR PROJECT

EXISTING LAND USE
1978

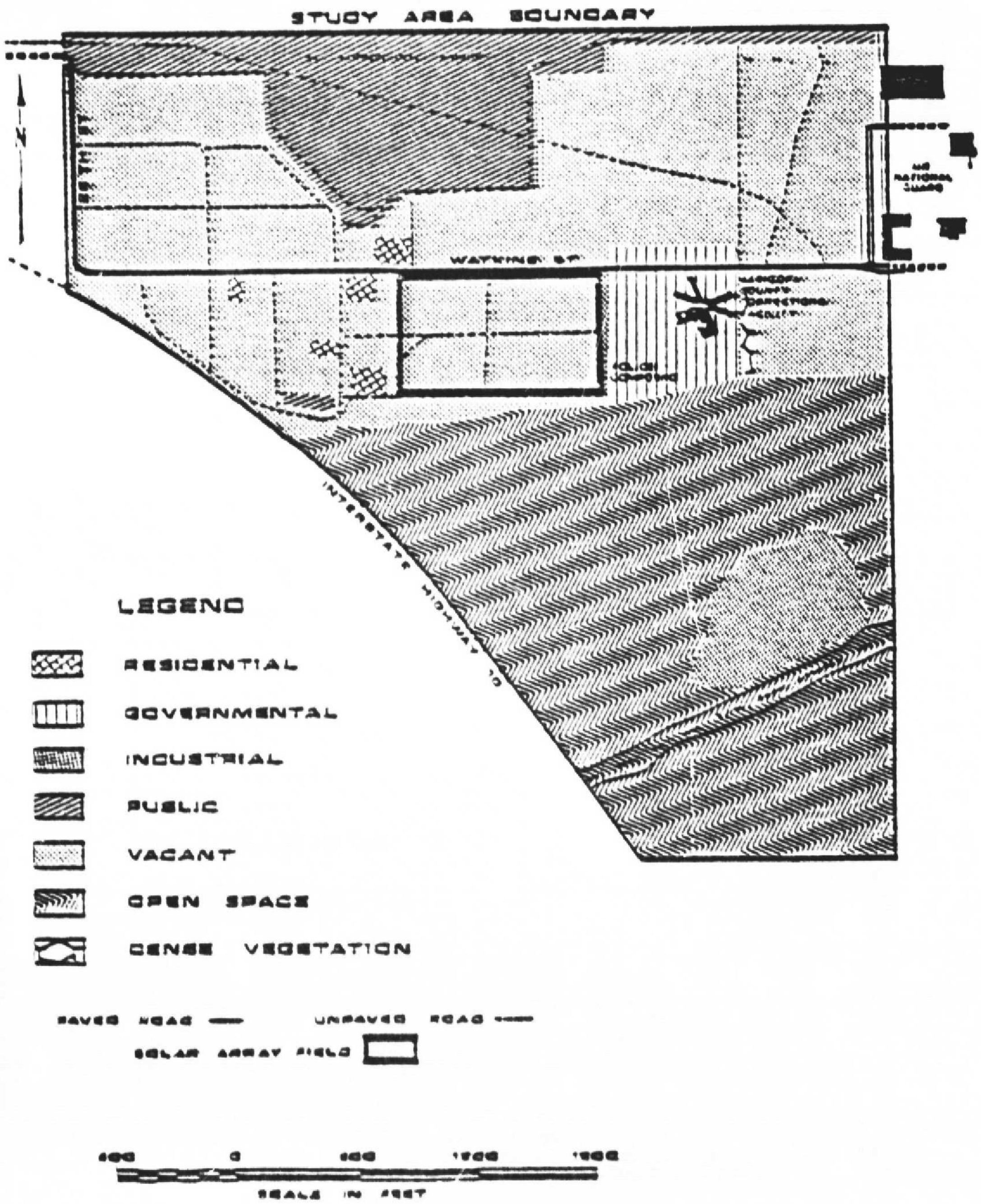
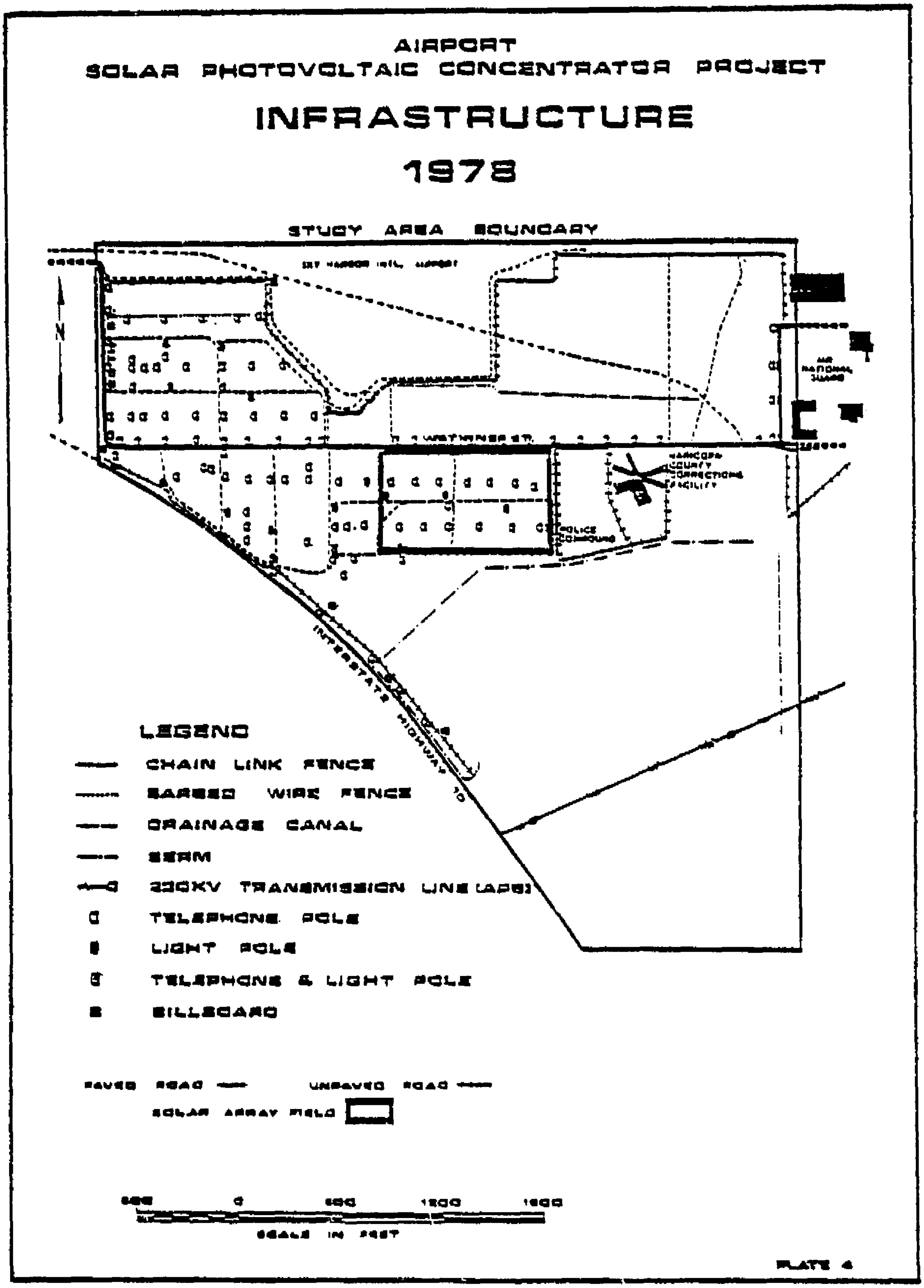
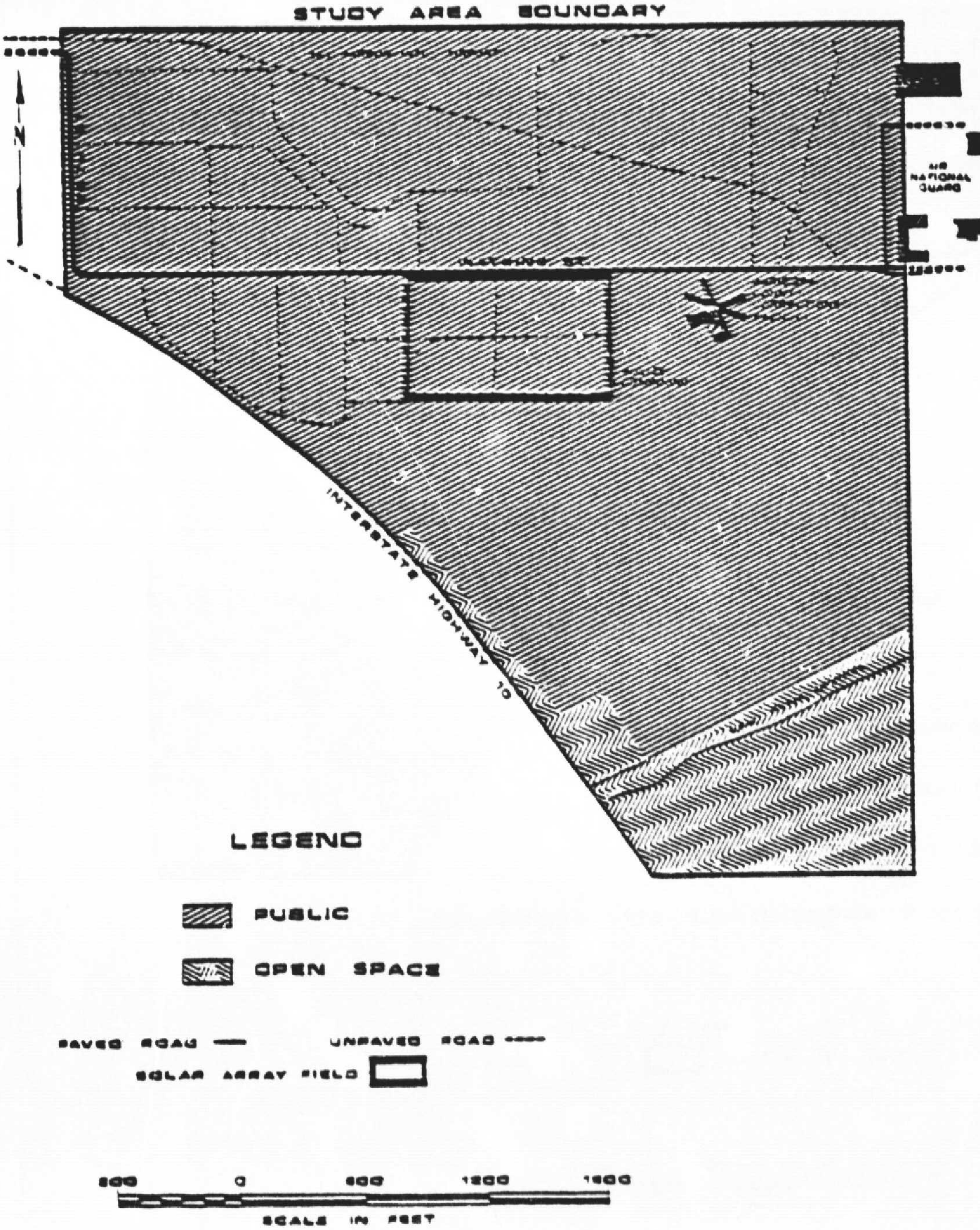


PLATE 3


AIRPORT
SOLAR PHOTOVOLTAIC CONCENTRATOR PROJECT
INFRASTRUCTURE
1978
STUDY AREA BOUNDARY
POLICE COMPOUND
INTERSTATE HIGHWAY 10
LEGEND
CHAIN LINK FENCE
BARBED WIRE FENCE
DRAINAGE CANAL
BERM
230KV TRANSMISSION LINE (APS)
TELEPHONE POLE
LIGHT POLE
TELEPHONE & LIGHT POLE
BILLBOARD
PAVED ROAD
UNPAVED ROAD
SOLAR ARRAY FIELD
SCALE IN FEET
PLATE 4

AIRPORT
SOLAR PHOTOVOLTAIC CONCENTRATOR PROJECT

PROPOSED LAND USE 1990



SOURCE: CITY OF PHOENIX PLANNING DEPT., 1990 LAND USE PLAN

PLATE 3

AIRPORT
SOLAR PHOTOVOLTAIC CONCENTRATOR PROJECT

EXISTING ZONING
1978

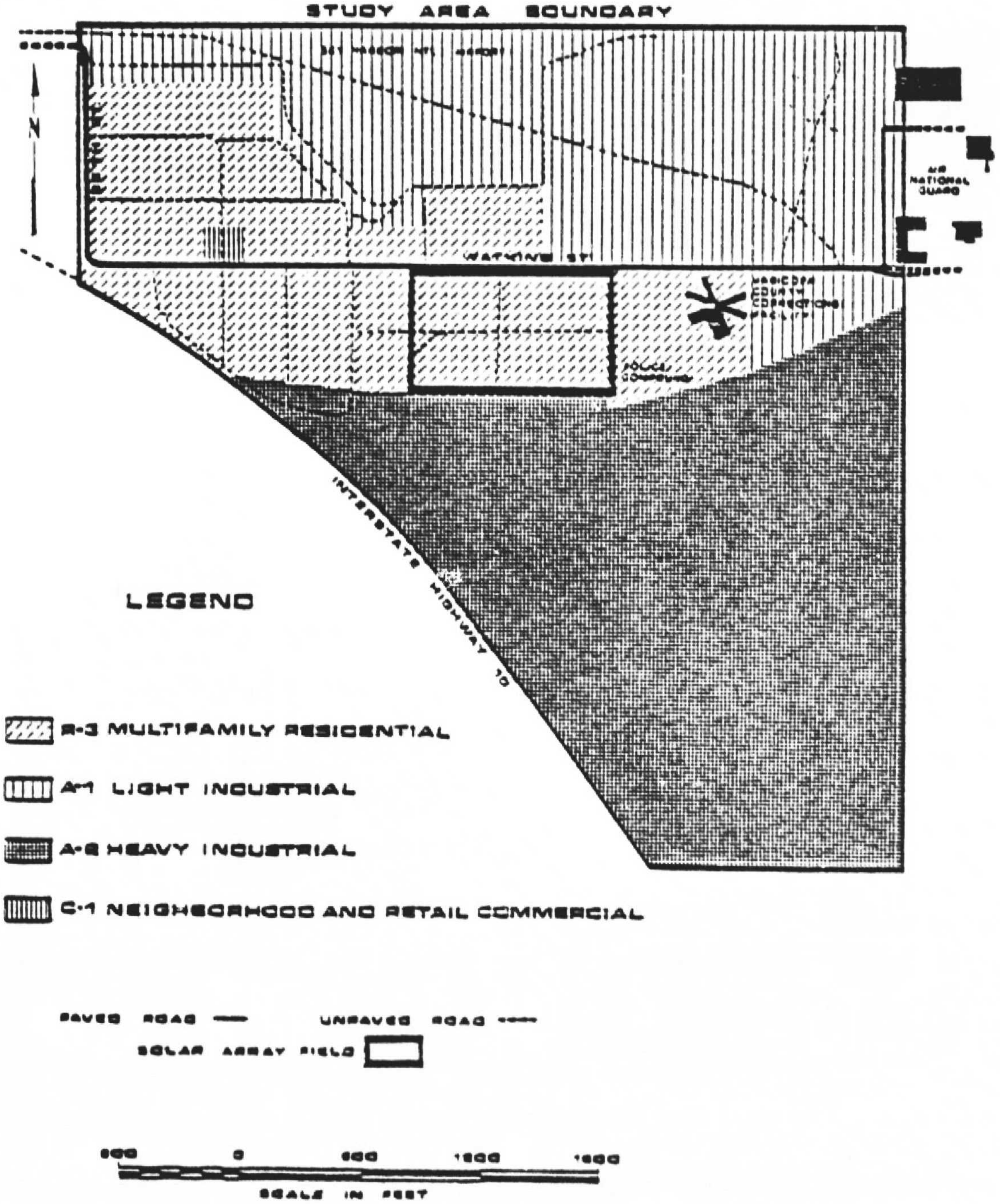
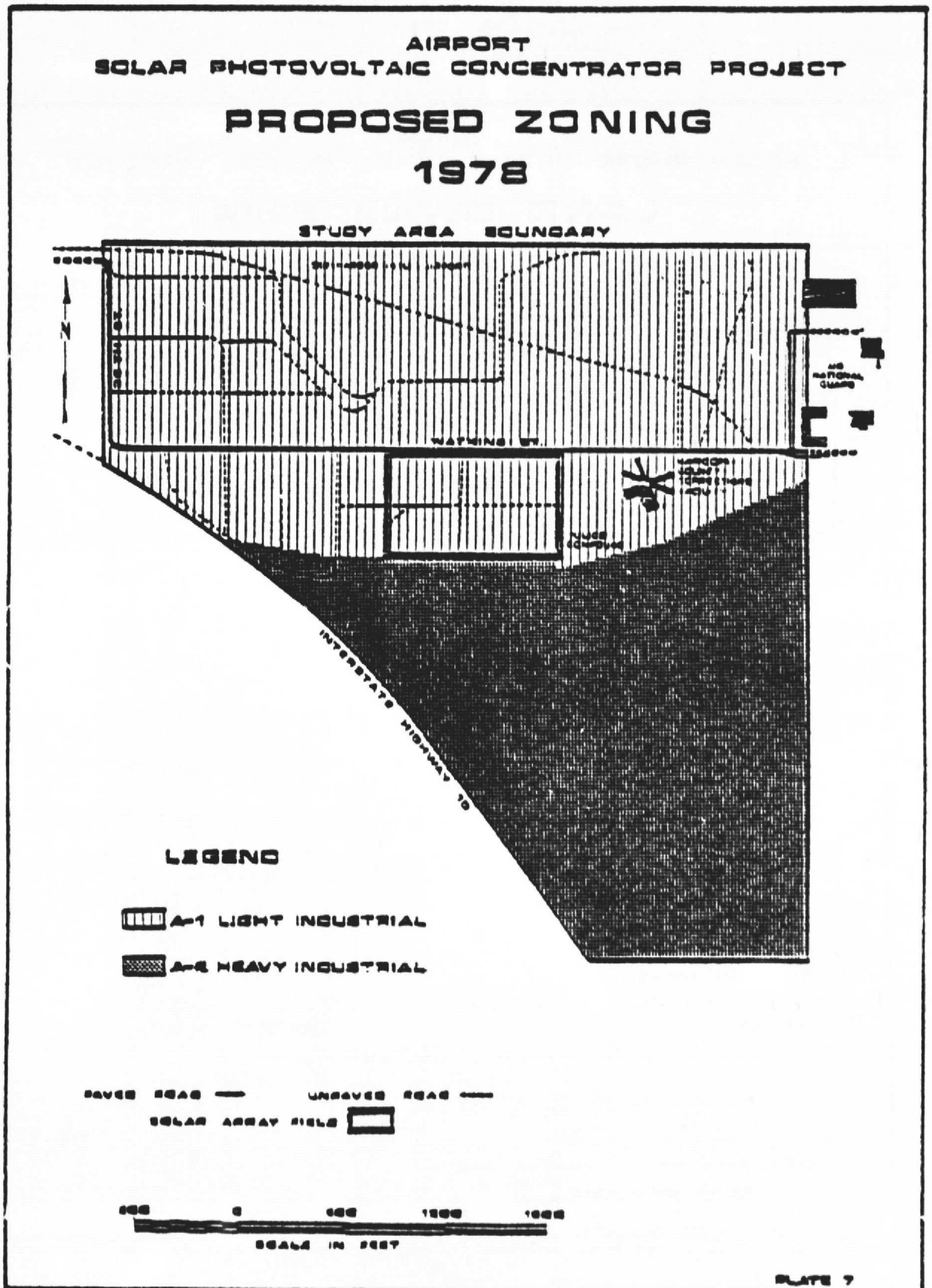


PLATE 6

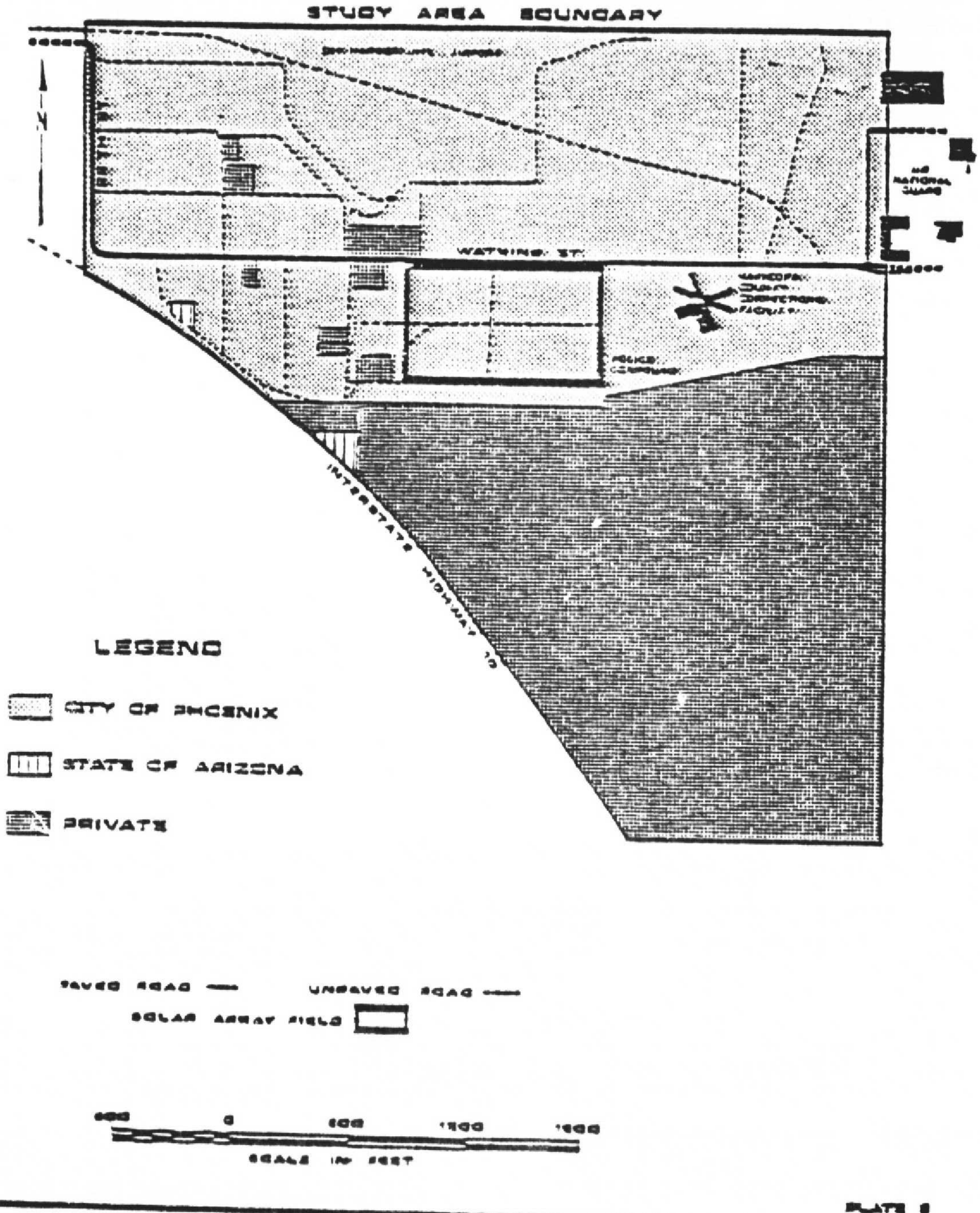

AIRPORT
SOLAR PHOTOVOLTAIC CONCENTRATOR PROJECT
PROPOSED ZONING
1978
STUDY AREA BOUNDARY
WATKINS ST.
INTERSTATE HIGHWAY 10
LEGEND
A-1 LIGHT INDUSTRIAL
A-2 HEAVY INDUSTRIAL
PAVED ROAD
UNPAVED ROAD
SOLAR ARRAY FIELD
SCALE IN FEET
PLATE 7

AIRPORT

SOLAR PHOTOVOLTAIC CONCENTRATOR PROJECT

LAND OWNERSHIP

1978



CULTURAL AND HISTORICAL STUDY

- PREVIOUSLY RECORDED SITES

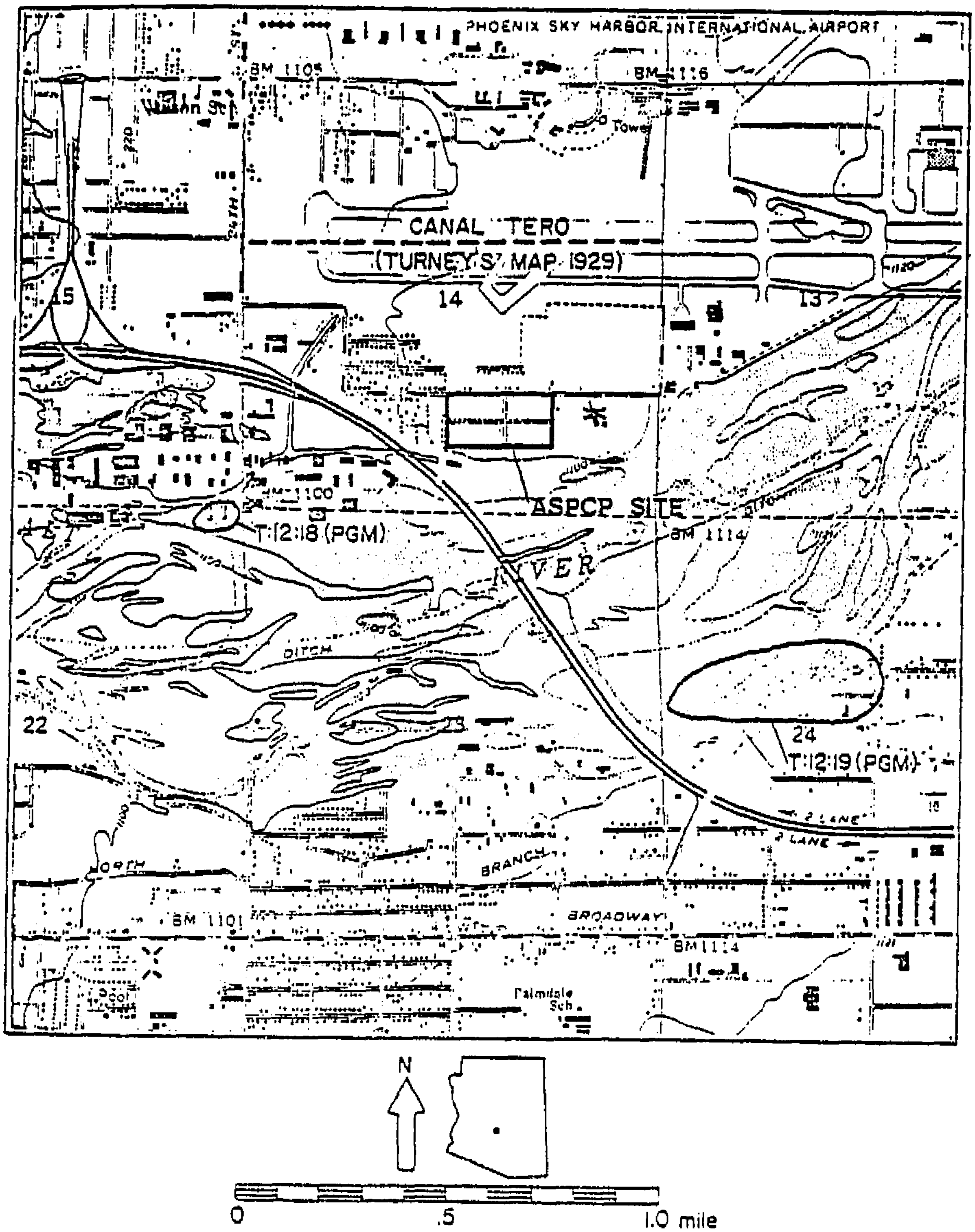


PLATE 9: Project area and vicinity with previously recorded sites.

GEOLOGICAL DESCRIPTION

- SONORAN DESERT REGION OF THE BASIN AND RANGE PROVINCE
- CHARACTERIZED BY NUMEROUS MOUNTAIN RANGES RISING ABOVE BROAD PLAINS OF VALLEYS OR BASINS
- GROUND WATER AND SUBSIDENCE
  - ASPCP CONSTRUCTION REDUCE RECHARGE POTENTIAL
- SUBSURFACE GEOLOGY
  - 0-48 M BELOW, MAJOR AQUIFIER IS QUATERNARY-AGE CHANNEL AND FLUID PLAIN ALLUVIAL SEDIMENTS
  - 48-231 M CRETACEONS AND TERTIARY INDURATED SEDIMENTS
  - NO FURTHER STUDY NECESSARY

EARTHQUAKE (SEISMIC) POTENTIAL STUDY

- PHOENIX NOT SUBJECTED TO GROUND MOTION OF MODIFIED MERCALLI INTENSITY 5 OR GREATER SINCE 1906
- NORTH CENTRAL PART OF STATE 5.0 TO 5.6 - THREE SHAKES
- SOUTHWESTERN CORNER OF STATE 5.0
- CONCLUSIONS
  - NOAA SEISMIC RISK MAY INDICATES MODERATE DAMAGE
  - ADEQUATE EARTHQUAKE ENGINEERING NOT TO BE OVERLOOKED

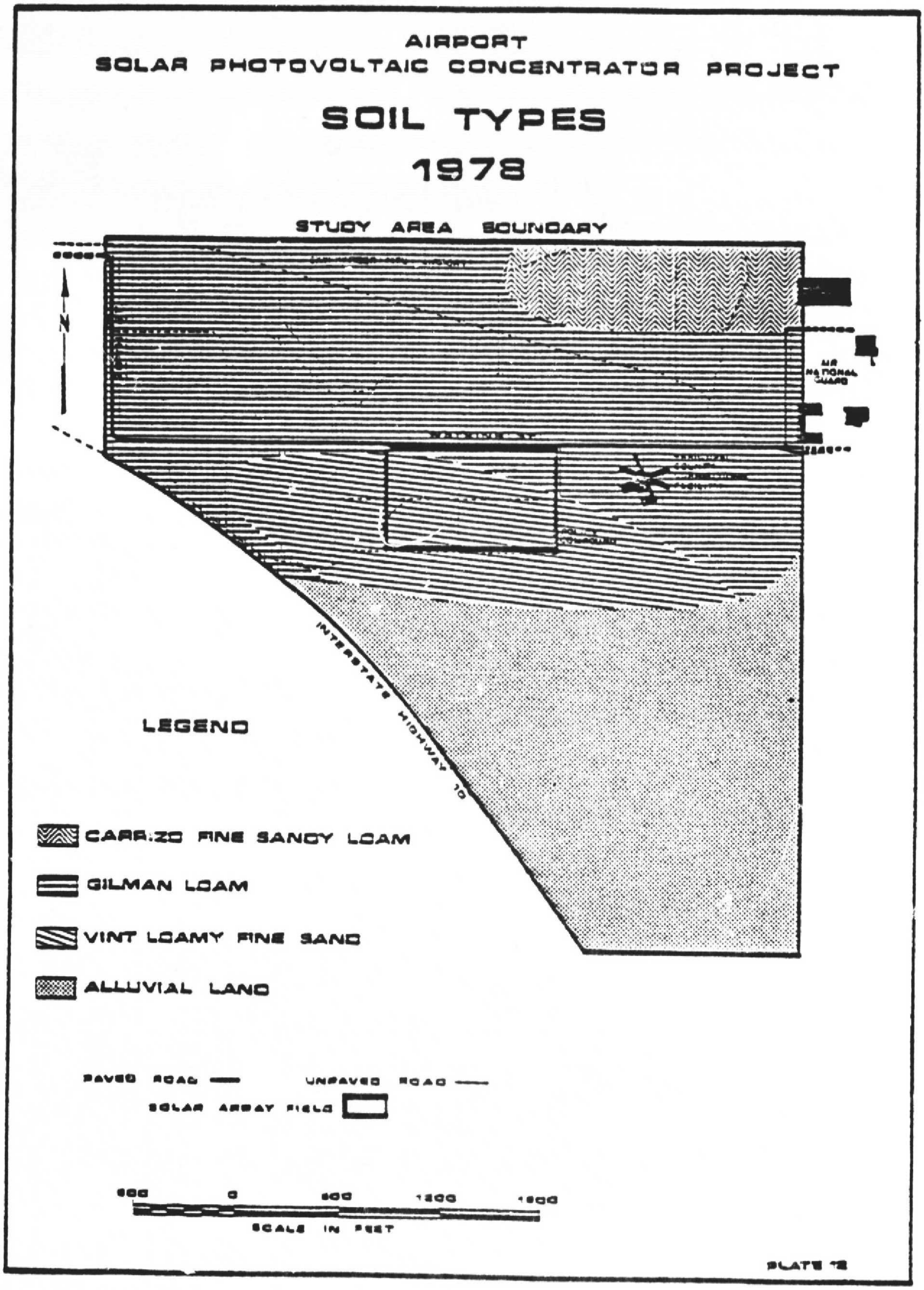
SOILS DESCRIPTION

- SOIL TYPES - TABLE 3
- RECOMMENDATIONS
  - TREAT BURIED CONCRETE OR STEEL SUPPORTS
  - STRENGTHEN SUBSURFACE SUPPORTS AGAINST EXPANSIVE CLAYS

TABLE 3

ASPCP SOIL TYPE	USDA TEXTURE	PERMEABILITY (IN/HR.)	SHRINK-SWELL POTENTIAL	CORROSIVITY TO UNTREATED STEEL
ALLUVIAL LAND	Variable	0.63-20.0	Low	Low
CARRIZO FINE SANDY LOAM	Very Gravelly Sand	>20.0	Low	Low
GILMAN LOAM*	Loam, Fine Sandy Loam	0.20-0.63	Moderate	Moderate
VINT FINE SANDY LOAM*	Loamy Fine Sand	2.0-6.3	Low	Low

*Indicates soil within construction zone.
(Data from U.S.D.A., S.C.S., AZ. AG. EX. STA., 1974)


AIRPORT
SOLAR PHOTOVOLTAIC CONCENTRATOR PROJECT
SOIL TYPES
1978
STUDY AREA BOUNDARY
N
INTERSTATE HIGHWAY 10
LEGEND
CARRIZO FINE SANDY LOAM
GILMAN LOAM
VINT LOAMY FINE SAND
ALLUVIAL LAND
PAVED ROAD
UNPAVED ROAD
SOLAR ARRAY FIELD
600 0 600 1200 1800
SCALE IN FEET
PLATE

FLOOD POTENTIAL STUDY

- Flood Boundaries 1978
- Recommendation
  - Change to 500 year flood plain
  - Increase height of existing levee

TABLE 3

ASPCP SOIL TYPE	EMBANKMENTS DIKES & LEVEES	SOIL BLOWING POTENTIAL	RUNOFF	EROSION POTENTIAL
ALLUVIAL LAND	High shear strength; high compacted permeability; low susceptability to piping, good compaction	Hazard	Slow	--
CARRIZO FINE SANDY LOAM	High shear strength; fair to good compaction; high compacted permeability; low compressability; medium to low susceptability to piping	Slight Hazard	Slow	Slight
GILMAN LOAM*	Medium to low shear strength; medium to low compacted permeability; medium compressability; high susceptability to piping, fair compaction	No Hazard	Slow	Slight
VINT FINE SANDY LOAM*	Medium shear strength; low to medium compressibility; low to medium compacted permeability; medium to high susceptability to piping; fair to good compaction	Slight Hazard	Very Slow	--

*Indicates soil within construction zone.
(Data from U.S.D.A., AZ. AG. EX. STA., 1974)

AIRPORT
SOLAR PHOTOVOLTAIC CONCENTRATOR PROJECT

FLOOD BOUNDARIES
1978

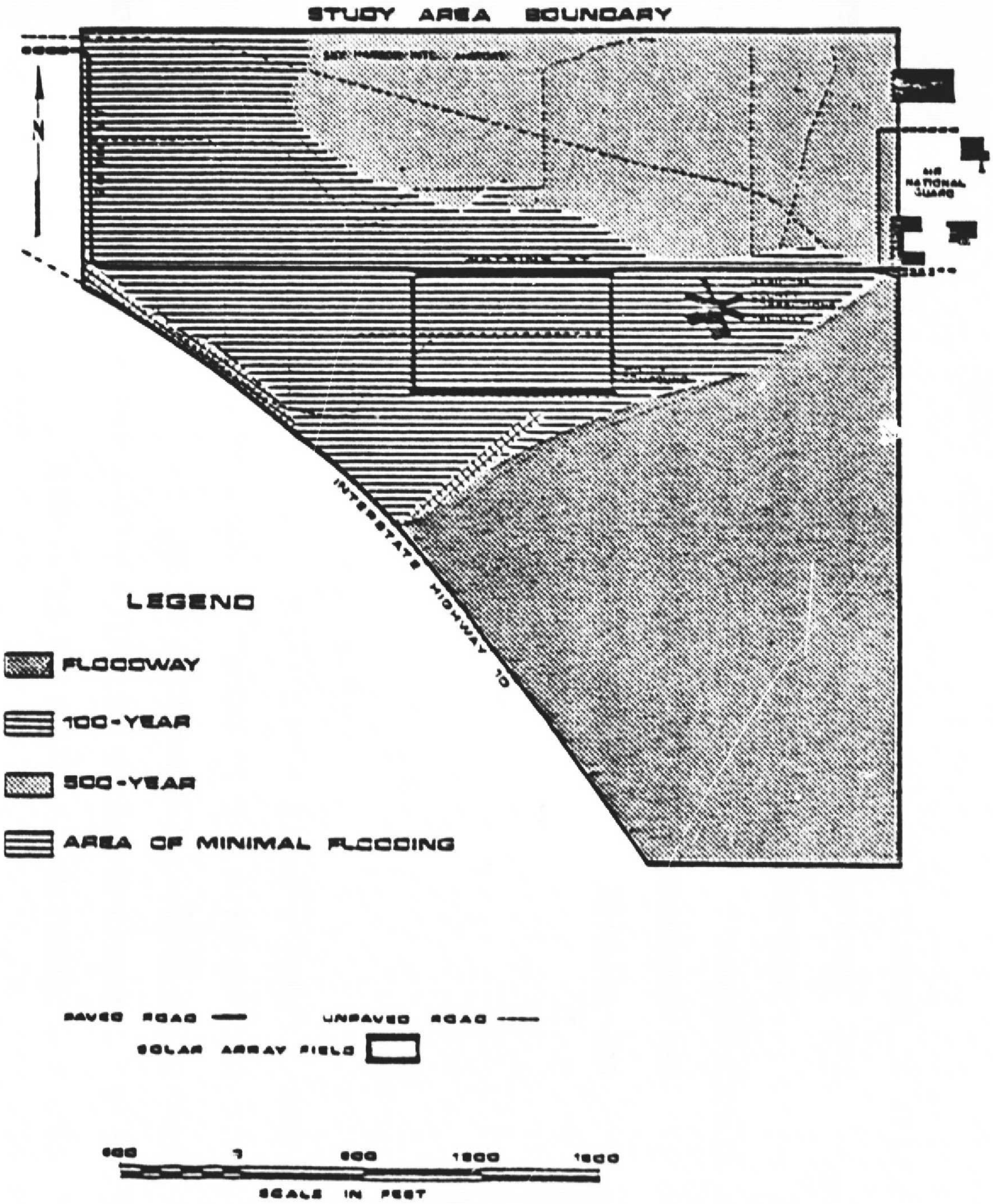


PLATE 13A

DRAINAGE STUDY

- CITY OF PHOENIX CITY CODE
  - "ON-SITE RETENTION OF STORM WATER REQUIRED ON ALL DEVELOPMENTS EXCEEDING 0.5 ACRES, UNLESS SITE SERVED BY STORM SEWER . . ."
- ACTION REQUIRED
  - DRAINAGE INTO SALT RIVER - NPDES PERMIT
  - HOLDING TANK TO MEET RETENTION TIME

BIOLOGICAL DESCRIPTION

- TABLE 4 PLANT SPECIES COMPOSITION
- SITE LOCATED WITHIN THE LOWER SONORAN LIFE-ZONE
- VERTEBRATE SPECIES COMPOSITION (TABLE 5)
- NO OFFICIALLY THREATENED OR ENDANGERED PLANT OR ANIMAL SPECIES RECORDED DURING RECONNAISSANCE STUDY OF SITE AREA

TABLE 4

PLANT SPECIES COMPOSITION

Scientific Name	Common Name
Amaranthus palmeri	Pig Weed
Atriplex polycarpa	Desert Salt Bush
Atriplex elegans	Wheel Scale
Bouteloua barbata	6 Weeks Gramma
Cercidium microphyllum	Green Palo Verde
Croton texensis	Dove Weed
Cuscuta sp.	Dodder
Cynodon dactylon	Burmuda Grass
Eriogonum deflexum	Wild Buckwheat
Helianthus annuus	Sun Flower
Hordeum sp.	Wild Barley
Lolium sp.	Annual Rye Grass
Portulaca coronata	Portulaca
Proboscidea parviflora	Devils Claw
Salsola iberica	Russian Thistle
Schismus sp.	(V. Common Annual Grass)
Tamarix cinesins	Salt Cedar
Tribulus terrestris	Goats Head
Heterotheca subaxillaris	Telegraph Plant
Machaeranthera linearis	Purple Aster
Tidestromia lanquinosa	Tidestromia
Verbesina enceliordes	Verbesina

TABLE 5

VERTEBRATE SPECIES COMPOSITION

Bird List

Scientific Name	Common Name
Buteo jamaicensis	Red-tailed Hawk
Lophortyx gambelii	Gambel's Quail
Centurus uropygialis	Gila Woodpecker
Dendrocopos scalaris	Ladder-backed Woodpecker
Auriparus flaviceps	Verdin
Campylorhynchus brunneicapillus	Cactus Wren
Salpinctes obsoletus	Rock Wren
Mimus polyglottos	Mockingbird
Toxostoma curvirostre	Curve-billed Thrasher
Polioptila melanura	Black-tailed Gnatcatcher
Regulus calendula	Ruby-crowned Kinglet
Phainopepla nitens	Phainopepla
Lanius ludovicianus	Loggerhead Shrike
Sturnus vulgaris	Starling
Richmondena cardinalis	Cardinal
Carpodacus mexicanus	House Finch
Amphispiza bilineata	Black-throated Sparrow
Zonotrichia leucophrys	White-crowned Sparrow
Zenaidura macroura	Mourning Dove

Mammal List

Scientific Name	Common Name
Dipodomys merriami	Merriam Kangaroo Rat
Canis latrans	Coyote
Sylvalagus audubonii	Desert Cottontail
Citellus sp.	Ground Squirrel
Onychomys torridus	Southern Grasshopper Mouse
Vulpes macrotis	Kit Fox
Lepus californicus	Blacktail Jackrabbit

AIR POLLUTION CONTROL

- Permit to be obtained from Maricopa County Air Pollution Control Advisory Council
    - oo For clearing, excavating and leveling
- Dust control through methods approved by Control Officer

EYE HAZARD EVALUATION

- ARRAY FIELD AS DESCRIBED
- POTENTIAL SUNLIGHT REFLECTIONS
  - FLUX INTENSITY LEVELS VS. DISTANCE
- EYE HAZARD WORST-CASE ANALYSIS
  - SUNLIGHT REFLECTED IN FRONT OF MODULE FROM PRIMARY OPTICAL SURFACE, ARRAY OFF-AXIS
  - REFLECTANCE IN FRONT OF MODULE FROM ILLUMINATED SOLAR CELL - ARRAY ON-AXIS
  - SUNLIGHT REFLECTED THROUGH TARGET AREA AND BEHIND MODULE, SOLAR CELL REMOVED, ARRAY ON-AXIS
- CONCLUSIONS
  - EYE HAZARDS CONFINED TO REGIONS NEAR THE OPTICAL MODULES
  - NO EYE HAZARDS TO AIRCRAFT PILOTS AND/OR AUTOMOBILES
  - SAFETY PROCEDURES FOR VISITORS AND OPERATIONS AND MAINTENANCE PERSONNEL

RADIO SERVICE INTERFERENCE

- Power inverter probable source of EMI
- Principle Radio Services at the Airport or in the Vicinity of the Airport (Table 1)
- Frequencies between 2000 to 8000 MHz
- Tracking motors - no probable source
- Control of EMI
  - Testing Program
  - Filtering Methods
- Radar Reflections from the solar collector
- Effect on Radar transponder operation

TABLE 6

PRINCIPLE RADIO SERVICES AT THE AIRPORT OR IN THE VICINITY OF THE AIRPORT

DESCRIPTION OF RADIO SERVICE	TYPE OF RADIATION	FREQUENCY (ALL IN MHz)	APP. DISTANCE FROM INV. BLDG. (IN FEET)
Communications; Aircraft to Tower and other Aircraft (Airborne Rec.)	cw (Voice FM Mod)	118-160	Variable Min = 1500
Communications; Tower to Aircraft	cw (Voice FM Mod)	118-160	4000
Airport Radar (ASR-8)	Pulse	2700-2900	5000
Airborne Rec: Glide Path and Localizer Beacon	cw	330	Variable Min = 1500
Airborne Rec: Marker Beacon	cw	75	Variable Min = 1500
Airborne Transponder:	Pulse	1030-1090	Variable Min = 1500
Television Broadcast	cw AM Mod	54-88 174-216 470-890	Variable Min = 2000
FM Broadcast	cw FM Mod	88-108	Variable Min = 1400
AM Broadcast	cw AM Mod	0.535-1.605	Variable Min = 1400
Citizens Band	cw (Voice FM Mod)	26.9-27.3 462-468	Variable Min = 1400
Radio Range Rec. Equipment (Airborne)	cw	0.326 0.281	Variable Min = 1500

EPRI PHOTOVOLTAICS PROGRAM OVERVIEW

Presented by

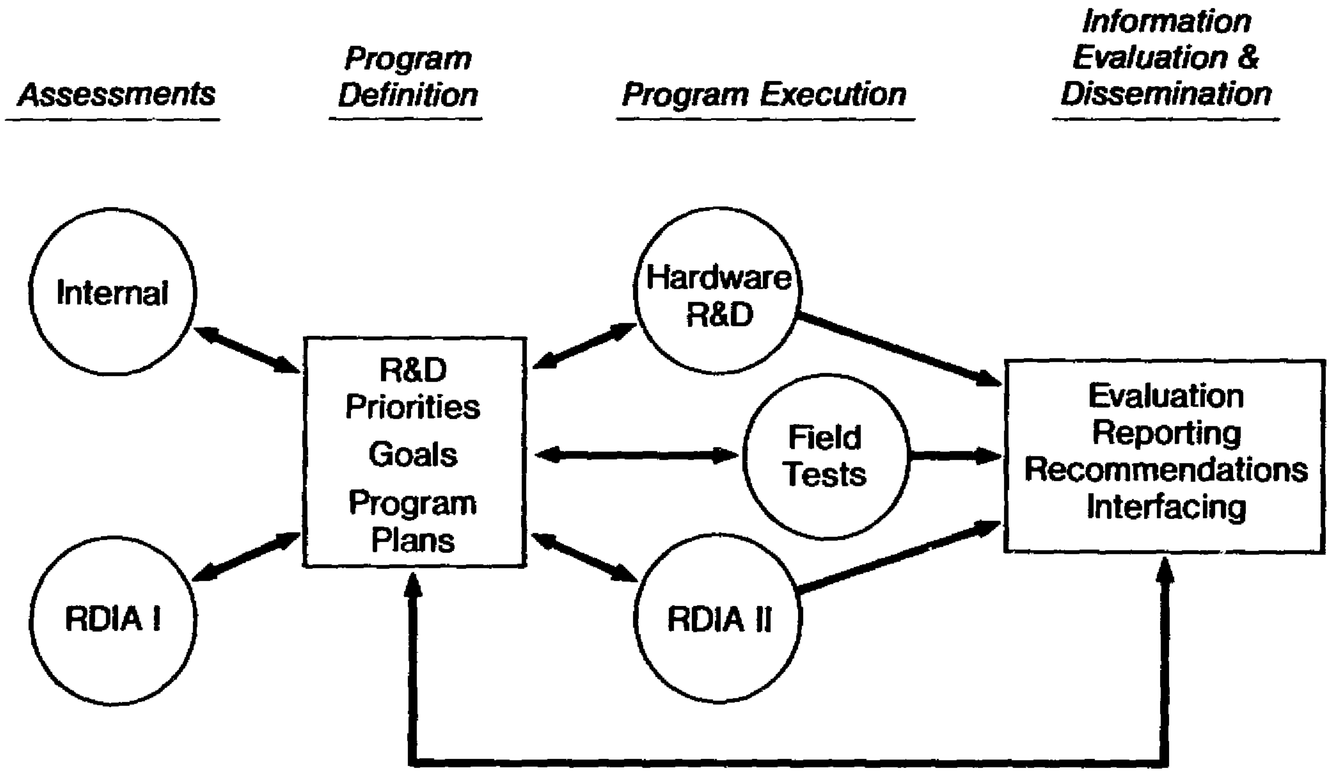
Edgar A. DeMeo
Solar Energy Program
ELECTRIC POWER RESEARCH INSTITUTE
Palo Alto, California 94303

Presented at the DOE Photovoltaics Technology Development and Applications Program Review

November 7 - 9, 1978

Arlington, Virginia

EPRI PHOTOVOLTAICS PROGRAM LOGIC



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EPRI PHOTOVOLTAIC PROGRAM
Requirements Definition & Impacts Analysis

- RP651: Requirements Assessment of PV Power Plants in Electric Utility Systems

  General Electric Co. $420K 2/76 – 6/78
  EPRI Report ER-685 June 1978

- RP1192: Assessment of Distributed PV Electric Power Systems

  JBF Scientific Corp. $537K 6/78 – 6/80

REQUIREMENTS DEFINITION & IMPACTS ANALYSIS
Objectives

METHODOLOGY DEVELOPMENT

VALUE ESTIMATES
- Capacity
- Energy

R&D RECOMMENDATIONS & GOALS

PENETRATION ESTIMATES

GOVERNMENT PROGRAMS INPUTS

REQUIREMENTS DEFINITION & IMPACTS ANALYSIS

Approach

UTILITY INDUSTRY EXPANSION PLANNING TOOLS

- Generation, Transmission, Distribution
- System Reliability (LOLP)
- System Operation Costs

TOTAL UTILITY SYSTEM REVENUE REQUIREMENTS

TOTAL COST OF ENERGY SUPPLY

- Utility
- Customer

RP651 REQUIREMENTS ASSESSMENT

KEY FINDINGS

- Established Planning Tools Adaptable to PV
- Capacity Value Without Storage
- Capacity & Energy Values Utility Specific
- Storage Best Operated Systemwide
- Fixed-Tilt Flat Plate Prospects Appear Best

RP1192 DISTRIBUTED PV ASSESSMENT

KEY ISSUES

- Scales of Application (generation & storage)
- Economy of Scale Impacts
- Safety
- Local Climatological Variations
- Construction Scheduling & Costs
- Market Distribution
- Institutional, Legal, Regulatory Issues

PHOTOVOLTAICS R&D PRIORITIES
Departures From Established PV Technology

LOW COST FLAT PANELS
- No Concentration
- $\geq$ 10%
- < \$20/m^2

VERY HIGH EFFICIENCY CONVERTERS
- Very High Concentration
- > 25%
- < \$10,000/m^2

Rationale: EPRI Report ER-589-SR

EPRI PHOTOVOLTAICS PROGRAM
PV Hardware R&D Activities

HIGH EFFICIENCY, HIGH CONCENTRATION

- RP790: Thermophotovoltaic Conversion With Silicon Cells
  Stanford University

  I: $175K 2/76 – 12/77
  II: $475K 1/78 – 12/79

  EPRI Reports ER-478 February 1977
  ER-633 February 1978

- RP1415: Thermophotovoltaic Conversion: Thermal & Optical Performance

  Contractor TBD 10/78 – 7/79

RP790 THERMOPHOTOVOLTAIC CONVERSION

TPV Device Performance

Basic Principle:	Spectral Compression
Project Objective:	Assess Achievable Cell Performance
Project Status:	26% Cell Efficiency (2/78)
Current Activity:	Cell Geometry Redesign
Immediate Goal:	35% Cell Efficiency (late 1979)

RP1415 THERMOPHOTOVOLTAIC CONVERSION
Thermal & Optical Performance

KEY ISSUES

- Thermal Losses in Confinement Chamber
- Degree of Concentration Required
- Optical Losses
- Materials Requirements

EPRI PHOTOVOLTAICS PROGRAM

PV Hardware R&D Activities

LOW COST THIN FILMS

- RP1193-1: Plasma Deposition of Silicon Films for Photovoltaic Devices

  Spire Corp. $170K 9/78 – 6/79

- RP1193-2: Thin Film Indium Phosphide Photovoltaic Devices

  Poly Solar, Inc. $135K 9/78 – 6/79

- RP1193: Phase 2 Contractor(s)TBD 6/79 – 12/80

RP1193 THIN FILM PHOTOVOLTAICS R&D

PLASMA DEPOSITION OF SILICON FILMS (RP1193-1)

- Large Grain Polycrystalline Film
- Reusable Substrate
- Low Fabrication Energy
- Abundant Raw Material

INDIUM PHOSPHIDE THIN FILMS (RP1193-2)

- Direct Bandgap: Low Material Requirement
- High Performance Single Crystal Precedent
- Transfer GaAs Thin Film Experience
- MOS and ITO Structures

CHARACTERISTICS OF A TYPICAL VILLAGE IN THE SOLAR BELT OF THE DEVELOPING COUNTRIES OF ASIA, AFRICA AND LATIN AMERICA

Dr. I. H. Usmani
United Nations

N79-25497

The Abstract from my paper on "ENERGY: A CRISIS OF TECHNOLOGY" highlights the points raised by me in the presentation at the Semi-annual Photovoltaic Review meeting convened by the United States Department of Energy (DOE) in Washington, D.C. on 8th November 1978.

. . . .

. . . .

Technology of Renewable Sources

It is unfortunate that in our race to develop compact and intensive sources of energy to sustain the infrastructure of the modern industrial Societies of the 20th Century, we have neglected to look into the potential that the universally available and renewable sources such as Solar energy, wind power and biomass, offer. To this list could be added sources which are of local significance but capable of generating enormous power like geothermal energy, ocean currents, waves and tides. Admittedly, there are many problems associated with the development of technologies of these sources but the science of materials has advanced to such a degree and modern techniques have developed to such a point that given adequate support, they can be harnessed to provide energy both at the micro as well as the macro level. The trouble is that during the last three decades our energy planners and decision makers made the mistake of placing all our eggs in the nuclear basket and relied on the continued supply of cheap oil. The events of October

1973 changed all that because it is only after then that they began to look seriously to new and alternative sources of energy. That Solar technology is not so complex or as distant as that of fusion is proved by the fact that a recent study in the United States by the President's Council of Environmental Quality (C.E.Q.) has shown, that Solar technology could meet up to 25% of the energy needs of the United States by the year 2000, which is the equivalent of nearly 10 million barrels of oil per day.[1/] A similar note of optimism has been sounded by a report commissioned by the Government of Canada[2/] according to which methanol produced from a hybrid feedstock of biomass (mainly forest wood) and natural gas available in Canada, could displace more than 200 million barrels of oil per year and compete in cost with oil when its price rises to $15-$20 per barrel.

On a micro level, the photovoltaic conversion of solar energy into electric power, the production of biogas (50% methane) from agricultural and animal wastes for cooking of food, generation of electric power and mechanical energy from windmills and tapping hydro power from the run-of-the river through mini-hydro turbines, provide technologies which already exist. What is needed is only a push to achieve competitiveness through mass-production and a broad-based research and development programme on lines similar to the research and development programmes launched to study the problems of nuclear energy in the 1950's. There is hardly any country in the world, which took to a nuclear programme and did not establish national centres, laboratories, and institutes for research exclusively on problems of nuclear energy on the model of Oakridge, Argonne and Brookhaven. Why can't such national laboratories be set up for Solar energy?

1/Solar Energy: Prospects and Promises; Council on Environmental Quality, Washington, D.C. (1978) Stock No. 041-011-0036-0.
2/Intergroup Consulting Economists Ltd. Winnipeg, Manitoba (May 1978)

Developing Countries

As far as the developing countries are concerned, they have two very distinct sectors: one is urban and the other is rural. Despite the fact that about 90% of the population of Africa, 75% of Asia and 55% of Latin America is rural in character, most of the development activities of the countries in these continents, are confined to the urban areas and their satellites. As such, their energy problems are very similar to those of the developed countries except that they are on a comparatively smaller scale. But the situation of the rural areas is totally different. Nearly 40% to 50% of the villages are small in size (50-100 families) and located in remote areas far removed from the national power grids and centres of economic activity. These villages embrace over a billion people - a population equal to the population of all the developed countries of the world combined - who subsist on primitive agriculture and live under sub-human conditions heavily polluted by the burden of eternal poverty. If there is anyone single factor that is responsible for this situation it is the "Energy Vacuum" in which the villagers of the Third World live. The only source they use is their own muscle energy and that of their animals. And this has an upper limit. Fortunately, there is a silver lining on the cloud. A vast majority of these villages happen to be located in what I call the "solar belt" of the world (30°N and 30°S of the equator) where the sun shines for more than 2,500 hours in a year and where agricultural and animal wastes are universally available, for aenorobic conversion into biogas (methane). In some locations, there is also a strong wind regime and micro-hydro power potential which can be tapped as additional sources of energy. As the basic energy needs of the small rural communities are modest and as the technology of harnessing the locally available renewable sources of energy (solar, wind, biogas, micro-hydro) already exists for production on a small-scale, the strategy for energy supplies for the rural areas of the Third World has to be based on the technology of harnessing these resources. Here I would like to point out that due to difficulties of obtaining spare parts, lubricants and lack of technical skills in the villages, the technologies to be introduced should as far as possible, be engineless. And these happen to be those of (a) aenorobic fermentation of biomass (agricultural and animal wastes) producing biogas (methane), (b) generation of electric power through Solar photovoltaic (P/V) cells and (c) the storage of power in a battery "bank" of lead acid accummulators. Biogas can be used as fuel for cooking to replace firewood and dung and panels of P/V cells can be used for rural electrification to meet all the other energy needs such as pumping of water for irrigation and running of small village industries which will add to the productivity of the village. Further, electric lights in the village could dispel that darkness which keeps the people illiterate and which perhaps contributes even to the population explosion! Some of my friends criticize this strategy and oppose the introduction of electricity into the village environment as "inappropriate" and costly. According to them Solar heat and biogas should be used for cooking, windmills should be used for pumping water and biogas should be used for lighting. I think such critics live in a world of their own and do great harm to the cause of development for the sake of retaining their fashionable identity as "appropriate" technologists. I have answered these critics in my paper published recently on the subject [1/] but here I would like to say that problems of social acceptability, etc. arise only when technologies are introduced on a family basis.

1/I.H. Usmani, Rural Electrification: An Alternative for the Third World; Nat.Res.Forum, April 1978.

C - 4

Rural Electrification

I envisage all electric power and biogas to be generated at what I call a "Rural Energy Centre" (R.E.C.) outside the village and supplies sent from the centre into each individual home so that instead of training every family in the art of maintaining a particular device, we train only a few local youngmen to maintain the biogas plants and the P/V panels, etc. at the R.E.C.. You will be pleased to know that three such centres are being established for purposes of demonstration: one in Srilanka (Asia), one in Senegal (Africa), and one in Mexico (Latin America) under the sponsorship of the United Nations Environment Programme (UNEP). Further, the critics do not realize that so far, there are no solar cookers which can be used at night and that even where the wind regime is good, the water well is generally in the heart of the village surrounded by structures and trees, etc. which prevent the wind from turning the blades of a windmill. Again the wind speeds may be very high on a hillock or in an open desert outside the village at the site of the R.E.C. and the water course (a canal, a stream or a river) may be far away from such a site. Under such circumstances, while the mechanical energy of the windmill if installed at the site cannot be transmitted to the water well or stream, the electric power generated by the windmill can be transmitted anywhere to operate an electric pump. In other words, windmills are effective as mechanical devices only when wind and water are at the same site. Even where such a situation prevails at let us say the individual farm, I think a farmer will be happier to have an electric pump plugged to the village grid fed by the R.E.C. rather than have a windmill of his own. In any case, if we had 100 windmills, 100 biogas plants and 100 P/V panels for 100 families, the village would become a monstrous sight leading to aesthetic pollution. I am convinced that no programme of rural development is complete or meaningful without rural electrification.

Unfortunately, the economists of the developing countries, who are trained in the Western schools of Harvard, London and Cambridge consider rural electrification to be un-economic and therefore, give it a very low priority in the national plans of the developing countries. They count everything in terms of money and the economic return on capital investment. To them investment in a project which aims at removing illiteracy or which attempts to improve the health and happiness of the people, is non-productive. They only chase the ghost of G.N.P. in their plans without attempting to quantify the social benefits that result from investment in such schemes as those of rural electrification. In my own country, Pakistan, results of planning by the Harvard and the London-trained economists have been disastrous. After more than 30 years of independence, Pakistan has an external debt liability of about $7.0 billion. More than 80% of the population of nearly 70 million people is totally illiterate. What is worse, the country despite the fertility of the Indus Valley, has a chronic shortage of food grains even though it used to be the granary of undivided British India. In the field of energy, despite all favourable indications of the existence of oil, and a large hydro power potential, Pakistan imports oil worth nearly $450 million per year which amounts to about 40% of the total annual earnings of foreign exchange from exports. I recall an occasion when these economists after working out the cost of local production of wheat found that it was more expensive than the cost of wheat imported from U.S.A. under the PL-480 programme, concluded that the cultivation of wheat in Pakistan was un-economic and should therefore be banned! I wonder whether they would commit suicide if free funerals were taking place! I think one of the great challenges before the economists is to find ways of quantifying the social benefits which could be incorporated into the G.N.P. if that continues to be the "Biblical" guide for our economists.

Reverting back to rural electrification, I have worked out certain figures in Tables A, B and C which speak for themselves. Table A, shows the characteristics of a typical village of a developing country located in th solar belt; Table B shows the estimated energy needs of a small rural community (100 families) living in such a village; and Table C shows the size of the biogas plant and of the P/V panels required to meet the energy needs of such a village. It will be seen from these Tables that a panel of P/V cells capable of generating 50 KW (peak) of power can meet all the power needs and that use of power for pumped irrigation can add a second crop of grains or vegetables or fruits to the gross domestic product giving additional income to the villagers. Similarly, power for industries could help in the creation of job opportunities and employment besides adding to the productivity of the village.

Breaking the Price Barrier of Photovoltaic (P/V) Cells

But the trouble is that because the total world production is less than 1 MW the present price of the P/V cells is exhorbitantly high - of the order of $10 per watt (peak). However, everyone agrees that with the build-up of demand and improvements in technology it will come down exponentially to about $0.5 per watt (peak) by 1986, when demand is expected to rise to about 500 MW per year.[1/] One of the ways to break the price "barrier" is to build up the demand by launching a vigorous programme of demonstration of P/V technology in about 300 villages in selected countries of Asia, Africa and Latin America and to offer to the industry a fixed-price/fixed-time contract of $3.0 per watt (peak) for the P/V system installed, spread over 5 years up to 1985. The $3.0 per watt (peak) price has been selected because it is

1/U.S. Dept. of Energy "Photovoltaic Programme" September 1977. See also Henry Kelly; Photovoltaic Systems: A tour through the alternatives, Energy II published by American Association for the Advancement of Science pages 151-152 (1978) the average break-even price of a diesel generating set of equivalent capacity in most of the developing countries where the price of oil is or likely to be 30-35 cents (U.S.) per litre. Such a contract would spur the contractor o work hard to bring down the price of the P/V cells system below the fixed contract price of $3.0 per watt (peak) because any price lower than the contract price will mean a profit to the contractor and any price above the contract will result in a loss. I have worked out the mechanics of such a fixed-price contract on the basis of certain assumptions which are given in Table D. The staggered installation of 15MW of the P/V system in 300 villages would result in a loss of $3.50 million in the first two years and a gain of $7.88 million in the last two years of the contract resulting in an overall gain of $4.38 million at the end of the contract. The figures are only illustrative of the approach but they clearly show that the future of the P/V cells in the developing countries is NOW! In the developed countries the P/V cells will not make a significant impact as a source of power unless they can generate thousands of megawatts of power at about $0.20 per watt for supply through the centralized grids. This may take 20 years or more leaving the P/V cells in the interim as a source of power only for remote areas and special applications.

Financing of Rural Electrification

In my paper on rural electrification[1/], I have pointed out that there is no dearth of money if only a concentrated international effort could be mounted to wipe out the darkness from the villages of the Third World through such a simple engineless device as the P/V cells. The developing countries have the money because their military expenditure has gone up to more than $30 billion per year[2/] and according to a World Bank study they are planning

1/Ibid, p. 276

2/Armament and Disarmament in the Nuclear Age. A handbook. Stockholm International Peace Research Institute (1976).

to spend no less than $10 billion on rural electrification in the next 10 years.[1/] Besides there are bilateral and multilateral aid funds available which can finance the program of rural electrification on a top priority basis as a part of those programmes which finance general rural development and such sectoral projects as the development of irrigation facilities, growing more food campaigns, etc.

There is yet another method of financing the rural electrification programme and that is to collect a small cess of 10 cents (U.S.) per barrel of oil imported by the oil-consuming developed countries of the world. I suggest this because statistics show that the big oil-importing countries already levy taxes on imported oil to raise revenues for their national budgets to finance social welfare and other programmes like building roads, hospitals and educational facilities. Figure 2 shows that the extent of these taxes in (Western) Europe was as much as $9.7 per barrel in 1976. It is thus obvious that an addition of just 10 cent per barrel to this figure will be too insignificant to be felt by the rich oil-importing countries. And yet, such a levy could yield as much as $2.5 billion per year on nearly 70 million barrels per day that on an average will continue to enter the import markets of the OECD countries up to the year 2000 if not beyond.[2/]

I believe that the successful demonstration of the P/V technology under the conditions actually prevailing in the developing countries of Asia, Africa and Latin America, is a pre-requisite to its large-scale application in the rural areas of such countries. As this technology is concentrated mostly in the United States, and as this country in its own self-interest should assist the developing countries in avoiding the fossil-fuel route

1/Rural Electrification: A World Bank Paper, (October 1975) p. 64
2/Report of the Workshop on Alternative Energy Strategies (WAES) Energy: Global Prospects 1985-2000, McGraw Hill Book Company, 1977.

for development, I urge the distinguished participants of this symposium to use their name and fame to influence the President of this great country to take the initiative of financing the demonstration of P/V technology in 300 selected villages of the poor countries which may cost about $10 million per year over a period of 5 years. This amounts to only 2% of the Solar research and development budget of the Department of Energy (D.O.E.), and is just peanuts compared to the overall foreign aid allocations authorized by the Congress every year.

From what I have said, Ladies and Gentlemen, it is clear that time has come to constitute an international organ under the auspices of the United Nations to keep the energy problems constantly under review and assist the developed and the developing countries in planning their strategies and national energy policies on the lines indicated by me. Such an organization could serve as a data bank in the field of energy, help in the dessimination of information, undertake the demonstration and transfer of new technologies, award research contracts to solve short and long-term problems and assist in the establishment of centres of research and development on a regional basis particularly in the developing countries. As I say this, I am painfully aware of the limitations if such an organization were purely an inter-governmental set-up. I believe as much in the dynamism of the private and public sectors in the energy field as in the importance of the contributions which members of the Academia can make to the solution of the energy problems. I would therefore like to suggest that the proposed organization should be a non-profit making International Energy Foundation with equal representation on its Board of Governors from the member-states of the United Nations, the Energy industry in the private and public sectors, and the members of the Academia belonging to centres of research and development in different regions of the world. The budget of this autonomous Foundation should be financed out of the small cess on imported oil, suggested by me. By such international action alone can the crisis of Technology be overcome and by such action alone can energy independence within the framework of inter-dependence, be translated into meaningful action without creating chaos and confusion. Thus, alone can international cooperation replace a possible international confrontation on energy issues.

Finally, let me conclude by stating that the poor of the world face death by starvation, the rich by nuclear annihilation. The poor suffer from lack of technology while rich have too much of it. The question is whether human wisdom can save them from converging to a common tragic end?

CHARACTERISTICS OF A TYPICAL VILLAGE IN THE "SOLAR BELT" OF THE DEVELOPING COUNTRIES OF ASIA, AFRICA AND LATIN AMERICA

A.

1. Population .... 500 persons
2. No. of homes/huts 100
3. No. cattle 250
4. Area cultivated (rain fed) .... 100 h.a.
5. Depth of the water well 25m
6. Average number of clear sunshine hours .... 2500 hrs/yr
7. Solar intensity (Hrs.) 800W/m²/h
8. Solar insolation .... 5.5 kwh/day
9. Conversion efficiency of Solar Photovoltaic (p/v) cells in array 10%
10. Generation of electricity from a 1KW peak panel of solar p/v cells .... 5.5 kwh(e)/day

B. VILLAGE REQUIREMENTS

1. Drinking water ... at 25 litres per person per day .... 12.5m^3/day

2. Drinking water (cattle) ..... 40 litres per day .... 10.0m^3/day

   TOTAL 22.5m^3/day

3. Irrigation water ... at 50m^3/day per h. a for 30h.a .... 1500m^3/day

4. Lighting for 100 homes having 3 fluorescent lights
   of 15W each all lighting for 5 hrs., 3 hrs. and 2 hrs.
   respectively, per night .... 15 kwh/night

5. Street lighting with 20 fluor. tubes of 25W each
   for 10 hrs/night .... 5 kwh/night

   TOTAL 20 kwh/night

6. Max. battery storage required for 3 nights at
   a stretch with 50% discharge of batteries .... 120 kwh.

C. BASIC ENERGY NEEDS OF THE VILLAGE:

1. Cooking of food at about 2 kwh(t) per person per day .... 1000 kwh(t)/day
2. Pumping of water for drinking .... $\frac{2.72 \times 22.5 m^3 \times 25 m \times 100}{50}$ = 3 kwh/day
3. Size of (p/v) panel for pumping drinking water .... $\frac{3 \text{ kwh}}{5.5}$ = .558 kw_p
   .600 kw_p
4. Pumping of water for irrigation of 30 h.a. at 50m^3/day from a depth of 25m .... $\frac{2.72 \times 1500 m^3 \times 25 m}{50} \times 100$ = 200 kwh/day
5. Size of (p/v) panel for pumping for irrigation .... $\frac{200 \text{ hw}}{5.5}$ = 36.36 kw_p
6. Lighting .... 20 kwh/night
7. Size of the p/v panel for lighting .... $\frac{20}{5.5}$ = 3.63 kw_p
8. Running the following:
   (a) 12 c. ft. refrigerator for storing drugs and medicines etc. .... 2.8 kwh/day
   (b) Color TV for educational programs on videotapes .... 1.2 kwh/day
   (c) Grain machines .... 15.0 kwh/day
   (d) Small village industries .... 29.5 kwh/day
   TOTAL 49.5 kwh/day
9. Size of the p/v panel for running items in 8 above .... $\frac{49.5}{5.5}$ = 9.0 kw_p
10. Total village needs (minus cooking) 49.59k
11. Size of the p/v panel for the village 49.54kwh

or say 50 kw_p

D. FINANCING OF RURAL ELECTRIFICATION DEMONSTRATION PROGRAMME IN 300 SMALL VILLAGES (500 PERSONS) LOCATED IN THE SOLAR BELT (2000 HRS/YEAR OF SUNSHINE) DEVELOPING COUNTRIES OF ASIA, AFRICA AND LATIN AMERICA

ASSUMPTIONS:
1. Size of the p/v panel for village .... 50 kw_p
2. Period of preparation and mobilization 1979-1981
3. Period of contract 1982-1985
4. Contract price $3/$w_p$ (installed) or $3 x 10^6/Mw_p
5. Doubling of production of p/v cells results in 25% reduction in cost

Year	No. of Villages	Capacity of p/v Panels	Expected Commercial Cost per W_p	Commercial Cost of Installation	Contract Cost of Installation	Loss (-) or Gain (+)
1982	20	1MW	$5.0	$5 x 10^6	$3 x 10^6	(-) $2 x 10^6
1983	40	2MW	$3.75	$7.50 x 10^6	$6 x 10^6	(-) $1.5 x 10^6
1984	80	4MW	$2.81	$11.24 x 10^6	$12 x 10^6	(+) $0.76 x 10^6
1985	160	8MW	$2.11	$16.88 x 10^6	$24 x 10^6	(+) $7.12 x 10^6

LOSS .... in 1982 & 1983 .... (-) $3.50 x 10^6
GAIN .... in 1984 & 1985 .... (+) $7.88 x 10^6
NET GAIN .... over the contract period .... (-) $4.38 x 10^6

SECTION II. TOPICAL SESSIONS

SESSION I

STANDARDS PERFORMANCE CRITERIA

Gary Nuss

SERI

MANUSCRIPT NOT AVAILABLE

PHOTOVOLTAIC PERFORMANCE CRITERIA

AND TEST STANDARDS PROJECT SUMMARY

PRESENTED AT THE DOE SAR
FOR PHOTOVOLTAICS
ARLINGTON, VIRGINIA
NOVEMBER 8, 1978

OMIT TO END

INTRODUCTION AND BACKGROUND

PRESENTED AT THE DOE SAR
FOR PHOTOVOLTAICS
ARLINGTON, VIRGINIA
NOVEMBER 8, 1978
GARY R. NUSS - SERI
GOLDEN, COLORADO

PURPOSE

The purpose in holding this workshop was to make the objectives, status, and plans of the Quality Assurance Element of the National Photovoltaic Program Plan open to public review and comment. Summarized here are the presentations made during the workshop, as well as the comments received during the workshop.

INTRODUCTION AND BACKGROUND

The National Photovoltaic Program is designed to expand the commercial use of photovoltaic systems as rapidly as possible through a program of research, process development, testing and applications. The quality assurance element within this program, which includes development of performance criteria and standards, as well as assisting, as appropriate, the development and implementation of laboratory accreditation and certification programs. SERI is coordinating and managing for DOE the project to develop these aspects of the Quality Assurance Program element. The project was begun in January of this year, and the key tasks and accomplishments for FY 78 were as follows:

First, we wanted to encourage industry participation, and instituted a Coordinating Council to provide focus and guidelines for the activities. The Coordinating Council consists of representatives from the photovoltaic community: industry, public interest, consensus standards organizations, government contractors, and independent testing laboratories. The Council provides internal review of project deliverables, review plans and results of supporting task groups, and assists in establishing priorities and requirements.

These requirements (the second and fourth tasks of 1978), were established through several meetings of the Coordinating Council and the Council's subcommittees which augmented the Council's expertise.

These activities have provided the basis for preparation of the plan to develop performance criteria and test methodology.

The plan will be published near the end of this year, and its key elements are the subject of the workshop.

The management structure of the project is graphically displayed in the next chart.

SCOPE

The broad scope of the project is aimed at the development and use of performance criteria and test methodologies which will contribute to the development and use of photovoltaic energy conversion systems.

OBJECTIVES

The broad objectives of the project are clear. They are:

- Support the development of a comprehensive body of standards for safety, performance and reliability for PV Solar Energy Conversion.
- Develop and implement accreditation criteria for test laboratories to test PV Solar Energy Conversion systems, subsystems, and components.
- Develop and implement certification procedures for PV Solar Energy Conversion systems.
- Develop and implement validation methodologies and mechanisms for review and monitoring of criteria and standards.
- Coordinate SERI project activities internally and externally with national and regional consensus standards and code organizations.

It is necessary to keep in mind that these are objectives of the national program. They should not be construed as being definitions of direct activities for governmental action. The project team will not write "standards". That task is the responsibility of the voluntary consensus community. The project team will provide information in a form which will be useful to that community, however.

Specific goals and objectives from FY 79 to FY 81 are articulated below. These broad objectives will be specifically articulated through four major tasks.

TASK # 1: PERFORMANCE CRITERIA & TEST DEVELOPMENT

This task is the development of performance criteria and test methodology. Key deliverables here are the Interim Performance Criteria document and the test methodologies to verify the criteria.

Again, these criteria and test methods are not standards. They are meant to provide a common basis for comparison of performance and a means by which systems and their parts can be characterized on a consistent basis.

We realize that the photovoltaics technology is still under development. The project team (and the Coordinating Council and the Subcommittees) are sensitive to the need not to create technology blocks through standards development.

The standards will be developed through the traditional institutional framework: the voluntary consensus system—this project will provide information and support to the voluntary consensus organizations.

The next figure presents the goals of Task #1.

TASK # 2 DEVELOPMENT OF LABORATORY ACCREDITATION AND PRODUCT/SYSTEM CERTIFICATION PROGRAMS FOR PHOTOVOLTAICS

In this task, the project team will develop information on testing requirements and on existing accreditation and certification programs. On the basis of this information on the experience gained from existing programs, guidelines will be published for the design and implementation of accreditation/certification program policies and procedures for photovoltaics. The expectation is that the design and implementation of these programs will be by independent third party organizations, with the project team assisting as appropriate.

The next figure presents the goals of Task #2.

TASK #3 THE VALIDATION OF TEST METHODOLOGIES

The validation task is extremely important, but it will begin later--when there is something to validate. Initial activities--on the part of the entire Photovoltaics Program--will be to develop and to coordinate data from field tests and applications and to review and adapt, as required, reliability analysis methodologies to photovoltaics data and applications.

The goal is to develop methods to judge the validity of the test methods adopted to measure photovoltaics performance. These questions will be asked: Are the test results meaningful? Are they predictive of system and component performance under real conditions? How should criteria and/or tests be altered to reflect field experience with data collected?

The next figure presents the goals of this task.

TASK # 4 COORDINATION OF PHOTOVOLTAICS QUALITY ASSURANCE PROGRAM WITH STANDARDS AND CODES ORGANIZATIONS

The final major task area is a continuing function throughout the project. The project team will continue to interact and to assist--again, as appropriate--with the voluntary consensus standards groups and to aid in the interpretation and application of standards and codes.

The next figure displays some important milestones. It is important to note at this time that the times are tentatively scheduled.

This, then, is the basic approach we are taking. In the topical session, various elements of the plan will be presented and discussed.

The agenda for the session follows. The initial items are intended to be brief and will place in context the activities to be undertaken by the Interim Performance Criteria task groups.

MAJOR TASKS FOR FY78

- ESTABLISHMENT OF A COORDINATING COUNCIL TO PROVIDE GUIDANCE AND PLANNING COUNSEL,

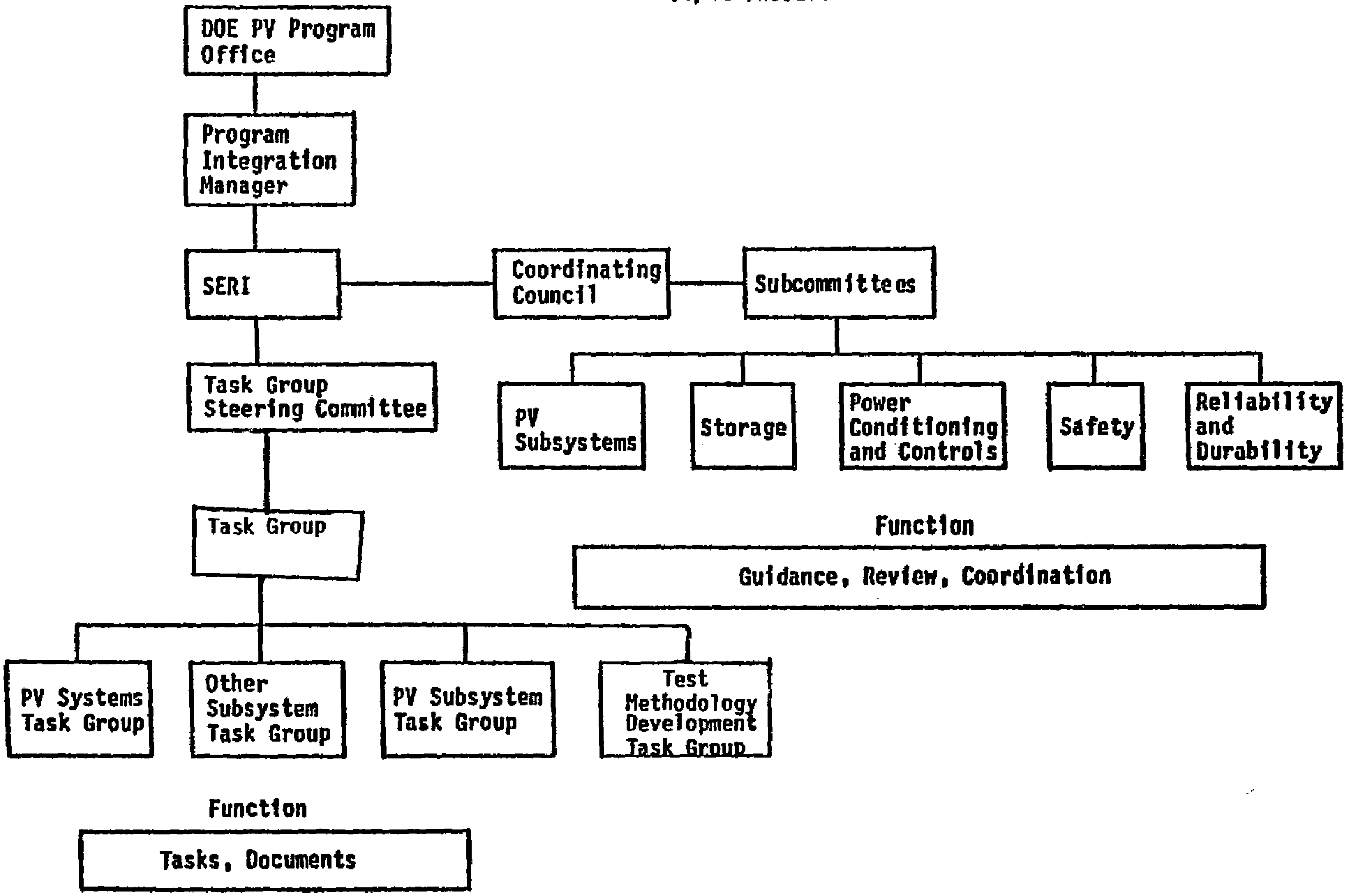
- PRELIMINARY REVIEW OF PERFORMANCE CRITERIA AND TEST STANDARDS DEVELOPMENT AND REQUIREMENTS,

- ESTABLISHMENT OF SUBCOMMITTEES TO ADDRESS PARTICULAR PV SUBSYSTEMS AND PERFORMANCE CRITERIA ISSUES,

- IDENTIFICATION, PRIORITY RANKING, AND ASSIGNMENT OF CRITERIA AND STANDARDS DEVELOPMENT PROJECTS,

- PREPARATION OF PERFORMANCE CRITERIA AND TEST STANDARDS DEVELOPMENT PLAN.

MANAGEMENT STRUCTURE PC/TS PROJECT



PHOTOVOLTAIC PERFORMANCE CRITERIA AND STANDARDS DEVELOPMENT

OVERALL OBJECTIVE:

TO STIMULATE THE DEVELOPMENT AND ADOPTION OF INDUSTRY ESTABLISHED PHOTOVOLTAIC MATERIAL, COMPONENT, SUBSYSTEM AND SYSTEM PERFORMANCE CRITERIA AND STANDARDS FOR THE DESIGN, APPLICATION AND OPERATION OF RELIABLE, SAFE AND QUALITY POWER SYSTEMS.

SPECIFIC GOALS:

FY 79:

- TO ASSIST IN THE DEVELOPMENT AND ADOPTION OF INTERIM PHOTOVOLTAIC PERFORMANCE CRITERIA AND TEST STANDARDS.
- TO ESTABLISH GUIDELINES FOR THE IDENTIFICATION AND ACCREDITATION OF QUALIFIED PHOTOVOLTAIC TESTING LABORTORIES.
- TO ESTABLISH GUIDELINES FOR DEVELOPMENT AND IMPLEMENTATION OF A PV CERTIFICATION PROGRAM.

FY 80:

- TO ASSIST IN INDUSTRY ADOPTION OF PHOTOVOLTAIC PERFORMANCE CRITERIA AND STANDARDS, AND TO ASSIST STANDARDS DEVELOPMENT IN THE CONSENSUS STANDARDS PROCESS.
- TO ASSIST IN THE DESIGN AND IMPLEMENTATION PLANNING OF ACCREDITATION AND CERTIFICATION PROGRAMS.
- TO PUBLISH AN INTERIM PERFORMANCE CRITERIA DOCUMENT.

FY 81:

- TO ASSIST IN INDUSTRY DEVELOPMENT, ADOPTION AND PROMULGATION OF PERFORMANCE CRITERIA, TEST METHODOLOGIES AND STANDARDS FOR PHOTOVOLTAICS.
- TO IMPLEMENT PROCEDURES FOR THE CERTIFICATION OF PHOTOVOLTAIC PRODUCTS AND SYSTEMS THROUGH AN INDEPENDENT AGENCY.
- TO ASSIST STATE AND LOCAL REGULATORY AGENCIES IN THE IMPLEMENTATION OF BUILDING CODE PROVISIONS FOR PHOTOVOLTAIC APPLICATIONS.

TASK 1

PERFORMANCE CRITERIA AND TEST DEVELOPMENT

- DEVELOPMENT OF PERFORMANCE CRITERIA
  - A. PREPARE AN INTERIM PERFORMANCE CRITERIA DOCUMENT
  - B. PUBLIC WORKSHOP FOR REVIEW AND COMMENTS
  - C. ANNUAL REVIEW AND UPDATE OF IPC
- DEVELOPMENT OF TEST METHODOLOGIES
  - A. DEVISE TEST MEASUREMENT METHODS
  - B. TEST METHODOLOGY EVALUATION BY INDEPENDENT TEST LABS
  - C. PREPARATION OF TEST STANDARDS
- LIAISON WITH CONSENSUS STANDARDS ORGANIZATIONS
  - A. TRANSFER OF DRAFT STANDARDS TO CONSENSUS STANDARDS GROUPS
  - B. SUPPORT FOR CONSENSUS STANDARDS ORGANIZATIONS TO ACCELERATE STANDARDS PROCESS

TASK 2

- DEVELOP ACCREDITATION CRITERIA AND PROCEDURES
  - A. IDENTIFY TEST LABORATORIES AND INVENTORY CAPABILITIES
  - B. REVIEW EXISTING/PLANNED ACCREDITATION PROGRAMS
  - C. PREPARE PRELIMINARY ACCREDITATION GUIDELINES
  - D. DESIGN AND IMPLEMENT ACCREDITATION PROGRAM
- DEVELOP CERTIFICATION CRITERIA AND PROCEDURES
  - A. REVIEW EXISTING/PLANNED CERTIFICATION PROGRAMS
  - B. PREPARE PRELIMINARY CERTIFICATION GUIDELINES
  - C. DESIGN AND IMPLEMENT CERTIFICATION PROGRAM
- INTEGRATE PV QUALITY ASSURANCE WITH CODE DEVELOPMENT ORGANIZATIONS
  - A. ESTABLISH LIAISON WITH MODEL CODE GROUPS
  - B. REVIEW SOLAR CODE DEVELOPMENTS FOR APPLICABILITY TO PV
  - C. PREPARE PV CODES, AS APPROPRIATE, THROUGH MODEL CODE ORGANIZATIONS

TASK 3

DEVELOPMENT OF VALIDATION METHODOLOGIES AND MECHANISMS

- FIELD TEST AND APPLICATIONS DATA ACQUISITION AND DATA ANALYSIS
  - A. COORDINATE MONITORING CAPABILITY AND SYSTEM FOR FTA WITH REGARD TO PV PERFORMANCE CRITERIA
  - B. ESTABLISH PC&S REQUIREMENTS FOR AND BEGIN COLLECTION OF DATA FROM FTA
  - C. REVIEW AND ESTABLISH METHODOLOGIES TO EVALUATE FTA DATA

- DEVELOPMENT OF METHODOLOGIES FOR RELIABILITY ANALYSIS
  - A. REVIEW EXISTING RELIABILITY ANALYSIS TECHNIQUES
  - B. SELECT AND TEST APPROPRIATE TECHNIQUES FOR PV USING FTA DATA

- VALIDATION OF TEST METHODOLOGIES
  - A. ESTABLISH PROCEDURE FOR VALIDATION OF PV TEST METHODLOGIES
  - B. ESTABLISH RELIABILITY ANALYSIS CAPABILITY

TASK 4

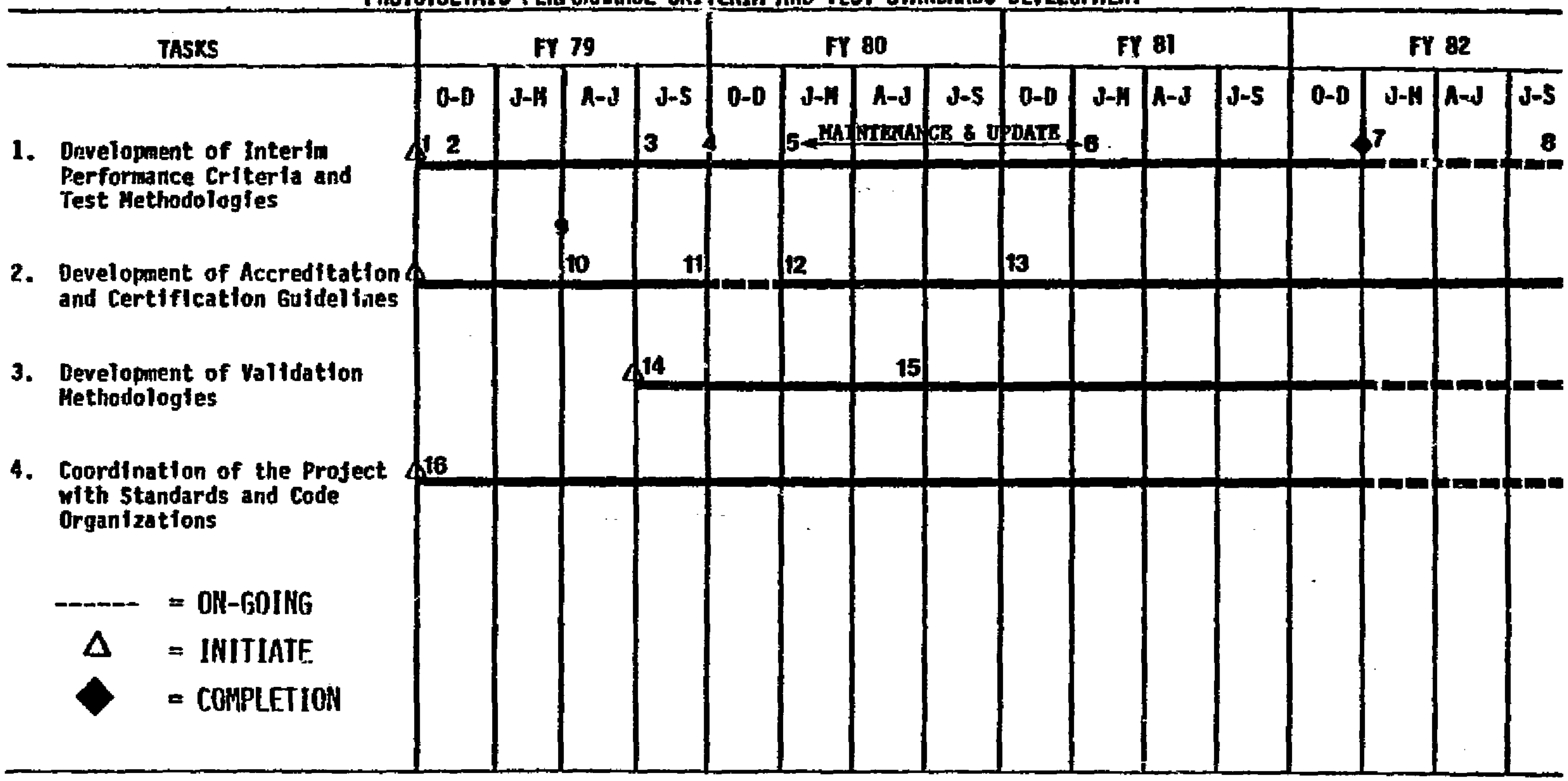
COORDINATION OF PV QUALITY ASSURANCE
WITH
STANDARDS AND CODE ORGANIZATIONS

- INTEGRATION OF PV QUALITY ASSURANCE WITH OTHER PV, STANDARDS, AND CODE ACTIVITIES

    A. COORDINATE AND SUPPORT PV PROGRAM CONTRIBUTIONS TO CONSENSUS STANDARDS GROUPS.

- MONITOR AND ASSIST IN THE INTERPRETATION AND APPLICATION OF DEVELOPED STANDARDS AND CODES

PHOTOVOLTAIC PERFORMANCE CRITERIA AND TEST STANDARDS DEVELOPMENT



MILESTONES (MAJOR)

1. Semi-Annual Review and public presentation of plan.
2. Task Groups organized & IPC initiated.
3. Initiate Round-Robin testing, if feasible, based on Task Group #4 recommendations.
4. Initiate IPC review process.
5. IPC Issued.
6. DPC (Definitive Performance Criteria) issued for review.
7. DPC revised and finalized.
8. Maintenance Mode.
9. Completion of Test Laboratory Inventory.
10. Status report on review of existing accreditation certification programs.
11. Final report on guidelines and recommendations for accreditation, certification of PV systems.
12. Prepare & initiate subcontract to design & plan implementation of accreditation / certification program.
13. Implementation of public sector accreditation & certification programs.
14. Initiate the development of data collection & evaluation of reliability methodology.
15. Evaluate test methods and IPC.
16. Initiate transfer of test methods to consensus standards community.

TOPICAL SESSION AGENDA

PERFORMANCE CRITERIA AND TEST STANDARDS (PC/TS) DEVELOPMENT

I. INTRODUCTION AND BACKGROUND -- THE ROLE OF THE PC/TS PROJECT IN THE NATIONAL PROGRAM.

II. ROLE AND PURPOSE OF STANDARDS IN NEW TECHNOLOGY DEVELOPMENT.

III. THE VOLUNTARY CONSENSUS STANDARDS SYSTEM -- AN OVERVIEW OF THE PROCESS, PARTICIPANTS, AND PROCEDURES.

IV. OBEJCTIVES AND FRAMEWORK OF THE PC/TS PROJECT.

V. PERFORMANCE CRITERIA DEVELOPMENT :

- A. PHOTOVOLTAIC SUBSYSTEMS
- B. POWER CONDITIONING, STORAGE SUBSYSTEMS
- C. SAFETY

THE PURPOSE AND ROLE OF PRODUCT STANDARDS IN THE COMMERCIALIZATION OF NEW ENERGY TECHNOLOGIES: A PRELIMINARY ANALYSIS

PRESENTED AT THE DOE SAR
FOR PHOTOVOLTAICS
ARLINGTON, VIRGINIA
NOVEMBER 8, 1978
DREW J. BOTTARO - MIT/EL
CAMBRIDGE, MASS.

PRODUCT STANDARDS AND COMMERCIALIZATION

The purpose of standards activities in the National Photovoltaics Program is to produce those socially beneficial effects, produced better by standards than by other alternatives. The need for standards arises from practical problems in the operation of markets.

Product standards provide one method for lubricating the market place and mitigating the costs of transactions. They benefit the market in one of two prinicipal ways; they provide information to those in the marketplace, whether they be buyers, sellers, or potential investors, or they represent agreements among those in the marketplace. Examples of agreements include those as to sizes, terminology, product grades, and minimum quality. Most standards contain elements of both benefits. For example, standards on lumber sizes (such as the dimensions of a 2x4) provide not only information on the product's size and quality but also represent an agreement as to what sizes will be produced (and hence bought and sold in the marketplace). Standards provide these twin benefits of information and agreement in a manner applicable to whole classes of transactions, thus saving the need in many circumstances for individual, i.e., contractual, agreement and information exchange between a particular buyer and a particular seller on many details of the transaction at hand. By substituting a single rule of general application for transaction-specific rules which, while individually less costly than a generally applicable rule, are most costly in the aggregate, standards produce their benefits to society.

Standards can have both positive and negative effects upon the industry to which they apply. These effects can be grouped into three basic categories: effects which affect the product's cost, effects which expand the demand for the product, and effects upon the competitive nature of the standardized product's industry. Each group of effects will be discussed below.

First, standards can affect the cost of the industry's product. "Unnecessary" grades or product lines can be eliminated, thus permitting greater economies of scale than would occur without standards. Interchangeability of parts can reduce the costs of assembling the product, can reduce the levels of inventory required to transact business, and can also reduce repair and maintenance costs arising during the product's use. Interchangeability may also result in increased technological competition, thus reducing unit costs. Standards may be a means of transmitting information regarding the technology. Some negative effects upon cost may also result. Emphasis of certain product attributes by the product standards might cause other product attributes to be overlooked or given inadequate attention. New designs may be judged by old standards, thus making radical design departures difficult.

Secondly, standards can, if properly designed, expand the demand for the industry's product. They can make the industry's product interchangeable with existing technology, thus allowing the new product to be substituted more readily for existing technology. For example, standardizing the screw threads for a new design of fluorescent bulb so that it fits incandescent bulb sockets will clearly make the new bulb more desirable. Information may be provided concerning the product and may facilitate comparison shopping with substitutes for the product; an increased ability to compare will help a new technology gain entry to established markets. The existence of a standardized product also tends to assure purchasers of a secure supply of the product as they are not forced to rely upon a single producer; this consideration is particularly important for intermediate goods which are purchased as inputs to the purchaser's manufacturing process. Consumer confidence in the product may rise with the existence of minimum quality standards for the product, thus increasing the product's demand. If improperly designed, however, standards can work against any of these effects and thus actually <u>reduce</u> demand for the product.

Third, standards can have effects upon the competitive nature of the standardized product's industry. While in some cases standards only reinforce the existing industrial behavior by making a competitive industry more competitive and an uncompetitive industry less so, they can also counter existing circumstances; they do not necessarily mirror market conditions. Standards can reduce product differentiation, thus making a market more competitive. Similarly, they may reduce the effects of branch names, thus lowering barriers to entry into the industry. If product standardization results in increased interchangeability of products, markets for the product will widen as sellers' capture of particular submarkets weakens; further lowering of barriers to entry may result. The effects are not all positive; the economies of scale derived from variety reduction and other effects of standards may result in raised barriers to entry. Furthermore, standardization by its very nature facilitates coordination among the suppliers of a product; such coordination might result in monopolistic activities such as price-fixing and could result in legal (anti-trust) problems.

In the commercialization context a governmental standards effort should be aimed to encourage standards which 1) are <u>desirable</u> but which 2) <u>would not be forthcoming</u> in a timely fashion or with the most desirable content if left solely to the private sector.

The role of standardization activities in a commercialization effort is defined by the market failures present in the new technology's industry and the suitability of standards as opposed to other options for attacking those market failures. Once that role is defined and the effects which the standardization activity aims to alleviate are made explicit, the types of standards to be developed may be selected by the types of effects they are likely to produce.

The specific strategy by which the selected types of standards are to be developed is defined by the traditional institutional framework: the voluntary consensus standards system. DOE must use that system to produce the effects it desires. The operation of that system, the incentives for its members' behavior, and the way the system is structured must enter into DOE plans for involvement

Planning efforts in the standards area must consider the role and the purpose of standards; must identify circumstances in which socially desirable standards activities would not arise from the private sector, identify which situations are most suitable for a solution of standards, and interact constructively with the voluntary standards system.

THE VOLUNTARY CONSENSUS STANDARDS SYSTEM AND THE PLAN FOR QUALITY ASSURANCE AND STANDARDS FOR PHOTOVOLTAICS

PRESENTED AT THE DOE SAR
FOR PHOTOVOLTAICS
ARLINGTON, VIRGINIA
NOVEMBER 8, 1978
JULIA D. RILEY - SERI
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THE VOLUNTARY CONSENSUS STANDARDS SYSTEMS AND THE PLAN FOR QUALITY ASSURANCE AND STANDARDS FOR PHOTOVOLTAICS

The voluntary consensus standards system is the traditional institutional framework used in this country to develop standards, that is definitions, classifications, specifications, methods of test, and recommended practices. Standards provide a common language between all members of a concerned technology community, and are developed, through the operation of due process, by all members of a concerned technology community.

Due process, as used in the voluntary consensus system, is the application of the principle that all who have an interest in a standards should have a voice in its development. In each voluntary standards organization, a balance of interests is maintained through rigid membership voting procedures. The right of minority dissent is protected through a review procedure.

Standards are to be written by all members of a concerned technology community. That includes manufacturers, users/consumers, general interest and public interest groups, members of regulatory agencies at all levels of government, labor unions, and academicians. The application of due process in this procedure includes: notice of proposed standards development to all persons likely to be affected, opportunity for wide participation of interested parties in meetings, adequate maintenance and distribution of meeting records, timely reports on ballots, and attention to minority opinions.

Standards-writing organizations have well established procedures for their operation. This long-range plan anticipates the transfer of test methodology and performance criteria to the voluntary consensus system.

The oversight function for the voluntary consensus system is maintained by the American National Standards Institute (ANSI). ANSI's membership is comprised of over 400 organizations in the United States, some of whom write standards. Although ANSI does not write standards, it approves the procedures of standards-writing organizations so that American National Standards can be drafted, written, and promulgated.

ANSI operates through technical committees, each of which organizes and manages standards-development through its organizational members. The ANSI Solar Standards Steering Committee will consider at its next meeting, later this month, whether to expand its scope to include photovoltaics. This committee has, to date, concentrated on standards for SHACOB and Solar Hot Water exclusively.

The American Society for Testing and Materials (ASTM), an organizational member of ANSI, organized ASTM E-44 on Solar Energy Conversion in Philadelphia in June of this year. ASTM E-44.09 on Photovoltaics, organized at the same time, has as its charge, the development of draft standards for photovoltaics through the voluntary consensus system. It is through this subcommittee that elements of the Interim Performance Criteria (IPC) Document are to be transferred. Those elements will then be subject to development in the voluntary consensus system. This subcommittee is presently concentrating on three draft standards for:

- cell performance measurement procedure
- cell solar simulation, and
- a reference cell.

It is useful at this time to discuss how the system works. The flow of responsibility goes up and down the organization chart of a standards-writing committee.

The main committee provides overall direction, the subcommittee receives that direction, and translates it into specific assignments for task groups. The task groups write a draft, and submit it to the subcommittee. The subcommittee ballots members for approval, and upon acceptance by a clear majority, with due consideration to opinions expressed as negatives or affirmatives with comments, the subcommittee submits the ballot to the main committee. The main committee in turn, ballots its members. Pending approval by a clear majority (actual percentage of affirmatives, and abstentions required vary from organization to organization) and due consideration to negatives and comments, the society itself is balloted for its approval. From there, the standard goes to ANSI for approval as an American National Standard. Procedures call for periodic review to keep the standard current with technological advances.

The Institute for Electrical and Electronics Engineers (IEEE), an organizational member of ANSI, has a standards interest in photovoltaics. Although no specific IEEE committee addresses photovoltaics, various technical committees do deal with aspects of photovoltaics systems, specifically those with scopes that address storage, power conditioning and control, and cabling.

The voluntary consensus system is effective at its business of writing standards. The system, however, is time-consuming, as it is a difficult process to achieve both technical excellence and consensus.

Standards are implemented in a number of ways, both voluntary and those ways that are mandatory. Of particular interest ar two: building code provisions and product/system certification.

Building code provisions will need to be written or modified to accommodate photovoltaics when residential applications enter the market. A building code inspector needs a reference or a source to consult so that he or she may approve a system or device for its health and safety characteristics. Standards are the source of those provisions. It is important to note here that building code officials have in their scope of work the enforcement of police power of the state; that is, the protection of the health, safety, and welfare of the citizenry. Performance aspects, except as related to safety, are not of their concern.

Product/system certification serves the building code inspector's need for a reference, and it also serves to assure a means of communication between the manufacturer and the user. This certification is done by means of testing by a referenced standard, usually an American National Standard, a product or system. This certification is done by neither a manufacturer or vendor, but a sponsor or validator who affixes a label or mark to attest to the certification. The actual testing is done by accredited third-party independent laboratories. Certification addresses, but is not exclusively limited to, the measurement of performance, or reliability and durability characteristics, as well as safety.

Because of the widespread interest in SHACOB, and particular concerns expressed by industry, government, and public interest groups, a number of certification programs on the state and national level, some voluntary, and some mandatory, have emerged. These programs emerged to fill a specific need at a specific time, and sometimes have conflicting requirements.

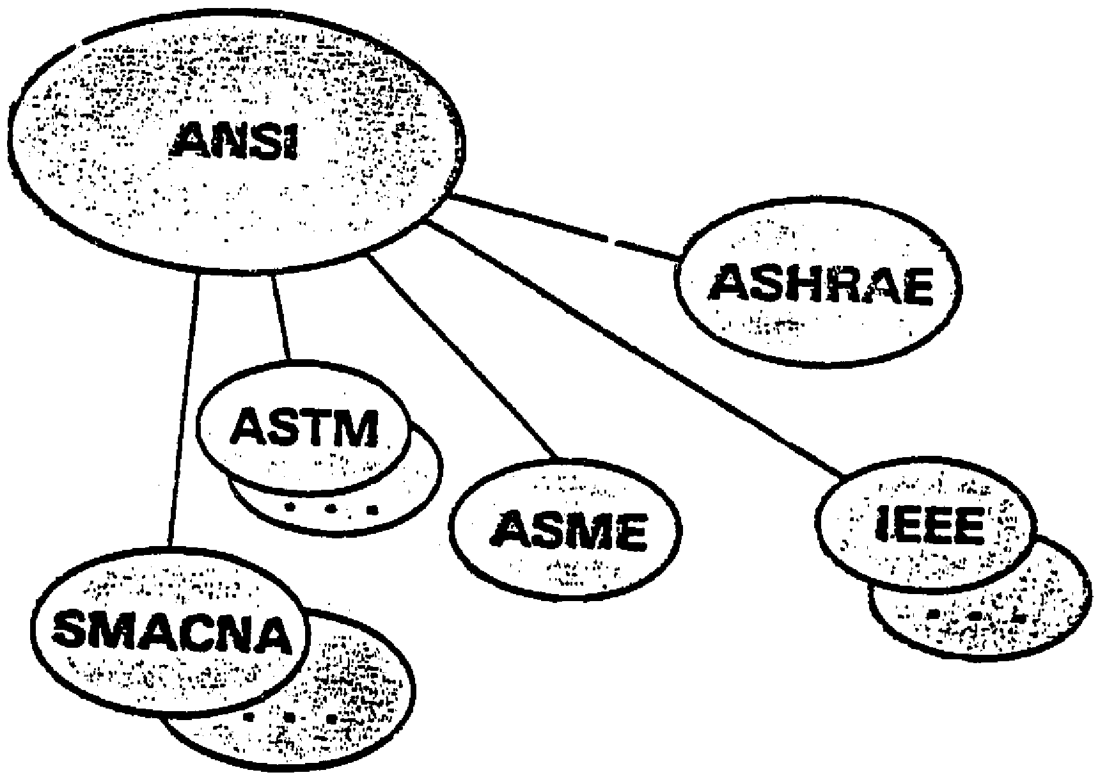
It is anticipated that for the photovoltaics technology, with careful planning while PV's are still in the initial commercialization stages, that plans can be developed so that there will be a consistent set of standards to be used as a consistent set of requirements for use in laboratory accreditation and certification programs. The development of those programs necessarily hinge on the development of standards. These programs will tap the existing institutional framework that already exists for their development. That framework comes from the voluntary consensus system; the standards will be developed in that system, and it will, in addition, provide generic procedures, guidelines and criteria to develop those programs.

Solar Interest Groups in Standards Committees

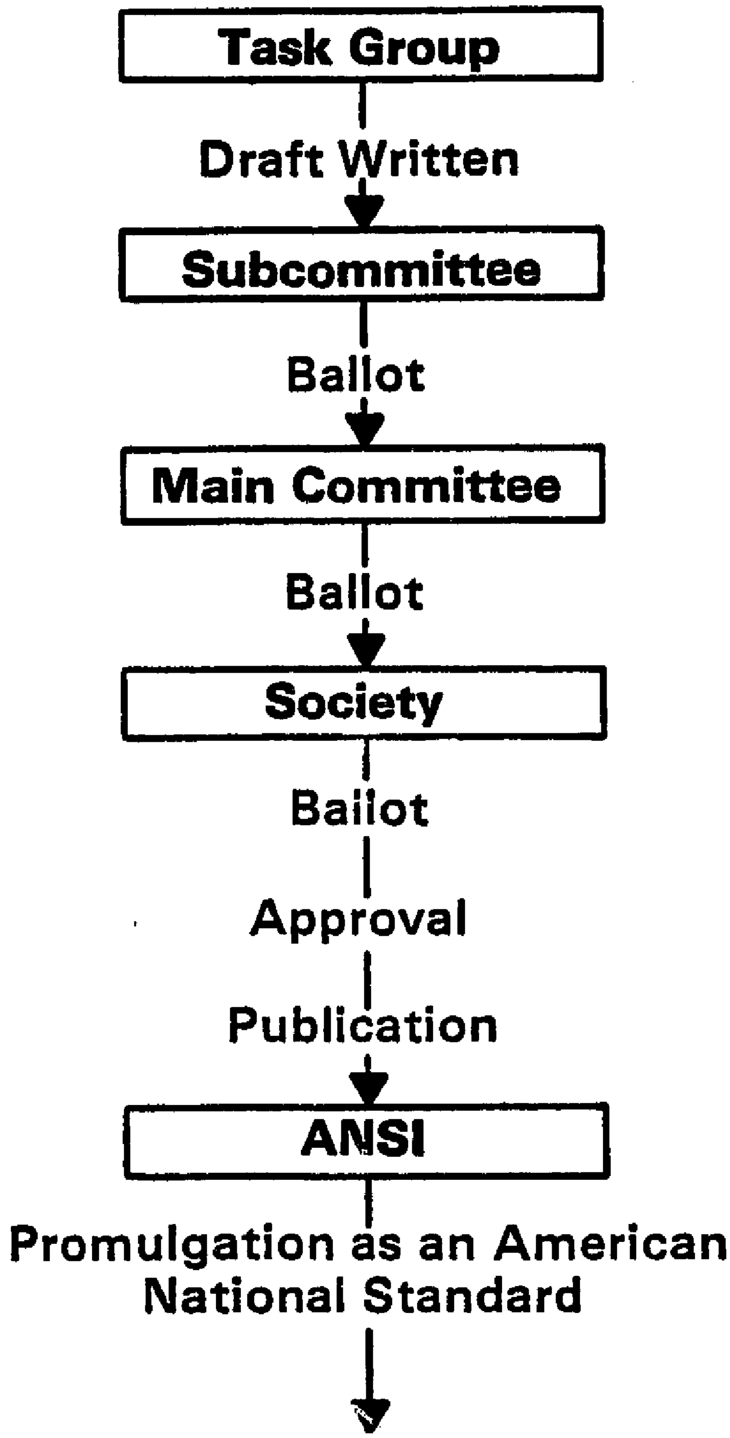
Standards Writing Committee

- Architects
- Builders
- Code Groups
- Engineers
- Installers-Contractors
- Insurance Companies
- Labor
- Manufacturers
- Regulatory Agencies
- Research Institutes
- Testing Laboratories
- Users

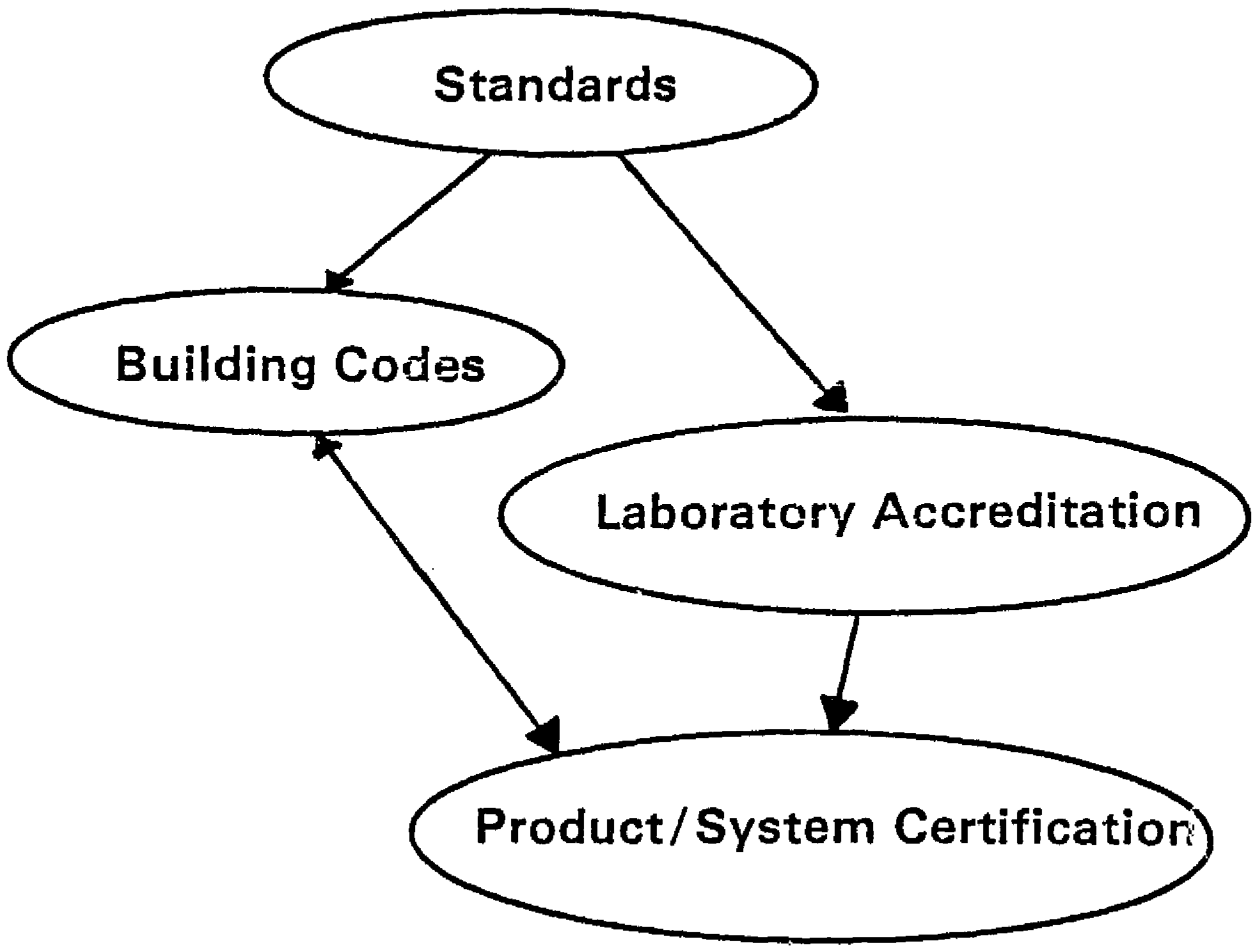
Voluntary Standards System
U.S.A.



Standards Writing Process



Standards Implementation — Promulgation



PHOTOVOLTAICS SUBSYSTEMS

PRESENTED TO THE DOE SAR
FOR PHOTOVOLTAICS
ARLINGTON, VIRGINIA
NOVEMBER 8, 1978
ALAN HOFFMAN & RON ROSS - JPL
PASADENA, CALIFORNIA

Significant items discussed during this presentation included criteria, test methodology, and standards priorities for each photovoltaics array element with respect to performance, reliability, durability, safety, environmental hazards and nomenclature. Some examples of types of performance considerations were given, such as, effects of temperature and intensity (illumination) on voltage current output of a module. Other examples of characterizations that will require attention include:

- o reference conditions for cells and modules

  for example, irradiance, spectrum, and cell temperature

- o electrical performance considerations

  including angle of incidence, energy v. power, parasitic power

In addition, the current status with respect to progress regarding performance characteristics and reliability/durability characterization of photovoltaics subsystems were reviewed.

ARRAY STANDARDS ACTIVITIES

R. ROSS

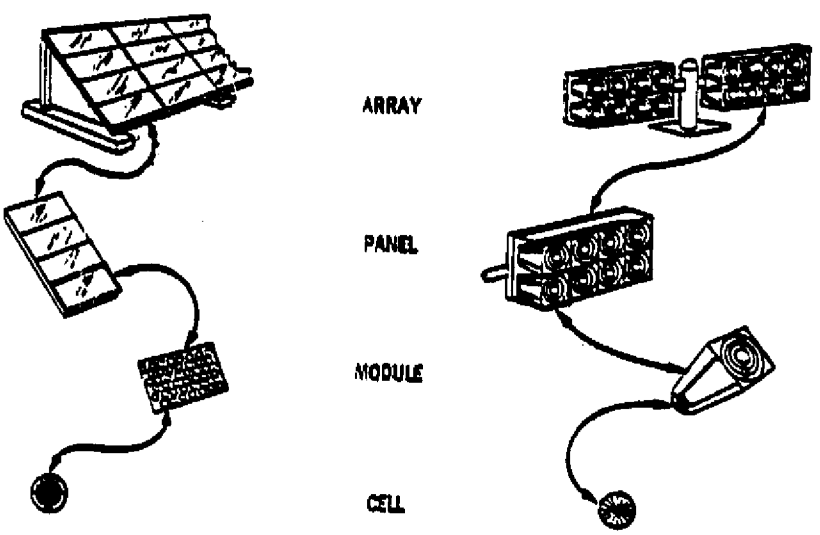
ARRAY-FIELD TASK GROUP

NOVEMBER 8, 1978

RGR
11/8/78

LOW-COST SOLAR ARRAY PROJECT

ARRAY NOMENCLATURE



RGR
11/7/78

LOW-COST SOLAR ARRAY PROJECT

CURRENT ACTIVITIES IN PHOTOVOLTAIC TESTING AND STANDARDS

DESIGN CRITERIA AND STANDARDS - SERI

FIELD TEST AND APPLICATION EXPERIMENTS

- MIT LINCOLN LAB
- NASA LEWIS RESEARCH CENTER
- DOD - MERADCOM
- ALBUQUERQUE OPERATIONS OFFICE (SANDIA)

FLAT PLAT ARRAY TECHNOLOGY - JPL, et. al

- DESIGN CRITERIA AND STANDARDS
- ENVIRONMENTAL TEST DEVELOPMENT
- LIFE PREDICTION STUDIES
- QUALIFICATION TESTING
- FIELD TESTING
- PROBLEM FAILURE REPORTING SYSTEM
- RELIABILITY ENGINEERING AND QA

CONCENTRATOR ARRAY TECHNOLOGY - SANDIA, et. al

- ACTIVITIES SIMILAR TO FLAT PLATE

RR
4/12/78

LOW-COST SOLAR ARRAY PROJECT

AREAS OF ENVIRONMENTAL SENSITIVITY

- THERMAL CYCLING
  - INTERCONNECT FATIGUE
  - ENCAPSULANT DELAMINATION
  - SOLAR CELL CRACKING
- HUMIDITY
  - CELL METALLIZATION DELAMINATION
  - ENCAPSULANT DELAMINATION
- STRUCTURAL LOADING
  - CELL INTERCONNECT FATIGUE
  - STRUCTURAL FATIGUE
- HAIL IMPACT
  - OPTICAL COVER BREAKAGE
  - CELL CRACKING
- OPTICAL SURFACE SOILING
- BIAS-HUMIDITY
  - CELL CORROSION (ION MIGRATION)
- ULTRAVIOLET
  - OPTICAL MATERIAL DEGRADATION
  - ENCAPSULANT DELAMINATION

RR
4/12/78

LOW-COST SOLAR ARRAY PROJECT

ARRAY RELIABILITY/DURABILITY SUMMARY

ENVIRONMENT	CELL		MODULE		RECEIVER	CONCENTRATOR OPTICS	ARRAY STRUCTURE	TRACKING CONTROL
	FP	C	FP	C				
ULTRAVIOLET	°	°	●	•	•	•	°	°
TEMPERATURE	◐	•	●	●	●	●		•
HUMIDITY	●	•	●	•	•	•		•
RAIN			○	◐				
HAIL			◐	◐	°	◐		
STR LOADING (WIND, SNOW, ICE)	•	•	●	●	•	•	•	
CORROSION/SALT SPRAY			◐	•	°	°	°	°
SOILING/CLEANING			●	●	•	●	°	°
HOT SPOT FAILURE SENSITIVITY			◐	◐	◐			
ELECTRICAL STRESS	○	°	•	•	°	°		
FLAMMABILITY			°	°	°	°		
SHIPPING/HANDLING			○	°	°	°	°	°

KEY

IMPORTANCE		PROGRESS
●	HIGH	○
◐	MEDIUM	○
○	LOW	°

RGR
11/7/78

LOW-COST SOLAR ARRAY PROJECT

PERFORMANCE STANDARDS CONSIDERATIONS

ELECTRICAL PERFORMANCE

- INTENSITY DEPENDENCE
- SPECTRUM SENSITIVITY
- OPERATING TEMPERATURE DEPENDENCE
- ANGLE OF INCIDENCE (POLAR)
- ENERGY VERSUS POWER
- FIXED VOLTAGE VERSUS MAX. POWER
- PARASITIC POWER

THERMAL PERFORMANCE

RGR
11/7/78

LOW-COST SOLAR ARRAY PROJECT

ARRAY PERFORMANCE STANDARDS SUMMARY

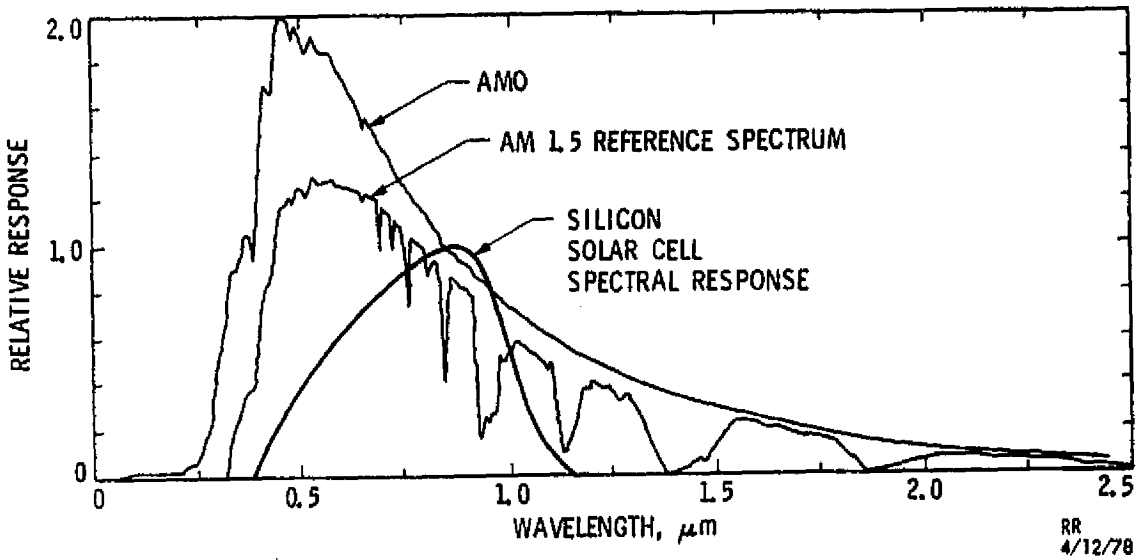
CHARACTERISTIC	ELEMENT							
	CELL FP	CELL C	MODULE FP	MODULE C	RECEIVER	OPTICS	ARRAY FP	ARRAY C
CURRENT/VOLTAGE	●	●	●	•	•		○	•
EFFICIENCY	●	●	●	•	•	●	○	•
TEMP. DEPENDENCE	○	◦	○	◦	◦	◦		◦
INSOL.DEPENDENCE	○	◦	○	◦	◦			◦
SPECTRAL RESPONSE	•	•	•	•	•	•		
ACCEPTANCE ANGLE	◦	◦	◦	•	◦	●	○	●
CONCENTRATION RATIO				◦				
NOCT			●	•	•		•	•
VOLTAGE ISOLATION			●	•	•		•	•
SHUNT RESISTANCE	○	◦	◦	◦	◦			
THERMAL OUTPUT			●	●	◦		◦	◦
ELECT./MECH INTERFACES	◦	◦	○	◦	◦	◦	◦	◦

KEY:

IMPORTANCE		PROGRESS
●	HIGH	○
•	MEDIUM	◦
◦	LOW	◦

RGR
11/7/78

LOW-COST SOLAR ARRAY PROJECT
SOLAR SPECTRUM CHARACTERISTICS



RR
4/12/78

LOW-COST SOLAR ARRAY PROJECT
PERFORMANCE MEASUREMENT REFERENCE CONDITIONS

CELLS

- STANDARD TEST CONDITIONS

IRRADIANCE:	100 mW/cm^2
SPECTRUM:	AM 1.5 PER NASA TM 73702
CELL TEMPERATURE:	28°C

MODULES

- STANDARD OPERATING CONDITIONS

IRRADIANCE:	100 mW/cm^2
SPECTRUM:	AM 1.5 PER NASA TM 73702
CELL TEMPERATURE:	NOMINAL OPERATING CELL TEMPERATURE (NOCT)

RR
4/12/78

LOW-COST SOLAR ARRAY PROJECT

ARRAY STANDARDS CATEGORIES
(FOR EACH ARRAY ELEMENT)

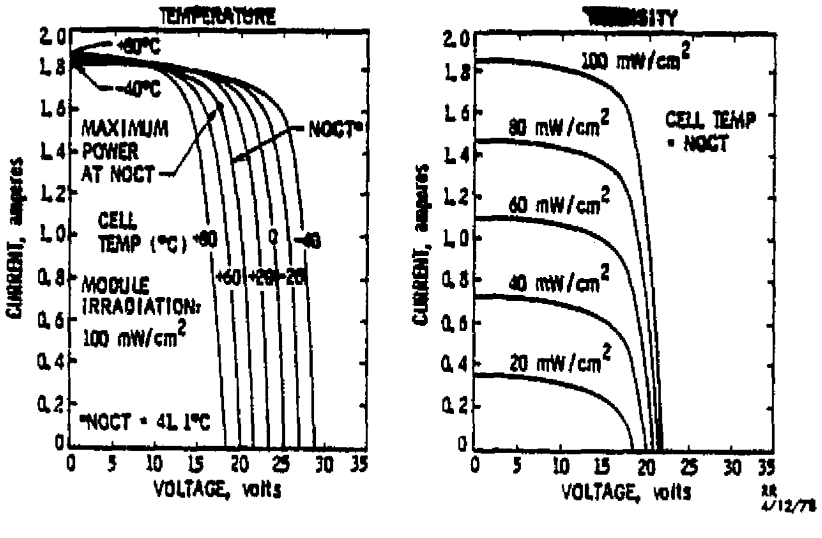
- PERFORMANCE
- RELIABILITY/DURABILITY
- SAFETY AND ENVIRONMENTAL HAZARDS
- NOMENCLATURE

} CRITERIA, TEST METHODS STANDARD PRACTICES

RGR
11/7/78

LOW-COST SOLAR ARRAY PROJECT

TYPICAL TEMPERATURE/INTENSITY PERFORMANCE CHARACTERISTICS



RR
4/12/78

ARRAY STANDARDS ACTIVITIES

R. ROSS

ARRAY-FIELD TASK GROUP

NOVEMBER 8, 1978

RGR
11/8/78

PERFORMANCE CRITERIA FOR PHOTOVOLTAIC
POWER CONDITIONING, CONTROL, AND STORAGE

PRESENTED AT THE DOE SAR
FOR PHOTOVOLTAICS
ARLINGTON, VIRGINIA
NOVEMBER 8, 1978
HARRY A. SCHAFFT - BS
WASHINGTON, D.C.

PERFORMANCE CRITERIA FOR PHOTOVOLTAIC POWER CONDITIONING, CONTROL, AND STORAGE

by

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Two subcommittees, one on Power Conditioning, Control, and Cabling, and one on Storage, met on June 22-23, 1978 in Vail, Colorado, to make initial identifications of performance criteria for these two major parts of a photovoltaic energy conversion system. The members of the two subcommittees, listed in graphic 1, were selected to provide a relatively broad representation while still keeping the number of participants to a manageable size.

The purpose of this paper is three-fold: (1) to report the highlights and directions taken by the two subcommittees, (2) to elicit comments on the approaches taken and the selections made by the subcommittees, and (3) to request recommendations for a task group that will have the responsibility for developing, in detail, performance characteristics necessary to meet user needs and expectations for these parts of a photovoltaic system and for identifying the measurement methods available for measuring these characteristics.

The Subcommittee on Power Conditioning, Control, and Cabling considered two subsystems: (1) power conditioning and (2) monitoring and control. They are defined as shown in graphic 2. Cabling was considered to be an integral part of both subsystems and was not addressed independently. The relationship of these two subsystems to each other and to the other parts of the photovoltaic systems is shown in graphic 3.

A basic decision was made in considering performance characteristics for the power conditioning subsystem. That decision was to consider performance characteristics of the subsystem relevant to its interfaces with the other parts of the photovoltaic system. Nine interfaces are indicated in graphic 4 according to whether they are inputs to or outputs from the power conditioning subsystem, and whether they are for ac or dc power.

With this approach in mind the subcommittee developed a list of performance characteristics which is shown in graphic 5. During the development of this list and the discussions that followed, it became clear that many of these terms will have to be examined more closely than there was time for and to have them defined.

With this list, each interface was considered in turn to see which of these characteristics applied and to discuss if there are any problems. Graphic 6 is a summary list of the performance characteristics associated with each of the nine interfaces. There are a number of interfaces and performance characteristics for which the members of the subcommittee expressed particular concern. These problem areas are indicated with an asterisk.

The dc input interface from the array was singled out as a problem area, primarily because more information is needed about array characteristics. One problem is the need to know what voltage variations to expect from the array. Another area is the matter of ripple imposed on the array by the power conditioning which depends on the interaction of the characteristics of the array and the power conditioning subsystem.

There are also problems with the input interface with the utility. Basically, they arise out of not knowing what to expect from the utility and of trying to protect the power conditioning from changes in power factor and distortion originating from the utility.

The output interface with the utility was of concern also. This concern was basically over the magnitude of the disturbance on the utility that the power conditioning would create. It was felt that some study will be needed to determine allowable levels of such disturbance. Furthermore, these levels will have to be reduced severely as a significant amount of the utility power is supplied by photovoltaic power. Significant here is of the order of five to ten percent of the utility power.

Other areas of concern are related to the charge-discharge characteristics of the storage subsystem, and motor starting transients in the load.

The ac interfaces to storage were felt to be new areas with no apparent need to address them, at least in the near future.

Performance characteristics identified for the monitoring and control subsystem are listed in graphic 7. Actually they are more like categories of performance characteristics. Because the scope of these categories is so broad, the subcommittee agreed that the development of definitions for these terms are in order. Four of these "characteristics" were called out in particular as needing study to understand better the factors to consider in optimizing performance. They are the ones indicated with an asterisk. Beyond an identification of the performance characteristics is the need to identify the various methods to measure these characteristics. This was recognized by the subcommittee as being a task that may require considerable effort.

The subcommittee briefly considered performance criteria for attributes other than functional. For criteria related to safety, the need for controlled access to both subsystems was called out in particular. Also, it was felt that there are many safety codes that should be applicable with some modifications. Related to structural and mechanical attributes, corrosion was felt to be a potential problem. Shipping and handling was considered to be a worst-case stress to these subsystems, so performance criteria directed to such stresses should be developed. Relevant to reliability and durability, the following environmental stresses were identified as being important: temperature, moisture, contamination, seismic shock, altitude, and insects and vermin. Approaches for achieving long life for these subsystems were discussed. Among the observations made were that there is no satisfactory methodology for determining long-term performance, and that it may be more cost effective to extend system life by appropriate maintenance procedures than to use high quality components to achieve system life goals.

The Storage Subcommittee used a generic approach to develop performance characteristics. The storage types identified as candidates for photovoltaic systems are listed in graphic 8. Most of the attention, however, was placed on batteries, under the first item on the list. The development of performance criteria for battery systems was cited as an immediate need while the development of performance criteria for the other storage types was felt to be important only in the near to distant future. The classification of photovoltaic systems to which these storage systems might be applied is given in graphic 9. With these identifications made, a Broad Base Generic Structure or Core was developed. The Core is essentially an attempt to construct a form that can be used as a guide in considering performance characteristics and test methodology in a systematic way for a given storage type and photovoltaic application. This form is shown in graphic 10. It was developed initially with lead-acid batteries in mind but the subcommittee felt that it will be usable for other storage types as well.

The listing of design criteria in the Core represents areas of major concern for the subcommittee and, in fact, represents categories of performance characteristics the subcommittee considered as necessary for storage subsystems.

In the category of sizing there are a number of characteristics of interest: capacity, voltage and current levels over charge and discharge ranges of operation, and cycle life, to name a few. Among the kinds of tests that were considered as being necessary were: acceptance tests, to make initial tests of capacity; performance tests, to assure adequate performance in service; and replacement tests, to determine if the storage units should be retired from service.

The category of interface and compatibility is included to respond to needs for adequate interfacing with other parts of the photovoltaic system: the power conditioning and control subsystems and the load, in particular. Here the need was expressed for good communication with power conditioning experts during the detailed preparation of performance criteria. This good communication should, in fact, be possible because performance criteria for both power conditioning-control and storage will be prepared by the same task group.

Installation criteria are important because of their effect on sizing design. Here such consideration as location, mounting, ventilation, temperature control, and environmental stress all can affect the sizing design.

Protection is another important design aspect where needs for adequate instrumentation and controls can be included to protect the storage element from faults and misuse.

Finally, the subcommittee felt it important to call out the need, separate from the design criteria, for an operation and maintenance manual and for adequate consideration of the problem of disposal of spent storage elements (batteries, primarily). The members of the subcommittee felt the need for guidance to address adequately concerns regarding safety and environmental impact.

POWER CONDITIONING/CONTROL AND CABLING SUBCOMMITTEE

TED CISZEK
SERI

EDWARD H. ERNST
GENERAL ELECTRIC CO.

BILL FEERO
DOE-EES

E. E. LANDSMAN
MIT LINCOLN LAB.

BOB LOSEY
WYLE LABS.

HANS MEYER
WINDWORKS, INC.

ALAN MILLNER
MIT LINCOLN LAB.

WALT PIJAWKA
GENERAL ELECTRIC CO.

JULIE RILEY
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STORAGE SUBCOMMITTEE

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JOHN J. BERGHAUSEM
ARGONNE NATIONAL LAB.

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ALAN MILLNER
MIT LINCOLN LAB.

BILL SPINDLER
EPRI

STEVE PATRICK
WYLE LABS.

CALVIN B. ROGERS
SANDIA LABS.

GRAPHIC 1

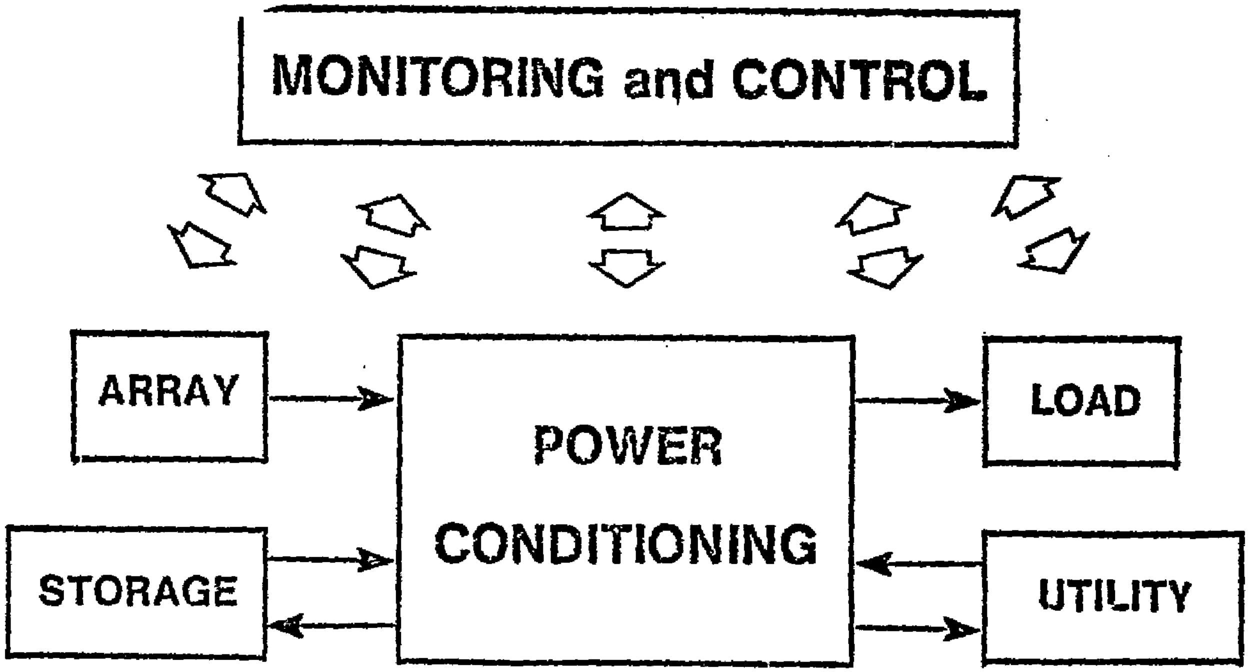
POWER CONDITIONING, CONTROL AND CABLING SUBCOMMITTEE

DEFINITIONS

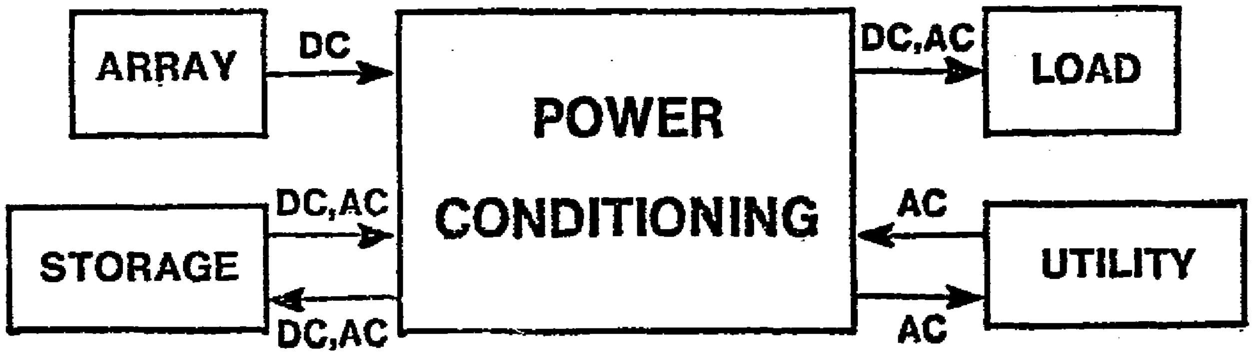
POWER CONDITIONING SUBSYSTEM: THOSE ELEMENTS IN A PHOTOVOLTAIC SYSTEM WHICH HANDLE THE EXCHANGE OF POWER BETWEEN THE VARIOUS SUBSYSTEMS: ARRAY, UTILITY, LOAD, AND STORAGE.

MONITORING AND CONTROL SUBSYSTEM: THE COLLECTION OF ELEMENTS PROVIDING THE LOGIC AND INFORMATION NECESSARY TO DETERMINE THE AMOUNT AND DISTRIBUTION OF POWER EXCHANGED BETWEEN SUBSYSTEMS.

GRAPHIC 2


MONITORING and CONTROL
ARRAY
POWER CONDITIONING
LOAD
STORAGE
UTILITY

GRAPHIC 3



POWER CONDITIONING INTERFACES

	DC INPUT	AC INPUT	DC OUTPUT	AC OUTPUT
Interfacing	ARRAY	UTILITY	LOAD	LOAD
Subsystems	STORAGE	STORAGE	STORAGE	UTILITY
				STORAGE

GRAPHIC 4

POWER CONDITIONING SUBSYSTEM

PERFORMANCE CHARACTERISTICS

1. VOLTAGE REGULATION
2. STEADY STATE STABILITY (VOLTAGE)
3. TRANSIENT RESPONSE (VOLTAGE)
4. WAVEFORM (VOLTAGE)
5. VOLTAGE UNBALANCE WITH UNBALANCED LOAD
6. PHASE BALANCE VOLTAGE
7. POWER FACTOR
8. VOLTAGE ADJUSTMENT RANGE
9. FREQUENCY REGULATION
10. STEADY STATE STABILITY (FREQUENCY)
11. TRANSIENT PERFORMANCE (FREQUENCY)
12. FREQUENCY ADJUSTMENT RANGE
13. PHASE LOCK
14. LOSS VERSUS LOAD
15. EMI GENERATION AND SUSCEPTIBILITY
16. PROTECTION
17. SYSTEM TURN ON
18. CURRENT, CHARGE CONTROL
19. VOLTAGE, CURRENT AS SEEN BY UTILITY
20. SHORT-TERM OVERLOAD
21. STABILITY TO INPUT LOAD

GRAPHIC 5

POWER CONDITIONING INTERFACES

PERFORMANCE CHARACTERISTICS	ARRAY	STORAGE				LOAD		UTILITY	
	DC IN	DC IN	DC OUT	AC IN	AC OUT	DC OUT	AC OUT	AC IN	AC OUT
1. Voltage regulation	X	X	X	X	X	X	X	X	X
2. Steady state stability (voltage)	X*	X	X	X	X	X	X	X	X
3. Transient response (voltage)	X*	X	X	X	X	X*	X*	X	X
4. Waveform (voltage)	X*	X	X	X	X	X	X	X	X
5. Voltage unbalance with unbalanced load				X	X		X	X	X
6. Phase balance voltage				X	X		X	X	X
7. Power factor				X	X		X	X*	X
8. Voltage adjustment range			X	X	X	X	X	X	X
9. Frequency regulation				X	X		X	X	X
10. Steady state stability (frequency)				X	X		X	X	X
11. Transient performance (frequency)				X	X		X	X	X
12. Frequency adjustment range				X	X		X	X	X
13. Phase lock				X	X		X	X	X
14. Loss versus load			X	X	X	X	X	X	X
15. EMI generation and susceptibility	X*	X	X	X	X	X	X	X	X
16. Protection	X*	X	X	X	X	X	X	X*	X
17. System turn-on	X	X	X	X	X	X	X	X	X
18. Current, charge control			X*						
19. Voltage, current as seen by utility								X*	
20. Short term overload					X		X		X
21. Stability to input load	X								

GRAPHIC 6

MONITORING AND CONTROL SUBSYSTEM

PERFORMANCE CHARACTERISTICS

1. Storage management
2. Input/output interfaces
3. Maximum power tracking*
4. Power management*
5. Manual control*
6. Remote control*
7. Load management
8. Synchronization with external sources
9. System diagnostics
10. Metering

GRAPHIC 7

STORAGE SUBCOMMITTEE

STORAGE TYPES

1. ELECTROCHEMICAL
2. FLUID
3. MECHANICAL
4. AIR
5. FUEL CELL
6. HYBRIDS OF ABOVE
7. THERMAL
8. SUPER CONDUCTING MAGNETIC ENERGY
9. HYDROGEN

GRAPHIC 8

STORAGE SUBCOMMITTEE

	APPLICATIONS	CAPACITY
1.	SMALL-REMOTE	< 10 kWH
2.	RESIDENTIAL	5-30 kWH
3.	MULTIFAMILY RESIDENCE	10-2,000 kWH
4.	COMMERCIAL, INDUSTRIAL	150-10,000 kWH
5.	CENTRAL	$10^5 - 6 \times 10^6$ kWH

GRAPHIC 9

BROAD BASE GENERIC STRUCTURE--CORE

A. Design Criteria	Recommended design criteria standards for:	Recommended Test Methodology Standards
1) Sizing	Sizing Criteria	Acceptance Performance Replacement Qualification (reliability/safety Committee)
2) Interface and Compatibility (I + C)* *Instrumentation & Control	Interface specifications (Recommended for all other PV subsystems, i.e., voltage, isolation, termination, mechanical, etc.	Interface Acceptance & Compatability Inspection and Test.
3) Installation	1) Criteria for installation design 2) Criteria for environmental capability.	Design Verification
4) Protection	Criteria for instruments and controls--protection of storage and of system from storage faults, i.e., circuit breakers, fuse, etc.	Anticipate tests will be part of overall PV system test.

B. Operation and Maintenance	Recommended Procedure and Testing Methods
1) Operation & Maintenance Manual	Guidelines (Family of recommended guideline standards)
2) Disposal	Combined effort with safety subcommittee.

GRAPHIC 10

PHOTOVOLTAIC ENERGY SYSTEMS SAFETY STANDARDS DEVELOPMENT

PRESENTED AT THE DOE SAR
FOR PHOTOVOLTAICS
ARLINGTON, VIRGINIA
NOVEMBER 8, 1978
RICHARD DE BLASIO - SERI
GOLDEN, COLORADO

INTRODUCTION

One of the major areas for criteria development to be addressed by the project task groups is safety. This includes safety criteria and safety criteria verification for the total photovoltaic energy system as well as subsystem and application interfaces.

In June of this year, a meeting of the PV standards Coordinating Council subcommittees took place in Vail, Colorado. The Subcommittee on PV Safety identified safety hazards that may be encountered at the systems level and established an approach to evaluating the PV system and its interfaces.

For the remainder of the discussion I plan to briefly review the guidelines established by the Photovoltaics Subcommittee on Safety, as well as recommendations provided by the Coordinating Council and the Task Group Steering Committee.

PHOTOVOLTAIC SAFETY STANDARDS DEVELOPMENT ACTIVITIES

A. STANDARDS COORDINATING COUNCIL SUBCOMMITTEE ON SAFETY (JUNE 1978 MEETING)

MAJOR PRODUCTS:

1. IDENTIFIED AN APPROACH TO SAFETY FOR PHOTOVOLTAIC (PV) ENERGY SYSTEMS.
2. PROPOSED SCOPE STATEMENT FOR PV SAFETY AS WELL AS SUPPORTIVE DEFINITIONS.
3. IDENTIFIED SEQUENCE FOR DEVELOPING SAFETY CRITERIA AND CRITERIA VERIFICATION TECHNIQUES.
4. IDENTIFIED GENERIC AREAS OF SAFETY CONCERNS.
5. IDENTIFIED PV SYSTEMS SAFETY HAZARDS AND RANKED HAZARDS ACCORDING TO THE DEGREE OF IMPORTANCE.

B. GENERAL SAFETY CONCERNS

I. MANUFACTURING

II. ON-SITE

SAFETY CRITERIA AND CRITERIA VERIFICATION GUIDELINES --

PHOTOVOLTAIC INTERIM PERFORMANCE CRITERIA DOCUMENT DEVELOPMENT

I. Safety Guidelines

The following safety guidelines are based on the information and recommendations provided by the Coordinating Council, subcommittees and task group steering committee. These criteria will include consideration of environmental hazards associated with the manufacture, assembly, installation and use of Photovoltaic energy systems. Equipment, as well as property safety, verses protecting people are also included. The IPC document recognizes but will not address environmental hazards with respect to siting of PV systems.

A defense-in-depth philosophy was adopted by the safety committee and was patterned and based on the following three elements:

1. Design
2. Detection
3. Mitigation

The following information was provided by the safety subcommittee:

1. Definition of Safety
2. Scope
3. Supportive Definitions
4. Common Safety Hazards

1. Definition of Safety:

   Safety is the surety that the environment that personnel or items are subjected to in a PV system is free from inadvertent or unexpected events which may result in injury to personnel or damage to the items exposed.

2. Scope:

   Photovoltaic safety is brought about by activities and procedures which protect people and property from hazardous situations through system design, detection of abnormal conditions, and mitigation of the aspects of abnormal conditions.

3. Supportive Definitions

   Normal Conditions: as designed for intended use.

   Abnormal Conditions: other than as designed, beyond safety limits (beyond design margin).

   Personnel: anyone coming in contact with a PV system.

A. STANDARDS COORDINATING COUNCIL SUBCOMMITTEE ON SAFETY
(JUNE 1978 MEETING)

1. <u>SAFETY APPROACH</u>

ADOPTED A DEFENSE - IN - DEPTH APPROACH PATTERNED AND BASED ON:

1. DESIGN
2. DETECTION
3. MITIGATION

2. SAFETY SCOPE STATEMENT AND SUPPORTIVE DEFINITIONS:

SCOPE:

PHOTOVOLTAIC SAFETY IS BROUGHT ABOUT BY ACTIVITIES AND PROCEDURES WHICH PROTECT PEOPLE AND PROPERTY FROM HAZARDOUS SITUATIONS THROUGH SYSTEM DESIGN, DETECTION OF ABNORMAL CONDITIONS, AND MITIGATION OF THE ASPECTS OF ABNORMAL CONDITIONS.

DEFINITION OF SAFETY:

SAFETY IS THE SURETY THAT THE ENVIRONMENT THAT PERSONNEL OR ITEMS ARE SUBJECTED TO IN A PV SYSTEM IS FREE FROM INADVERTENT OR UNEXPECTED EVENTS WHICH MAY RESULT IN INJURY TO PERSONNEL OR DAMAGE TO THE ITEMS EXPOSED.

SUPPORTIVE DEFINITIONS:

NORMAL CONDITIONS: AS DESIGNED FOR INTENDED USE.

ABNORMAL CONDITIONS: OTHER THAN AS DESIGNED, BEYOND SAFETY LIMITS (BEYOND DESIGN MARGIN).

PERSONNEL: ANYONE COMING IN CONTACT WITH A PV SYSTEM.

4. Common Safety Hazards:

1. Electrical Shock
2. Fire and Flammability (including explosions)
3. Surface temperature
4. Optical
5. Structural Hazards
6. Hazardous Materials
7. Electromagnetic Interference

The approach in developing safety criteria and criteria verification techniques for PV energy systems would be to follow the following sequence:

1. Synthesize the total system followed by:
   a. Subsystem (i.e. storage) evaluation
   b. Subsystem interfaces evaluation
   c. Subsystem components (i.e. module) evaluation
   d. Interfaces (utility, loads, applications)

The following common safety hazards have been synthesized at the systems level according to priority for standards development with respect to design, failure and maintenance and operation. This approach follows the defense-in-depth philosophy. Once evaluated at the systems level, the same process should be followed for the subsystem, subsystem interfaces, subsystem components and interfaces.

1. HAZARD: ELECTRICAL SHOCK

Photovoltaic systems should be designed to minimize the potential for electrical shock under normal or abnormal conditions.

A. DESIGN

(1) Qualification testing for electrical shock hazard
(2) Material selection relative to shock
(3) Physical and electrical isolation and separation provision(s)
(4) Provision for overvoltage or over current protection
(5) Grounding provisions (if applicable)

B. FAILURE

(1) Failure mode identification
(2) Abnormal condition detection and indication

3. SEQUENCE FOR DEVELOPING SAFETY CRITERIA AND CRITERIA VERIFICATION TECHNIQUES

SYNTHESIZE THE TOTAL SYSTEM FOLLOWED BY:

A. SUBSYSTEM (I.E. STORAGE) EVALUATION

B. SUBSYSTEM INTERFACES EVALUATION

C. SUBSYSTEM COMPONENTS (I.E. MODULE) EVALUATION

D. INTERFACES (UTILITY, LOADS, APPLICATIONS)

4. IDENTIFIED GENERIC AREAS OF SAFETY CONCERNS

A. SYSTEM DESIGN

B. SYSTEM FAILURE

C. OPERATION

D. MAINTENANCE

5. IDENTIFIED PHOTOVOLTAICS SYSTEM SAFETY HAZARDS AND DEGREE OF IMPORTANCE

1. ELECTRICAL SHOCK
2. FIRE AND FLAMMABILITY (INCLUDING EXPLOSIONS)
3. SURFACE TEMPERATURE
4. OPTICAL
5. STRUCTURAL HAZARDS
6. HAZARDOUS MATERIALS
7. ELECTROMAGNETIC INTERFERENCE

C. MAINTENANCE AND OPERATION

(1) Electrical shock inspection criteria

(2) Modification procedures

(3) System certification standard (if applicable)

(4) Emergency procedures

2. HAZARD: FIRE, FLAMMABILITY AND EXPLOSION

Photovoltaic systems should be designed to minimize the potential for fire, flammability and explosion.

A. DESIGN

(1) Testing criteria for material selection are needed

(2) Design criteria for circuit configuration and component selection are needed

B. FAILURE - testing criteria are needed for:

(1) detection

(2) extinguishing

(3) fire hazards analysis including inventory of materials

C. OPERATION AND MAINTENANCE - areas will be governed by local fire codes and special attention will be paid to:

(1) occupant egress

(2) emergency procedures

There are requirements in some building codes such as separation criteria. Test methods should be performed on a component basis.

The consensus of the committee is that an overall fire flammability and exposure inspection criteria may not be either applicable or feasible. However, advice should be sought from Factory Mutual, OSHA and ASTM, and UL.

3. HAZARD: SURFACE TEMPERATURES

(Key: to protect people from burns)

PV systems should be designed to minimize the potential for excessive exposed surface temperatures under normal and abnormal conditions. Existing UL standards for protection of people from harmful surface temperatures should be reviewed.

A. Design and Failure

(1) A recommended practice should be developed to protect poeple from high temperature surfaces under normal or abnormal conditions.

B. Maintenance and Operation

(1) Procedures need to be established for systems with known hot spots.

4. HAZARD: OPTICAL

PV systems should be designed to minimize the potential for optical hazards under normal and abnormal conditions.

Optical Hazard: illumination of sufficient intensity to cause physical damage.

A. Design and Failure

(1) A recommended practice in needed to protect personnel from optical hazards under normal or abnormal conditions.

B. Maintenance and Operation

(1) Procedures need to be established with known optical hazards.

5. HAZARD: STRUCTURAL HAZARDS

PV systems should be designed to minimize structural hazards to personnel.

A. Design

(1) As a minimum, design according to local building codes.

B. Failure

(1) Structural hazards analysis
eg: falling objects, flying debris, protrusions, sharp edges.

C. Maintenance and Operation

(1) Establish procedures to protect personnel from structural hazards.

6. HAZARD: HAZARDOUS MATERIALS

PV systems should be designed to minimize the use or production of hazardous materials.

A. Design

(1) Use existing standards and codes for hazardous materials. OSHA and NEC are sources.

B. Failure

(1) Inventory of hazardous or potentially hazardous materials.

C. Maintenance and Operation

(1) Develop procedures for working around or with hazardous materials.

7. HAZARD: ELECTROMAGNETIC INTERFERENCE (EMI)

Recommended tests should be developed to determine the possibility of electromagnetic interference by a PV system with communications equipment, pyrotechnic devices and medical devices (pacemakers).

B. GENERAL SAFETY CONCERNS

I. MANUFACTURING

1. HEALTH AND SAFETY

A. CADMIUM DUST, SILICON DUST, AND OTHER PARTICULATES.
B. CADMIUM OXIDE, NITROGEN OXIDES, SULFUR OXIDES, CARBON MONOXIDE, AND OTHER FUMES.
C. HANDLING HAZARDOUS CHEMICALS USED IN MANUFACTURING PROCESSES SUCH AS PHOSPHINE, BORON TRICHLORIDE, HYDROCHLORIC ACID, ETC.

2. FIRE SAFETY

A. TOXIC FUMES, E.G., CADMIUM SULFIDE.
B. AUTOIGNITION OF MATERIALS.
C. FIRE FIGHTER ACCESS.
D. COMBUSTIBILITY OF MATERIALS/FLAME SPREADS/FLASH POINT.

3. ECOLOGICAL

A. PARTICULATE RELEASES, E.G. CADMIUM DUST, ARSESIC COMPOUNDS.
B. FUMES
C. LIQUID AND SOLID WASTES, E.G. METAL CHLORIDES, ACIDIC EFFLUENTS, ALUMINA SLUDGE.

II. ON-SITE

1. FIRE SAFETY

A. OCCUPANTS EGRESS
B. TOXIC FUMES, E.G., CADMIUM SULFIDE
C. AUTOIGNITION OF MATERIALS
D. FIRE FIGHTER ACCESS
E. COMBUSTIBILITY OF MATERIALS/FLAME SPREADS/FLASH POINT

2. TOXICITY

A. CADMIUM DUST
B. ARSENIC COMPOUNDS
C. OUTGASSING OF FUMES

3. PERSONAL HAZARD

A. GLASS BREAKAGE
B. MAINTENANCE ACCESS
C. HOT SURFACES
D. LIGHTENING PROTECTION (SHOCK HAZARDS).
E. GROUNDING PROVISION
F. TEMPERATURE OR BURN HAZARDS

II. ON-SITE (CONTINUED)

4. STRUCTURAL SAFETY

A. SEISMIC WINDS DESIGN CONSIDERATIONS
B. THERMAL AND STRUCTURAL PROPERTY DEGRADATIONS
C. ROOF LOADING (RETROFITS)
D. ROOF LIFTING

5. ECOLOGICAL

A. MICRO CLIMATIC MODIFICATIONS (CENTRALIZED APPLICATIONS)
B. MAINTENANCE ACTIVITIES, E.G., ACCESS ROADS, DUST, WASTE, SOLUTION, ETC.

6. VISUAL

A. VIEW
B. GENERAL APPEARANCE (AESTHETICS)

SESSION II

COST/ECONOMICS

Richard D. Tabors

MIT/Energy Laboratories

ECONOMIC & MARKET MODELS OF PHOTOVOLTAIC SYSTEMS

NEED: RATIONALIZE DIFFERENCES

HYPOTHESES:

A. THREE TYPES OF MODELS

MARKET (HOW MANY)

PROCESS/SIMULATION (AT WHAT PRICE)

MACRO (GIVEN COMPETITION HOW MANY)

B. WITHIN ABOVE GROUPS ANSWERS ARE THE SAME.

OUTLINE

1) STRUCTURE OF MODEL AND SUBMODELS

2) ASSUMPTIONS
   A. RATE STRUCTURE
   B. DISCOUNT RATE
      (FCR)
   C. FUEL ESCALATION
   D. CELL DEGRADATION AND LIFETIME
   E. BUYBACK
   F. BALANCE OF SYSTEMS

3) LATEST RESULTS

ECONOMIC MODELS SESSIONS - WEDNESDAY - 1:30-5:30

CHAIRMAN - R. D. TABORS, MIT/ENERGY LABORATORY

SESSION A - MARKET MODELS

SESSION CHAIRMAN - GARY LILIEN, MIT/SLOAN SCHOOL

PRESENTATIONS - DR. ORRIN MERRILL, SAI
THOMAS MCCORMICK, MIT

SESSION B - PROCESS/SIMULATION MODELS: RESIDENTIAL

SESSION CHAIRMAN - JEFFREY SMITH, JPL

PRESENTATIONS - EDWARD MEHALICK, G.E.
PAUL CARPENTER, JPL (MIT)
EDWARD KERN, MIT/LINCOLN LABORATORY
BARRY SIEGAL, AEROSPACE
PAUL PITTMAN, WESTINGHOUSE

SESSION C - PROCESS/SIMULATION MODELS: UTILITY

SESSION CHAIRMAN - STANLEY LEONARD, AEROSPACE

PRESENTATIONS - BARRY SIEGAL, AEROSPACE
SUSAN FINGER, MIT
, G.E.

SUMMARY SESSION

SESSION CHAIRMAN - RICHARD TABORS

PANEL - GARY LILIEN
JEFFREY SMITH
STANLEY LEONARD
RAYMOND HARTMAN

PHOTOVOLTAIC PROGRAM GOALS

SESSION CHAIRMAN - RICHARD TABORS, MIT ENERGY LABORATORY

- BACKGROUND - PAUL CARPENTER, JPL (MIT)
- ALTERNATIVE APPROACHES - JEFFREY SMITH, JPL
- UTILITY RESPONSE - EDGAR DEMEO, EPRI
- CONSUMER INFORMATION - DREW BOTTARO, MIT ENERGY LABORATORY

GENERAL ELECTRIC

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REGIONAL CONCEPTUAL DESIGN AND ANALYSIS STUDIES FOR RESIDENTIAL PHOTOVOLTAIC SYSTEMS

Ed Mehalick

GENERAL ELECTRIC COMPANY
ADVANCED ENERGY PROGRAMS
VALLEY FORGE, PENNSYLVANIA

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SCOPE - PV RESIDENTIAL STUDY

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- DIVIDE U.S. INTO REGIONS OF SIMILAR CLIMATE
- PREPARE RESIDENCE DESIGNS FOR 1986 PERIOD
  - SINGLE STORY DETACHED (SOUTHERN CLIMATE)
  - TWO STORY DETACHED (NORTHERN CLIMATE)
  - MULTI-FAMILY TOWNHOUSE
- SOLARIZE RESIDENCES
  - PV-ONLY
  - COMBINED PV/THERMAL COLLECTORS
  - SIDE-BY-SIDE PV & THERMAL COLLECTORS
- ANALYZE PERFORMANCE & ECONOMICS IN VARIOUS REGIONS
- RANK ORDER CONCEPTS
- PREPARE CONCEPTUAL DESIGNS
  - TEST-BED FACILITY
  - HABITABLE RESIDENCE
- RANK TEST PROGRAMS

SIMULATION MODEL INPUTS

SOLAR ARRAY

- SOLAR CELL I-V CHARACTERISTICS
- SERIES – PARALLEL CELL MATRIX
- INCIDENCE ANGLE TIME DEPENDENCE
- INSOLATION
- THERMAL CHARACTERISTICS
- WEATHER DATA (AMBIENT TEMP., WIND VELOCITY)

STORAGE

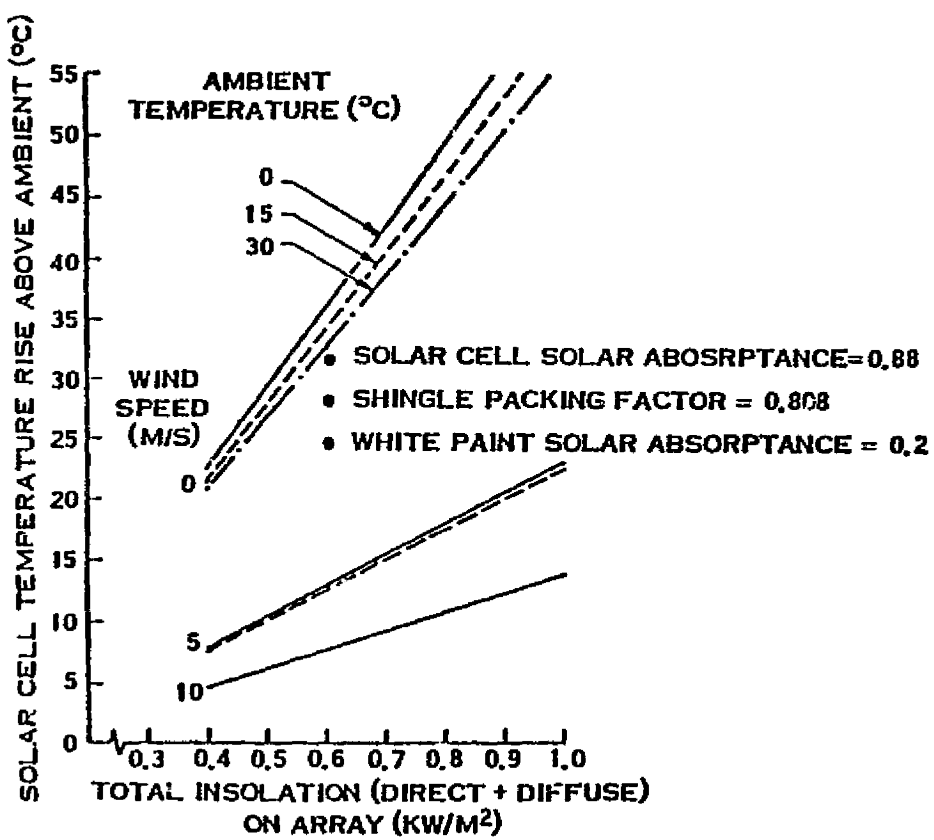
- STATE OF CHARGE
- CHARGE AND DISCHARGE RATES
- OVERCHARGE AND MAXIMUM DISCHARGE LIMITS

INVERSION

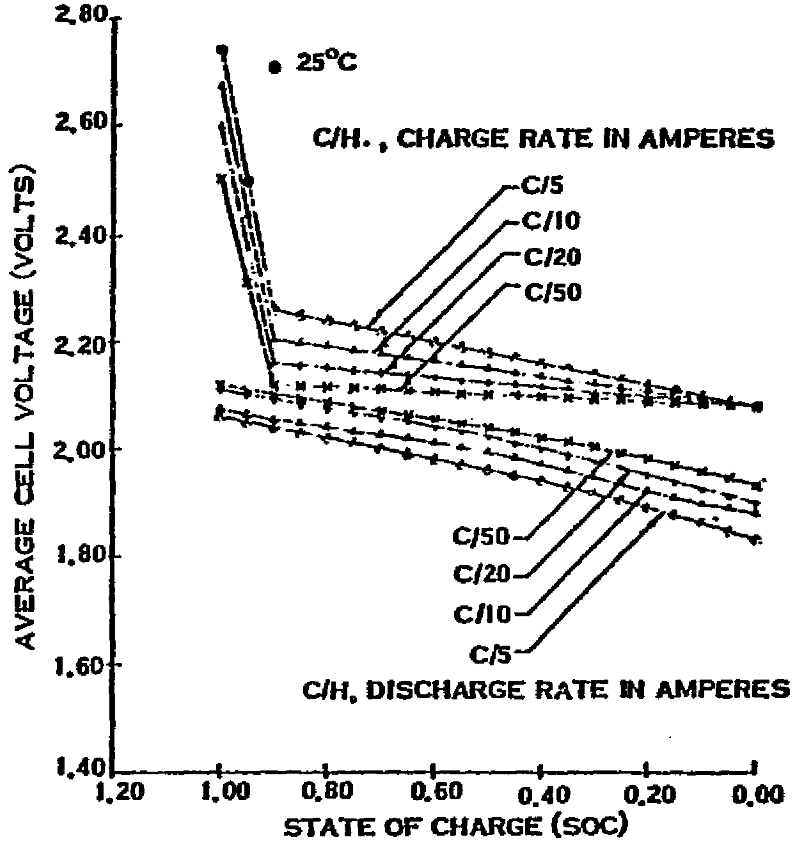
- EFFICIENCY VERSUS PERCENT RATED LOAD
- MAXIMUM OUTPUT LIMITS

EXAMPLES OF SIMULATION INPUTS

ARRAY TEMPERATURE

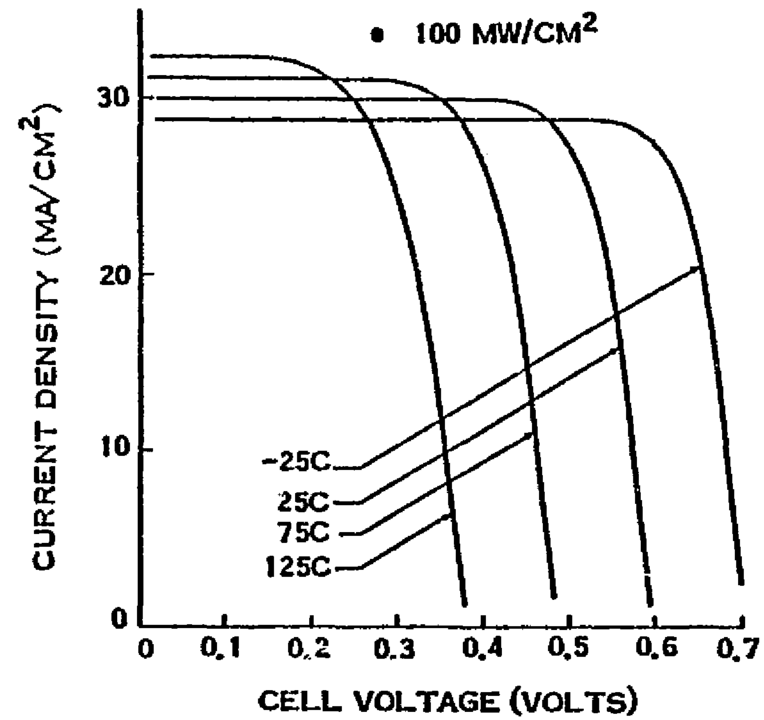


BATTERY CHARACTERISTICS

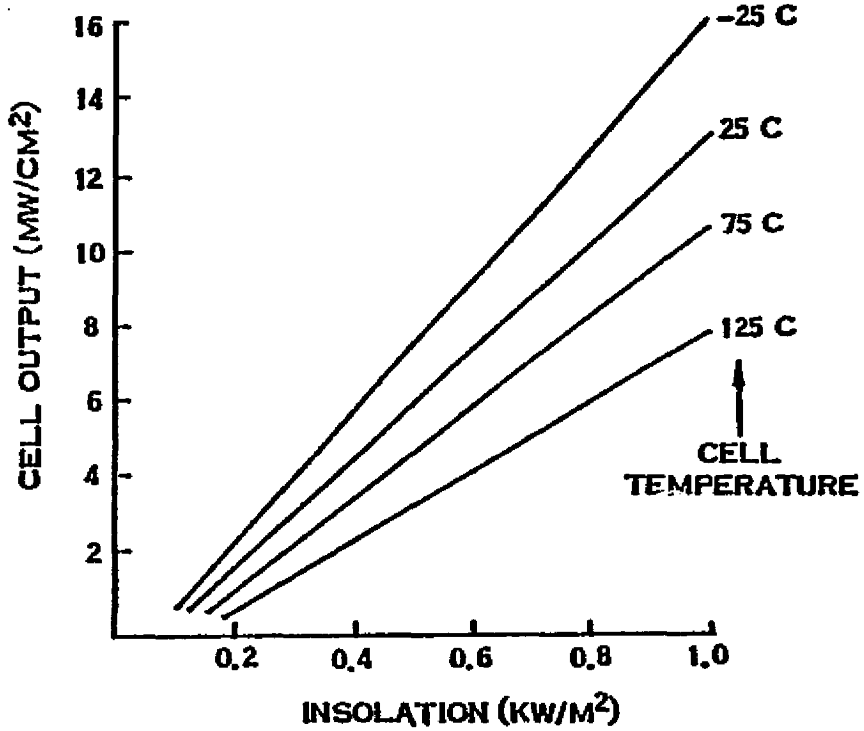


EXAMPLES OF SIMULATION INPUTS

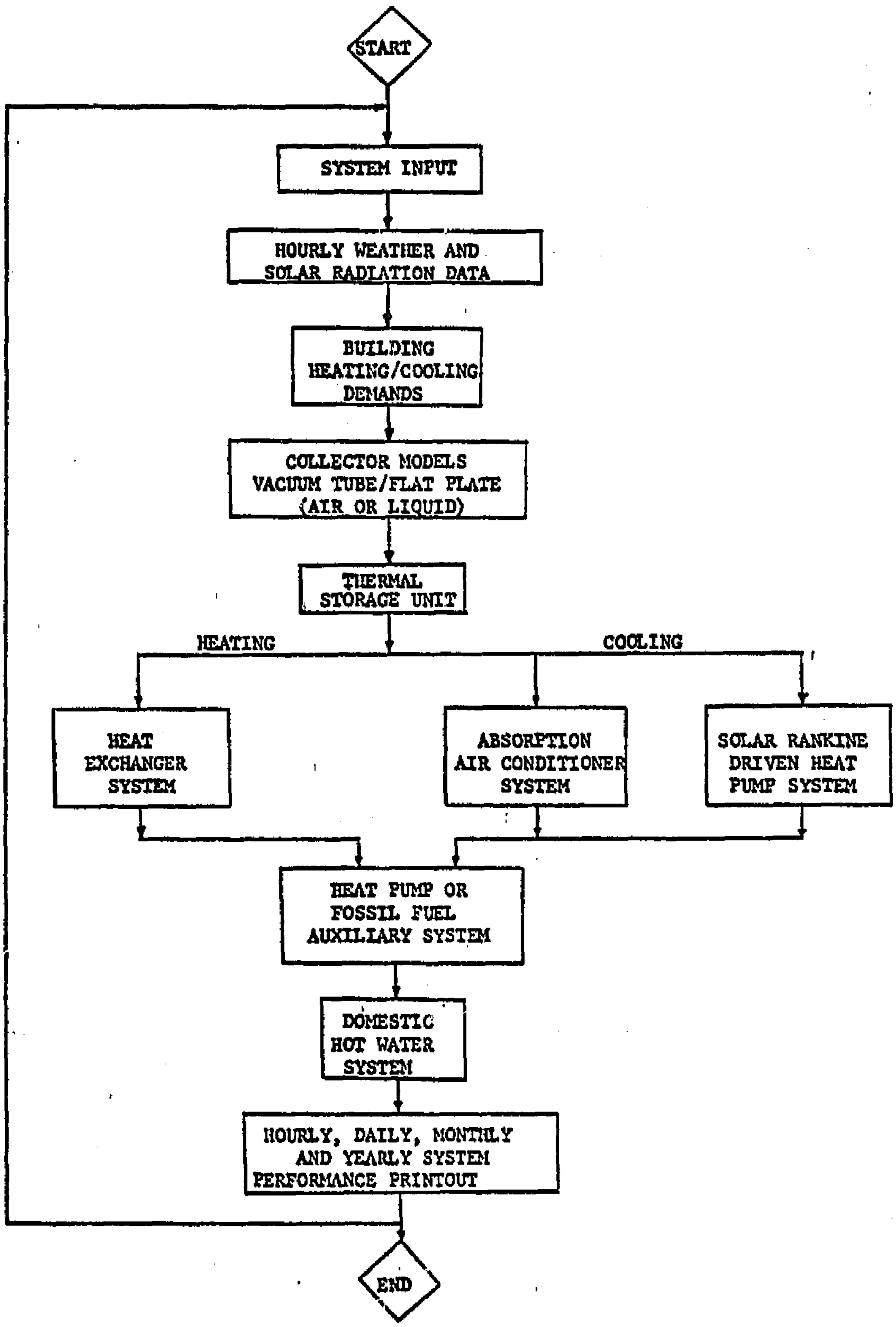
SOLAR CELL
I-V CHARACTERISTICS



SOLAR CELL MAX
POWER OUTPUT



Solar System Simulation Program - Flow Schematic



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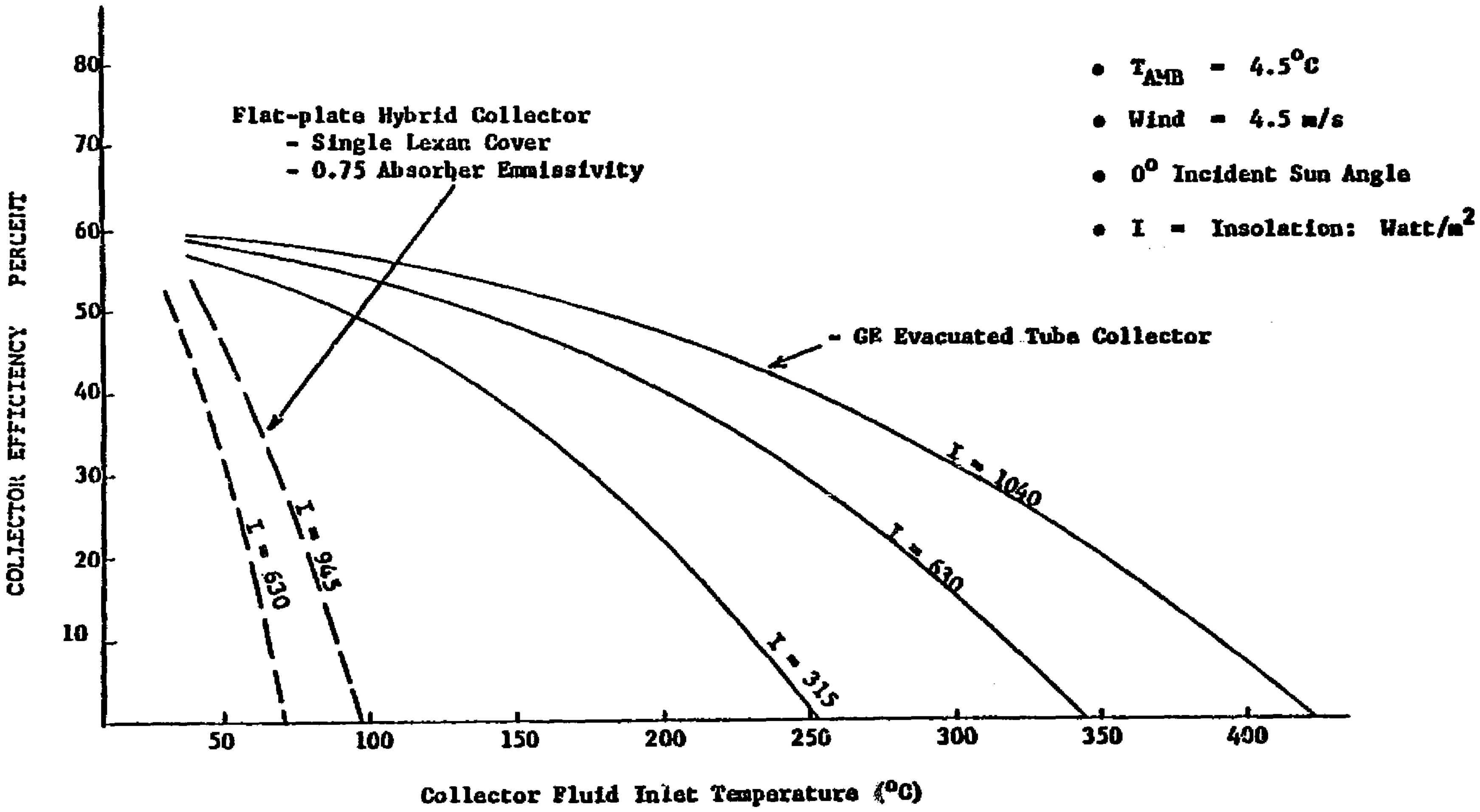
COLLECTOR MODEL PERFORMANCE



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CONCEPT RANKING GROUND RULES

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2-80

- 1986 START
- GENERAL INFLATION RATE : 5%
- INSURANCE : .5% OF CAPITAL COST
- ELECTRICITY PRICE ESCALATION : 4% OVER INFLATION
- MORTGAGE RATE : 10%
- TAX BRACKET : 30%
- NO PROPERTY TAX
- SELL BACK TO BUY RATIO : .5
- SYSTEM LIFE : 20 YR.
- BATTERY LIFE : 10 YR.
- ARRAY COST : $500/K W_P (FOB) ($660/K W_P @ SITE)
- BATTERY COST : $25/KWH OF NAMEPLATE RATING
- BALANCE OF PV PLANT COSTS :

	WITH STORAGE	WITHOUT STORAGE
VARIABLE	$26.20/$M^2$	$34.20/$M^2$
FIXED	$3832	$1047

- THERMAL SYSTEM TO PV SYSTEM COST RATIO : 2:1
- COMBINED SYSTEM COST SAME AS THERMAL-ONLY SYSTEM COSTS

GENERAL ELECTRIC

REGIONAL PERFORMANCE SUMMARY OF PV-ONLY SYSTEM WITHOUT STORAGE

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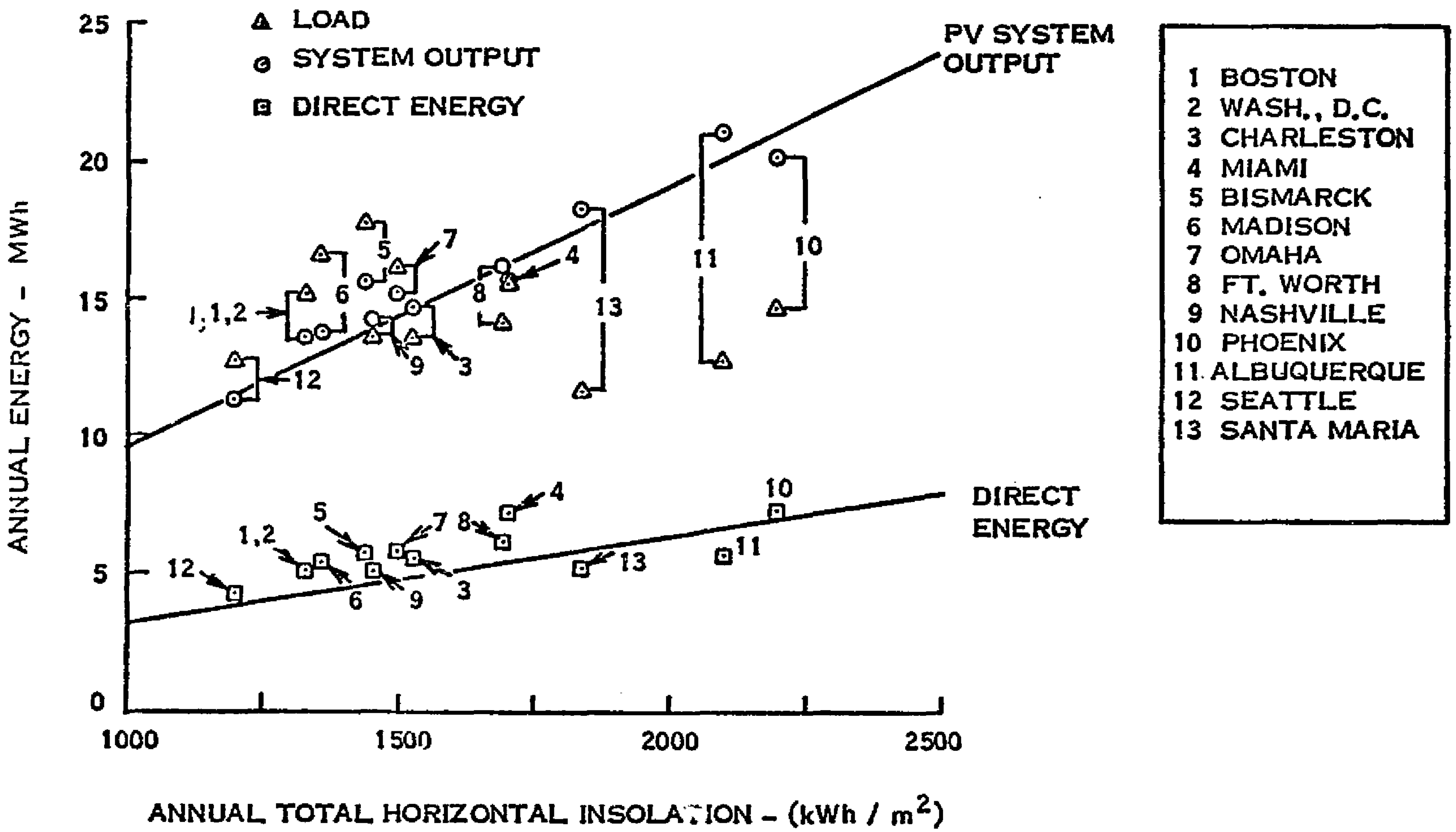

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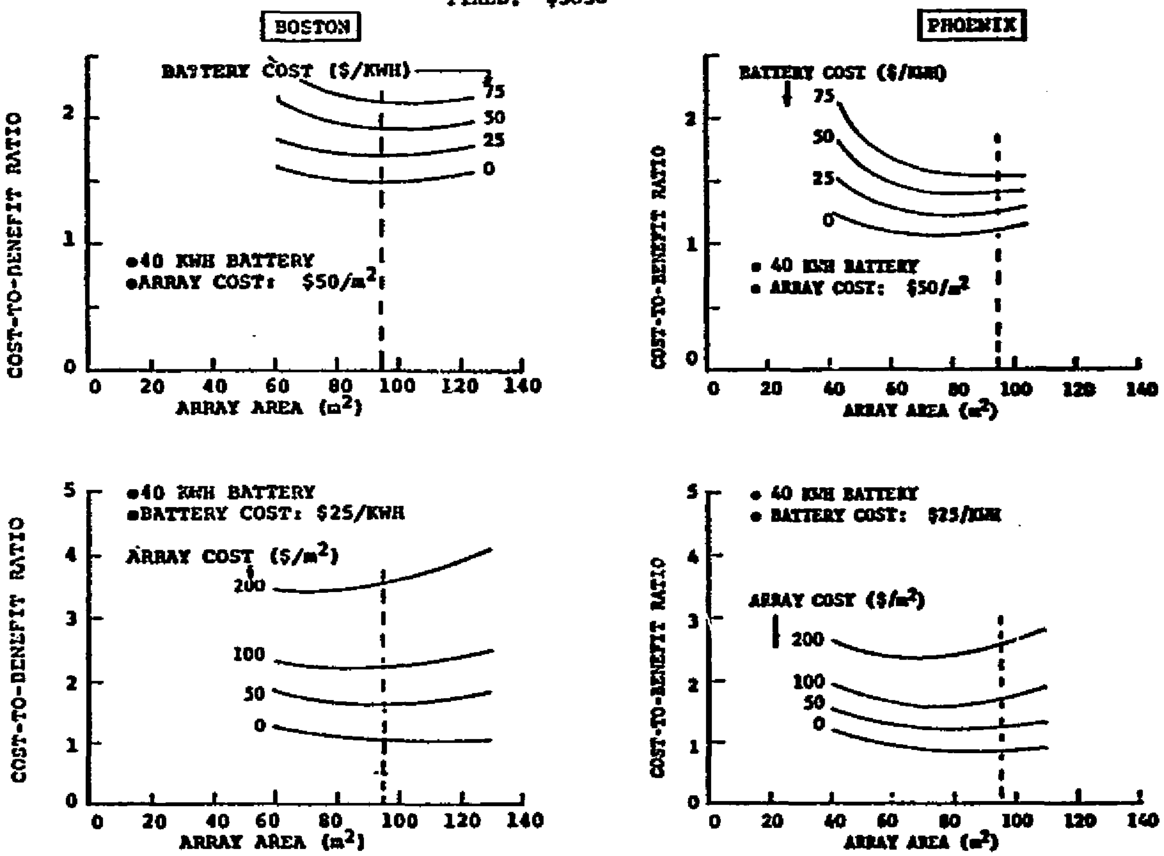
1(a) PV-ONLY SYSTEM: ALL ELECTRIC, WITH STORAGE
ARRAY AREA OPTIMIZATION

- ESCALATION: 2% ABOVE INFLATION
- BALANCE OF PLANT COSTS
  - VARIABLE: $22.3/m^2$
  - FIXED: $3830



OPTIMUM AREA FOR ANALYSIS IS 95 M²

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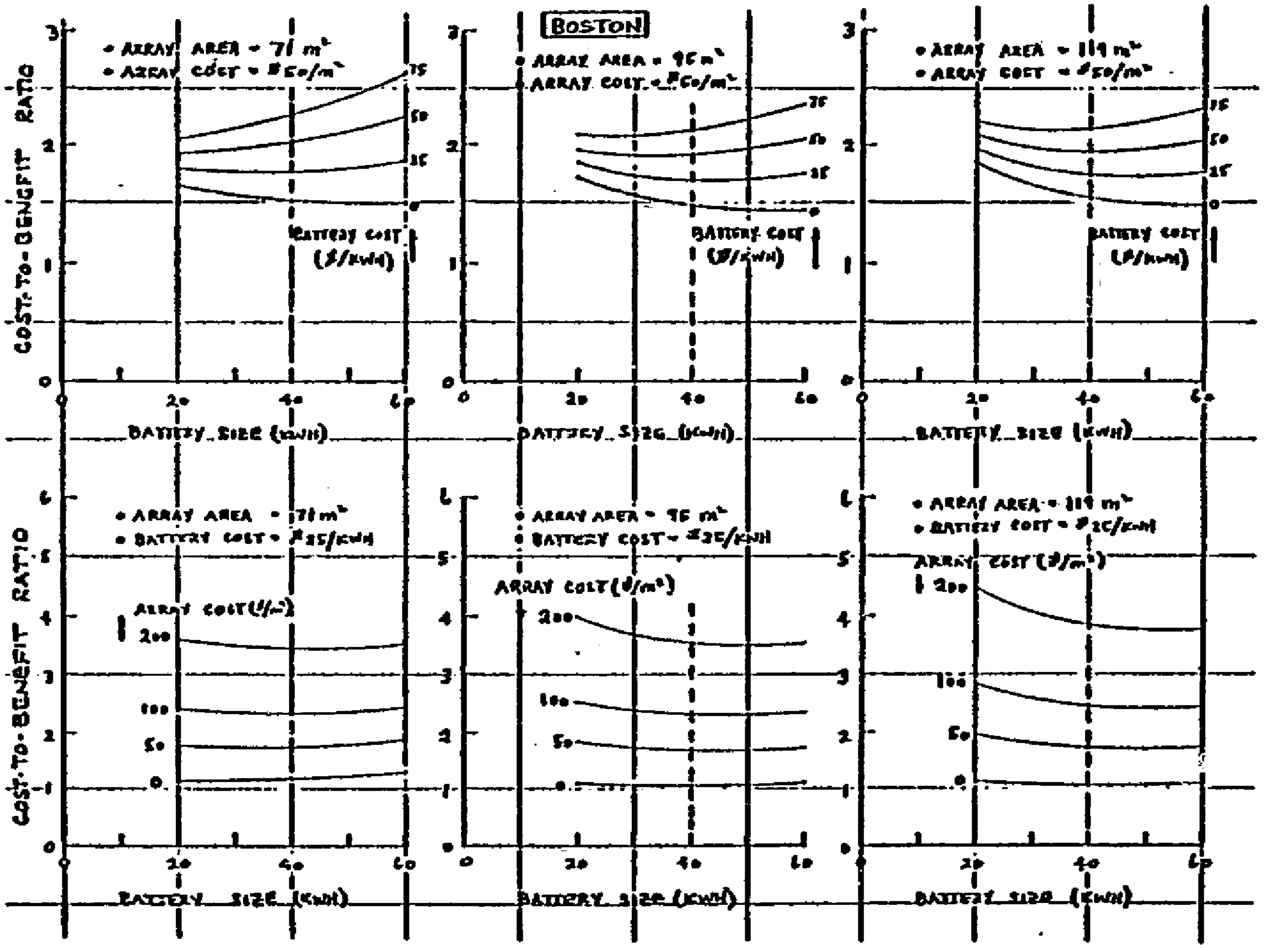
I(a) PV-ONLY SYSTEM: ALL-ELECTRIC, WITH STORAGE

BATTERY SIZE OPTIMIZATION

- BALANCE OF PLANT
- ESCALATION 2% ABOVE INFLATION

VARIABLE: $22.3/m^2

FIXED: $3830



OPTIMUM BATTERY SIZE FOR ANALYSIS IS 40 kWh

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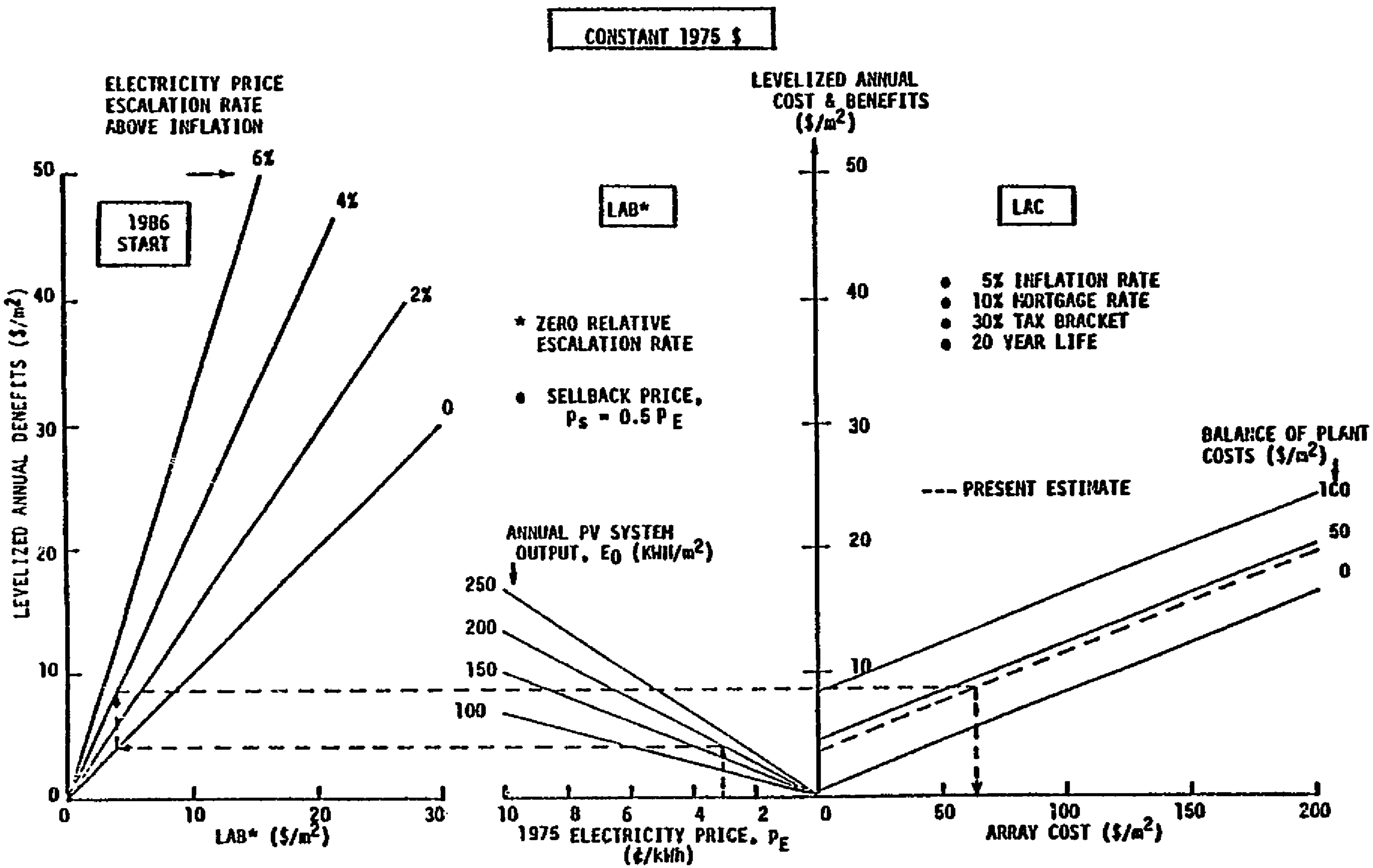
ECONOMIC NOMOGRAPH FOR RESIDENTIAL PV SYSTEM WITH SELLBACK MODE



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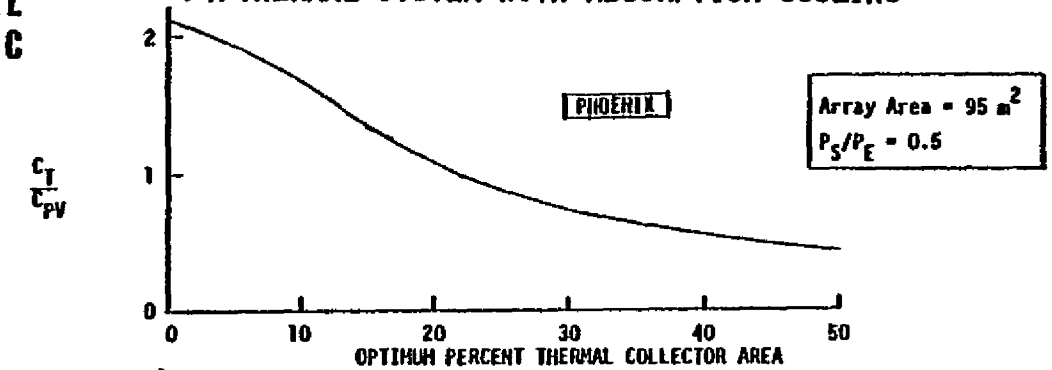
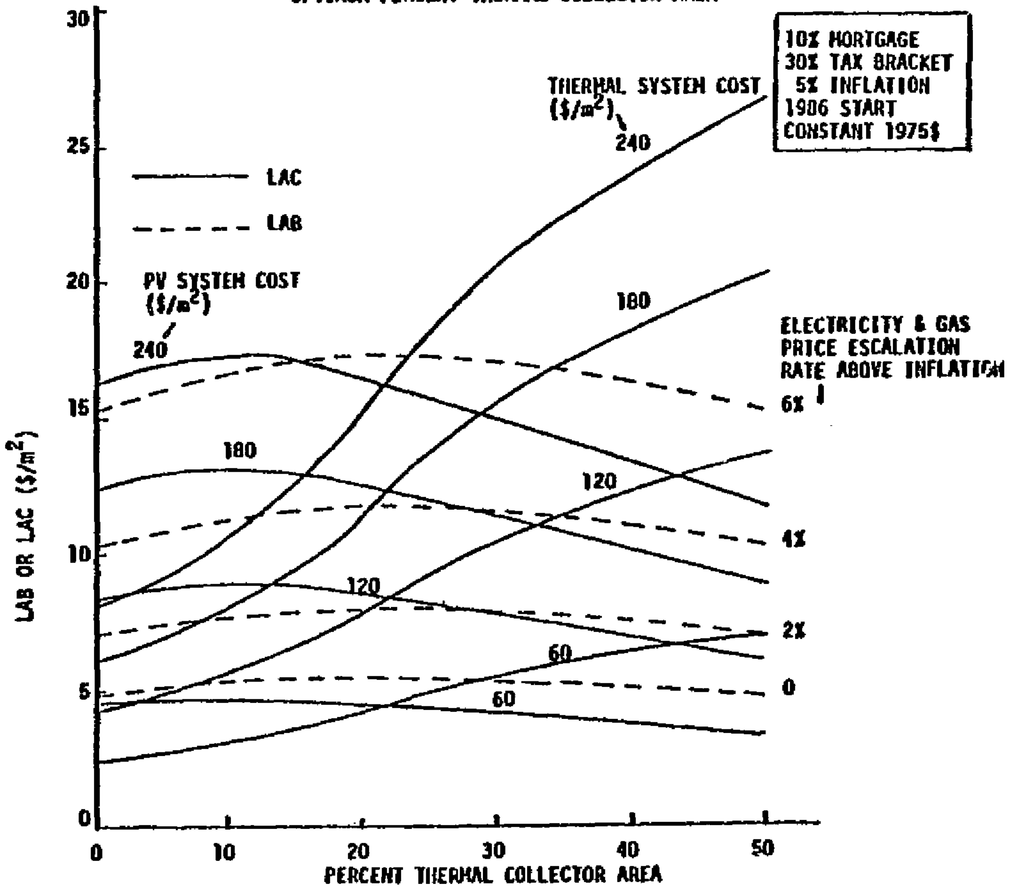
C-5

PARAMETRIC DATA FOR SIDE-BY-SIDE PV/THERMAL SYSTEM WITH ABSORPTION COOLING





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RELATIVE RANKING OF RESIDENTIAL SYSTEM PERFORMANCE AND ECONOMICS THROUGH COST-TO-BENEFIT RATIO

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SYSTEM CATEGORY / KEY WORD DESCRIPTOR / COLLECTOR AREA	PV-ONLY SYSTEMS — SINGLE					PV-ONLY SYSTEMS — CONCENTRATOR		SIDE-BY-SIDE SYSTEMS				COMBINED SYSTEMS	
	I(a)	I(e)	I(b)	I(c)	I(d)	I(e)	I(f)	II(a)	II(b)	II(c)	II(d)	III(a)	III(b)
	DIR.CHG STORAGE	NIGHTTIME CHARGE	FOSSIL HEAT	ALL ELECTRIC	MAX.TRACK STORAGE	ALL ELECTRIC	FOSSIL HEAT	ELECTRIC SOLAR HEAT	FOSSIL SOLAR HEAT	RANKINE	ABSORPTION	ELECTRIC SOLAR HEAT	FOSSIL SOLAR HEAT
REGION	95 M²	95 M²	95 M²	95 M²	95 M²	32 M²	32 M²	95 M²	95 M²	95 M²	95 M²	26 M²	26 M²
1. BOSTON	1.13	1.00	0.96	0.87		1.64	1.82	0.87 (0%)*	0.96 (0%)	0.85 (7%)	0.95 (13%)	1.65	1.99
2. WASHINGTON, D.C.	(1.59)		(1.37)	1.20		2.49	2.75						
3. CHARLESTON	(1.43)		(1.24)	1.08		2.17	2.41						
4. MIAMI	(1.34)		(1.16)	.96		2.10	2.33			0.91 (5%)			
5. BISMARCK	(1.59)		1.36	1.15		1.[illegible]5	2.16	1.15 (0%)	1.36 (0%)			3.72	3.06
6. MADISON	(1.65)		(1.42)	1.24		2.37	2.64						
7. OMAHA	(1.69)		(1.46)	1.26		2.16	2.40						
8. FORT WORTH	1.90		1.67	1.53		2.73	3.03			1.48 (3%)	1.63 (19%)		
9. NASHVILLE	(2.10)		1.85	1.62		3.12	3.46	1.56 (6%)	1.85 (0%)			2.86	4.06
10. PHOENIX	0.83	0.82	0.69	0.64	0.83	0.88	0.97	0.61 (4%)	0.69 (0%)	0.63 (5%)	0.76 (4%)	1.20	1.76
11. ALBUQUERQUE	(1.11)		1.00	.89		1.20	1.34	.85 (6%)	1.00 (0%)	.84 (7%)			
12. SEATTLE	(6.78)		(5.86)	5.40		10.58	11.76						
13. SANTA MARIA	(1.44)		(1.24)	1.14		1.82	2.02						

*OPTIMUM PERCENT THERMAL COLLECTOR AREA

( ) RESULTS BASED ON CORRELATION

MAJOR PROGRAM CONCLUSIONS

BASED ON ASSUMED ECONOMIC SCENARIO

- PV SYSTEMS WITH UTILITY SELLBACK RATES GREATER THAN 50% OF THE BUY RATE ARE MORE ATTRACTIVE THAN SYSTEMS WITH BATTERY STORAGE
- MOST SITES SHOW ECONOMIC VIABILITY IN THE 1986 TIME FRAME AT 50¢/WATT CELL COSTS
- SIDE-BY-SIDE PV/THERMAL SYSTEMS SHOW ECONOMIC VIABILITY IF PV SYSTEM TO THERMAL SYSTEM COST RATIO IS NEAR 1
- IMMEDIATE IMPLEMENTATION OF PV - ONLY SYSTEM TEST FACILITIES IN THE SOUTHWEST, NORTHEAST AND SOUTHEAST IS RECOMMENDED.

GRID-CONNECTED RESIDENTIAL PHOTOVOLTAIC SIMULATION MODEL FOR ECONOMIC ANALYSIS*

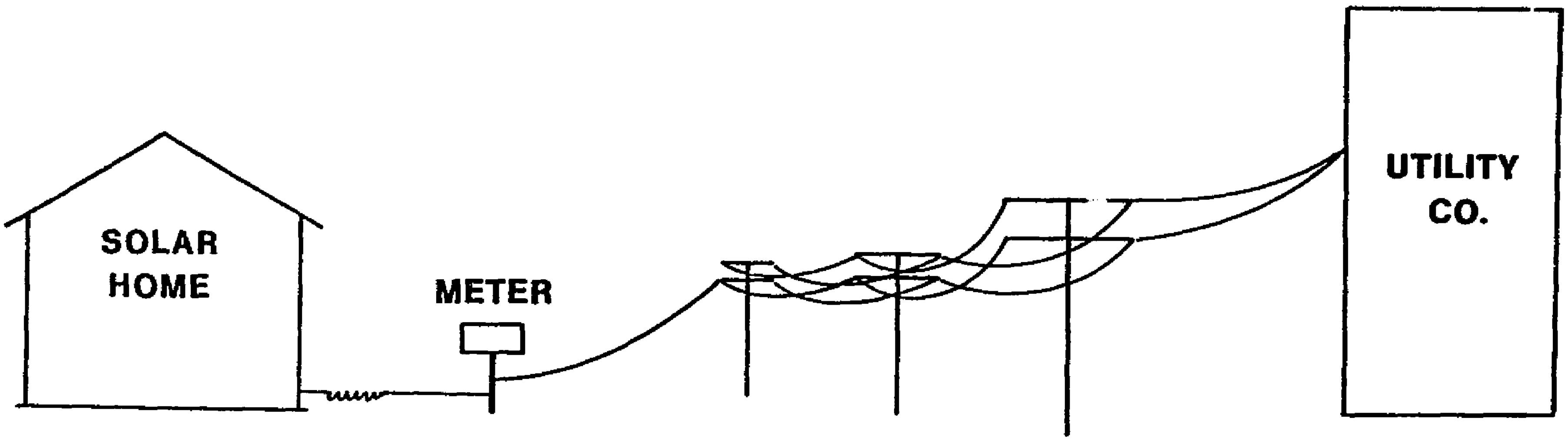
MIT ENERGY LABORATORY

PRESENTED BY:

PAUL R. CARPENTER

JET PROPULSION LABORATORY

*THE REPORT DETAILING THIS WORK, AN ECONOMIC ANALYSIS OF GRID-CONNECTED RESIDENTIAL SOLAR PHOTOVOLTAIC POWER SYSTEMS, PAUL R. CARPENTER AND GERALD A. TAYLOR, MIT ENERGY LABORATORY REPORT MIT-EL-78-007, CAN BE CONTAINED FROM THE MIT ENERGY LABORATORY, CAMBRIDGE, MASS. 02L39


SOLAR
HOME
METER
UTILITY
CO.

MODEL STRUCTURE

PV ARRAY MODEL

SOLMET INSOLATION (HOURLY)
SYSTEM DESIGN
OPERATING CHARACTERISTICS
↓
PV SYSTEM OUTPUT

SCHEDULING MODEL

APPLIANCE LOADS
APPLIANCE USE BEHAVIOR
RATE STRUCTURE (BUYBACK RATE)
↓
PURCHASES W/O PV
PURCHASES WITH PV
UTILITY SELL-BACK

ECONOMIC MODEL

ECONOMIC ASSUMPTIONS
DEGRADATION
↓
NPV
BREAKEVEN COSTS

SIMULATION MODEL SCHEDULING HEURISTIC

1. IS LOAD IN MUST-RUN PERIOD? RUN THOSE LOADS THAT MUST BE RUN.

2. IS LOAD "RUNNABLE"? A LOOK-AHEAD IS PERFORMED FOR RUNNABLE LOADS WHICH ATTACHES COSTS TO THE LOADS IN VARIOUS RUN SCENARIOS BASED ON THE AVERAGE UTILITY PRICE OVER THE RUN PERIOD. LOADS ARE RANKED IN ORDER OF MOST EXPENSIVE AND, IF THERE ARE TIES, BY LARGEST LOAD.

3. IS THERE SOLAR AVAILABLE? RUNNABLE LOADS ARE SWITCHED ON IN PRIORITY ORDER WHILE EXCESS SOLAR EXISTS. IF INSUFFICIENT SOLAR EXISTS TO COVER FULL LOAD, THEN LOAD IS SWITCHED ON WHILE THE WEIGHTED PRICE OF SOLAR PLUS UTILITY POWER IS LESS THAN A PRE-SET LIMIT.

4. LEFT-OVER SOLAR IS SOLD BACK TO UTILITY.

5. IF NO SOLAR THEN LOADS OTHER THAN "MUST-RUNS" ARE POSTPONED.

ASSUMPTIONS FOR LATEST RESULTS

LIFETIME = 20 YEARS

DEGRADATION = 5% IN FIRST TWO YEARS (PER YEAR)
.7% THEREAFTER (PER YEAR)

DISCOUNT RATE = 3%

FUEL PRICE ESCALATION RATE = 3%

ARRAY SIZE = 35 M^2

MODULE EFFICIENCY = 12.7%

SYSTEM EFFICIENCY = 10.2%

APPLIANCE AND BEHAVIORAL ASSUMPTIONS AS OUTLINED IN PREVIOUS REPORT

NO STORAGE

LATEST RESULTS ($/$W_P$ SYSTEM)

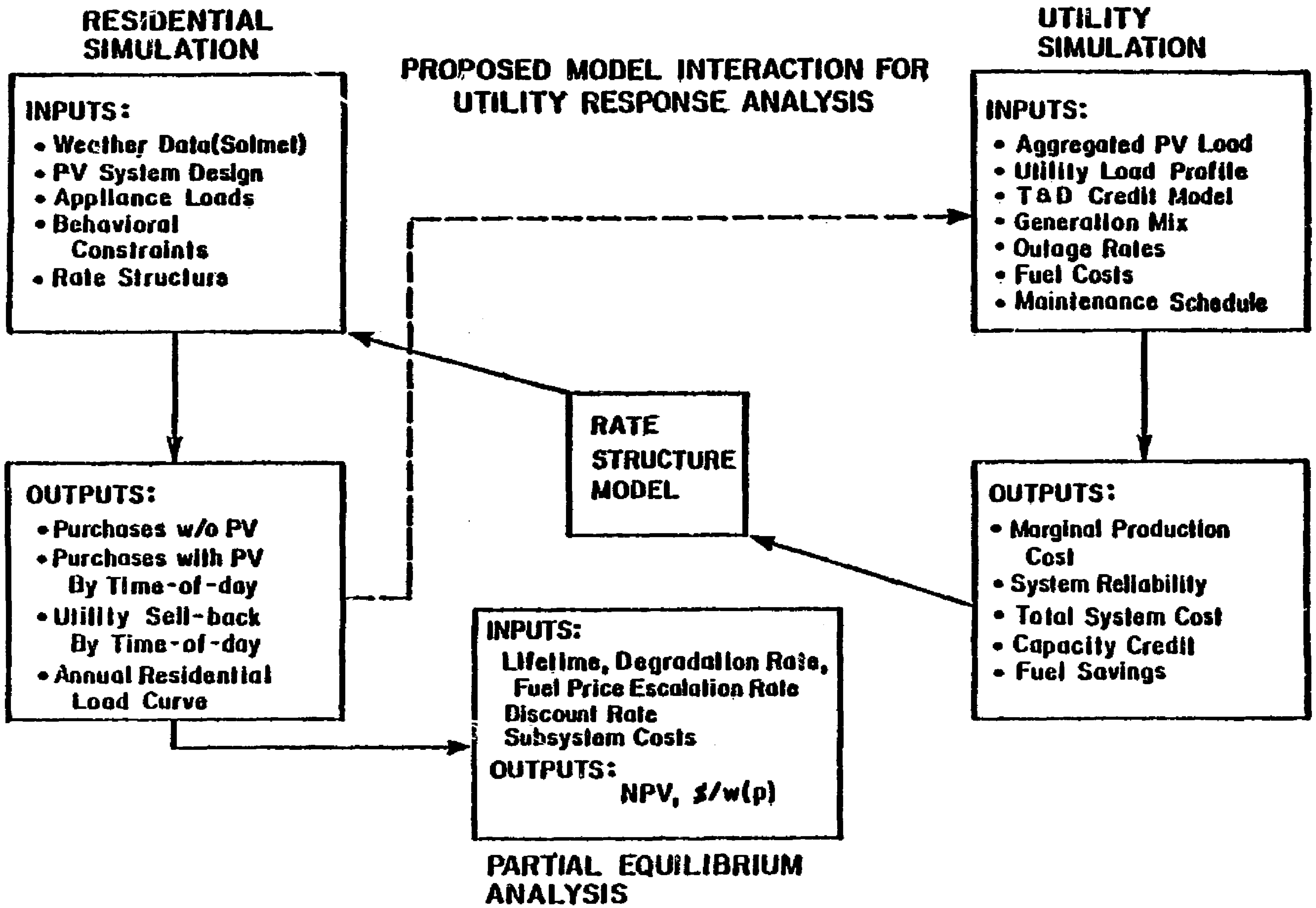
TIME-OF-DAY PRICING (FIRST QUARTER 1975 DOLLARS)

	50% BUYBACK	100% BUYBACK
BOSTON	$ .97	$1.34
OMAHA	.76	
PHOENIX	1.51	1.88

RESULTS (P. 2)

FLAT RATES (33% FUEL COMPONENT)

	50% BUYBACK	100% BUYBACK
BOSTON	$ .90	$1.24
OMAHA	.88	
PHOENIX	1.47	1.92


PROPOSED MODEL INTERACTION FOR
UTILITY RESPONSE ANALYSIS
RESIDENTIAL
SIMULATION
INPUTS:
• Wecther Data(Solmet)
• PV System Design
• Appliance Loads
• Behavioral
Constraints
• Rale Structura
OUTPUTS:
• Purchases w/o PV
• Purchases with PV
By Time-of-day
• Utility Sell-back
By Time-of-day
• Annual Residential
Load Curve
RATE
STRUCTURE
MODEL
UTILITY
SIMULATION
INPUTS:
• Aggregated PV Load
• Utilily Load Profile
• T&D Credit Model
• Generation Mix
• Outage Rates
• Fuel Costs
• Maintenance Schedule
OUTPUTS:
• Marginal Production
Cost
• System Reliability
• Total System Cost
• Capacity Credit
• Fuel Savings
INPUTS:
Lifetime, Degradation Rate,
Fuel Price Escalation Rate
Discount Rate
Subsystem Costs
OUTPUTS:
NPV, $/w(p)
PARTIAL EQUILIBRIUM
ANALYSIS

ANALYSIS METHODOLOGY:
ON-SITE PHOTOVOLTAIC SYSTEM APPLICATIONS

B. Siegel

The Aerospace Corporation

El Segundo, California

Presented at

U.S. Department of Energy

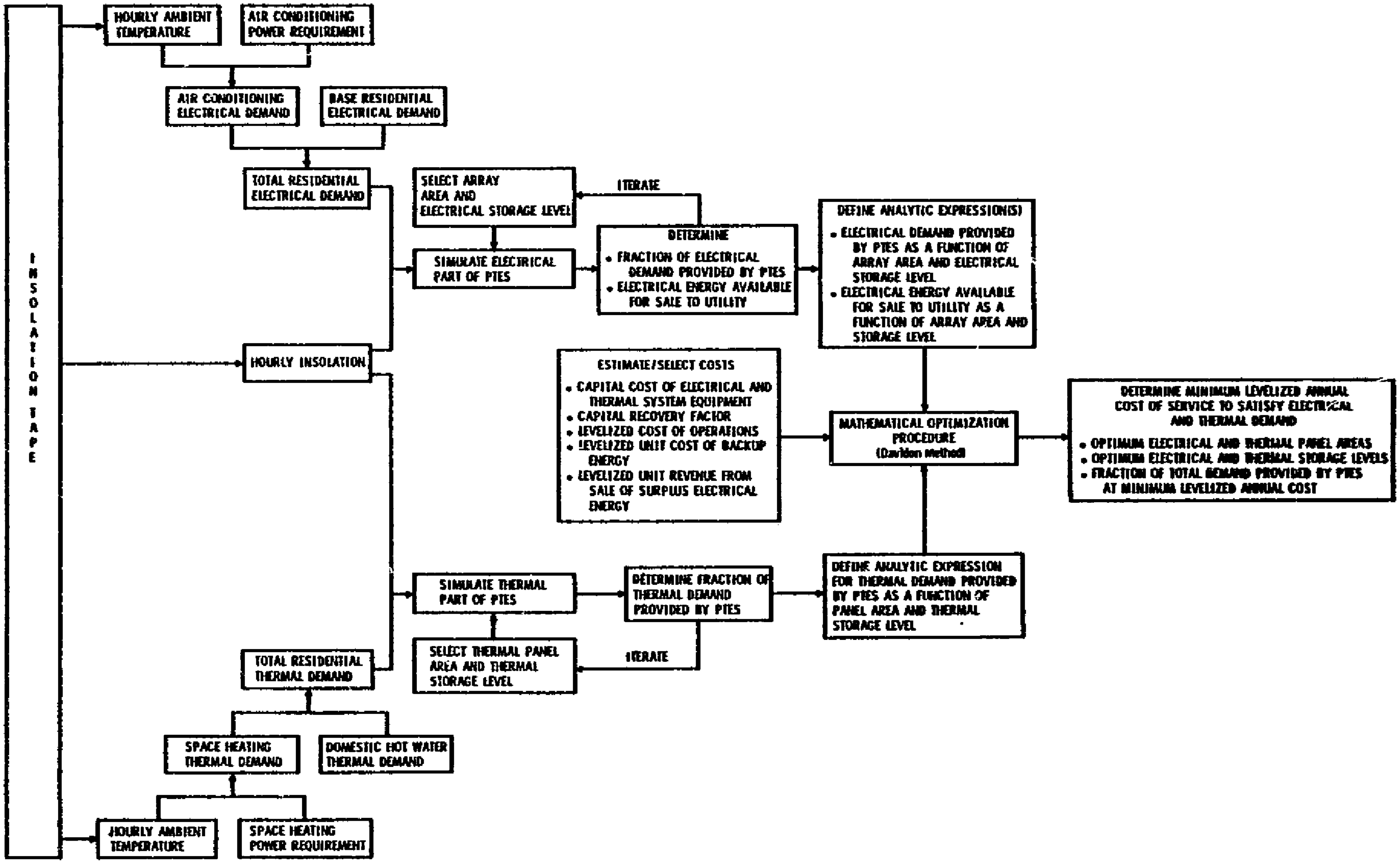
PHOTOVOLTAICS TECHNOLOGY DEVELOPMENT AND APPLICATIONS PROGRAM REVIEW

Arlington, Virginia

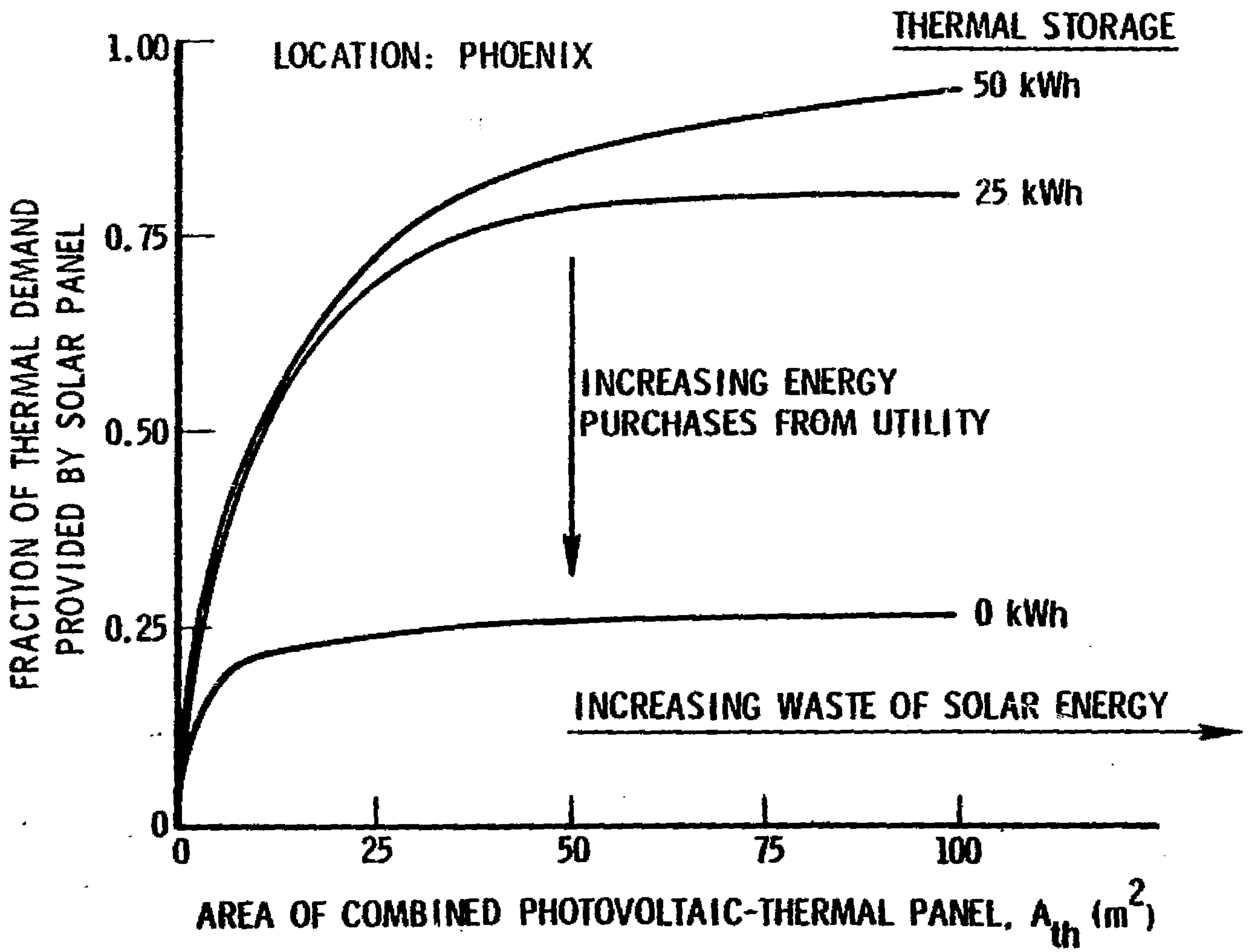
November 7-9, 1978

Analysis Flow

PHOTOVOLTAIC TOTAL ENERGY SYSTEMS FOR RESIDENTIAL APPLICATIONS



System Performance Simulation



Economic/Cost Assumptions

- LEVELIZED ANNUAL COST OF SERVICE
  - (CRF) $C_c + C_{O\&M} + C_{Bu} - C_R$
  - 1975 DOLLARS

CRF = CAPITAL RECOVERY FACTOR

C_c = INSTALLED CAPITAL COST

$C_{O\&M}$ = LEVELIZED COST OF OPERATIONS AND MAINTENANCE

C_{Bu} = LEVELIZED COST OF BACKUP ENERGY

C_R = LEVELIZED REVENUE FROM FEEDBACK

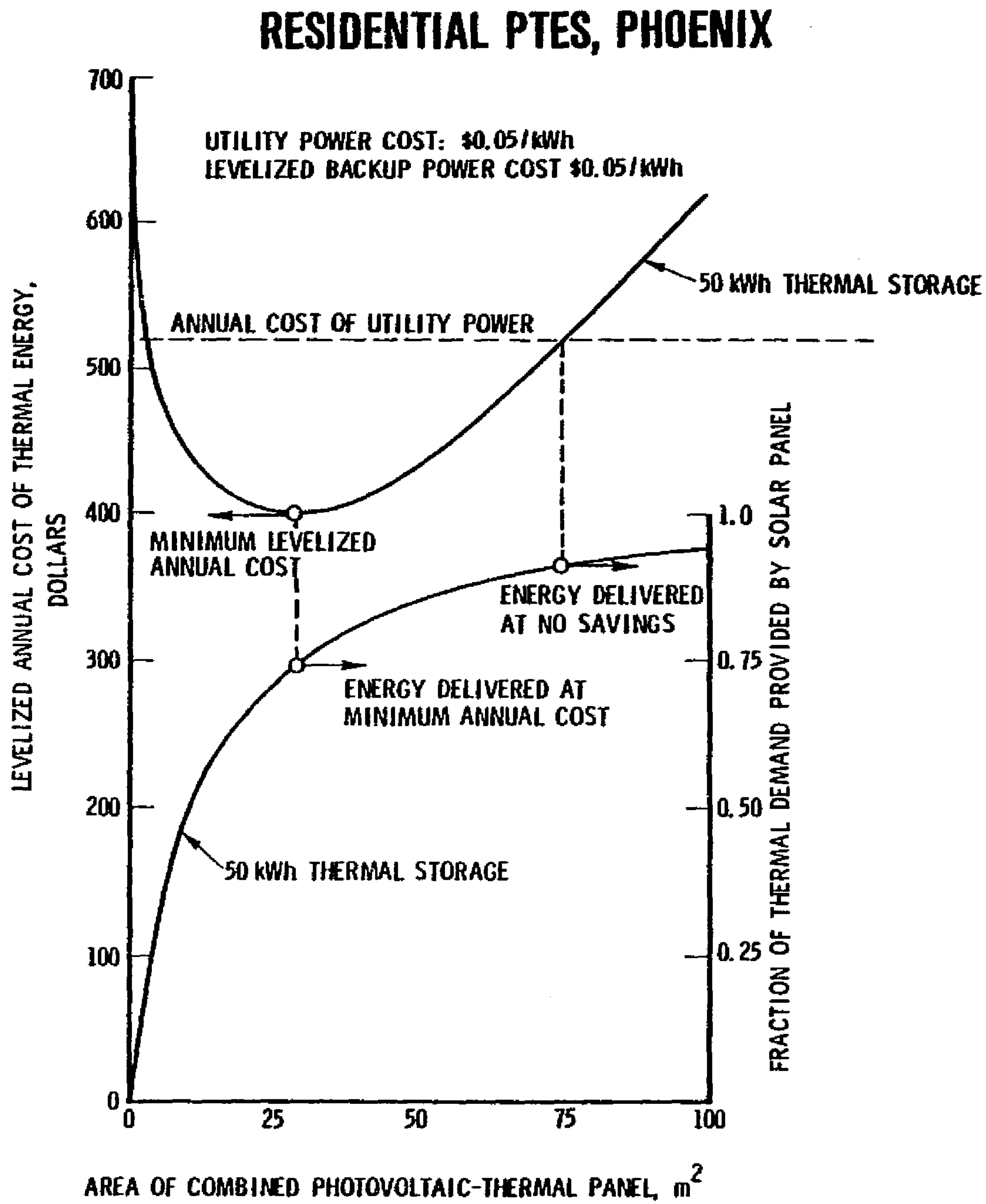
- ASSUMPTIONS FOR RESIDENTIAL TOTAL ENERGY STUDY
  - THERMAL PANEL COST = $50/m^2
  - THERMAL STORAGE COST = $10.66/kWh
  - COST OF PUMPS, VALVES, PIPES, HEAT EXCHANGERS = $1000
  - ARRAY EFFICIENCY = 13.5% @ 20°C
  - ARRAY STRUCTURE COST = $10/m^2 (roof mounted)
  - ARRAY COST = VARIABLE ($100/kW$_{pk}$ to $1000/kW$_{pk}$)
  - ELECTRIC STORAGE COST = $40/kWh
  - POWER CONDITIONER COST = $100/kW$_{pk}$
  - LEVELIZED COST OF BACKUP ENERGY = VARIABLE ($0.05/kWh to $0.10/kWh)
  - LEVELIZED REVENUE FROM FEEDBACK (0 to $0.03/kWh)
  - CRF = 0.09 OR 0.11, 30 YEAR SYSTEM LIFE (discount rate = 0.08 or 0.10)
  - $C_{O\&M} = 0.015\ C_c$

Levelized Annual Cost of Energy

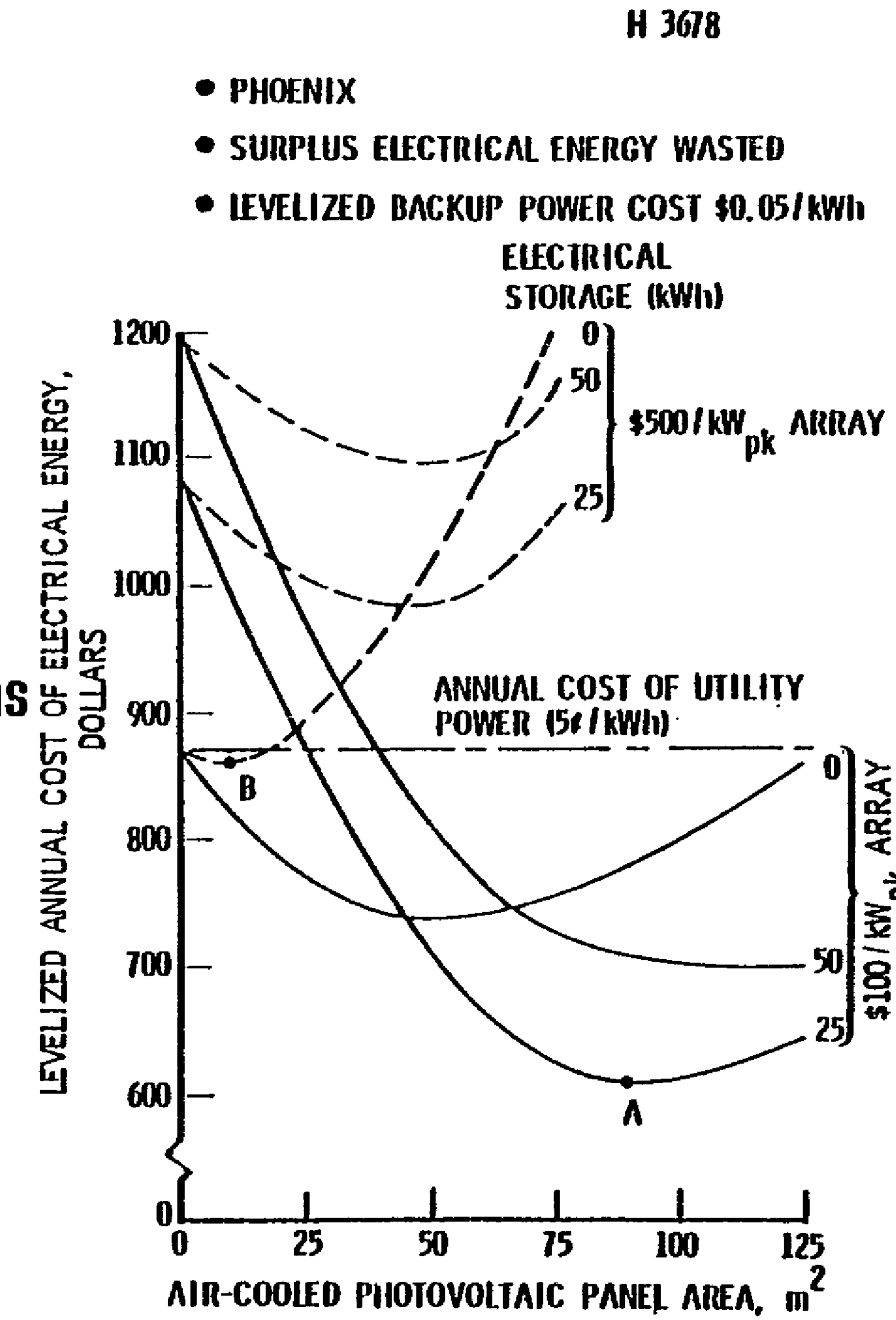
THERMAL ENERGY

RESIDENTIAL PTES, PHOENIX

G5663



Effect of Changes in System Cost Assumptions



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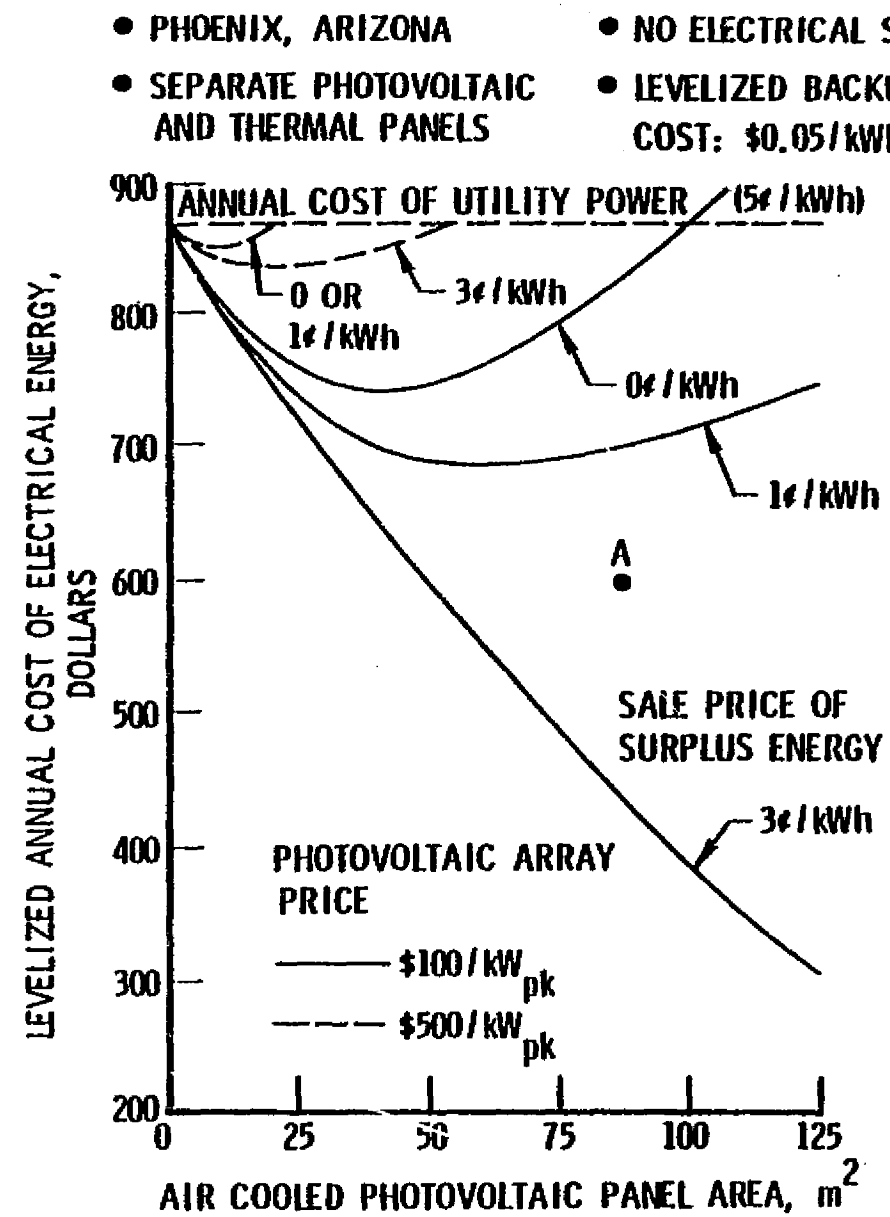
Effect of Sale of Surplus Electrical Energy to Utility

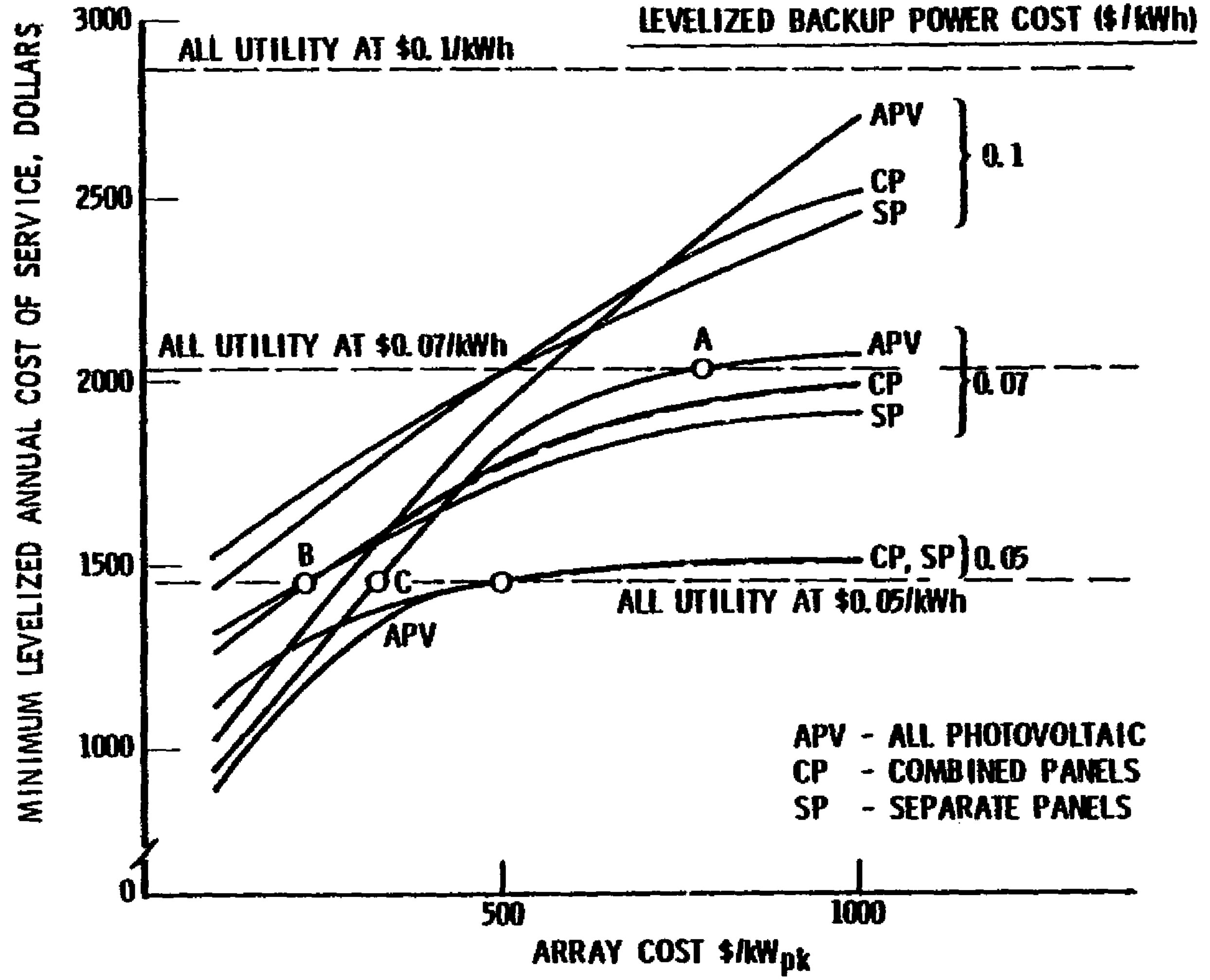


Photovoltaic Total Energy Systems

H2230

MINIMUM LEVELIZED ANNUAL COST OF SERVICE

- SINGLE-FAMILY RESIDENTIAL APPLICATION
- PHOENIX, TOTAL DEMAND 28,850 kWh
- CRF - 0.09



Effect of Changes in Economic Assumptions on Breakeven Array Cost for PTES

All-Photovoltaic System, Phoenix
System Begins Operation in 1986 (30 year life)
1975 Dollars

• **Baseline Case** CRF = .09 (8% mortgage money), Cost of Utility and Backup Power Equal, No Power Feedback, Cost of Utility Power Increases at Same Rate as Annual Rate of Inflation (5%/year, 1975 - 2016)	$ 490/kW_{pk}
• Baseline with 7% Annual Inflation Rate, 1975 - 2016	$930/$kW_{pk}$
• Baseline with a 2% Annual Increase over the Annual Rate of Inflation (5%/year), 1975 - 2016	$1200/$kW_{pk}$
• Baseline with CRF = .11 (10% mortgage money)	$ 430/kW_{pk}
• Baseline with CRF = .051 (3% loan money for solar systems - proposed legislation)	$1050/$kW_{pk}$
• Baseline, with Utility Power Cost Always 10% Less than Backup Power Cost	$ 380/kW_{pk}
• Baseline, with Power Feedback, Utility Accepts All Energy Available and Pays 3¢/kWh	$ 725/kW_{pk}

U. S. DOE PHOTOVOLTAICS TECHNOLOGY
DEVELOPMENT AND APPLICATIONS PROGRAM REVIEW

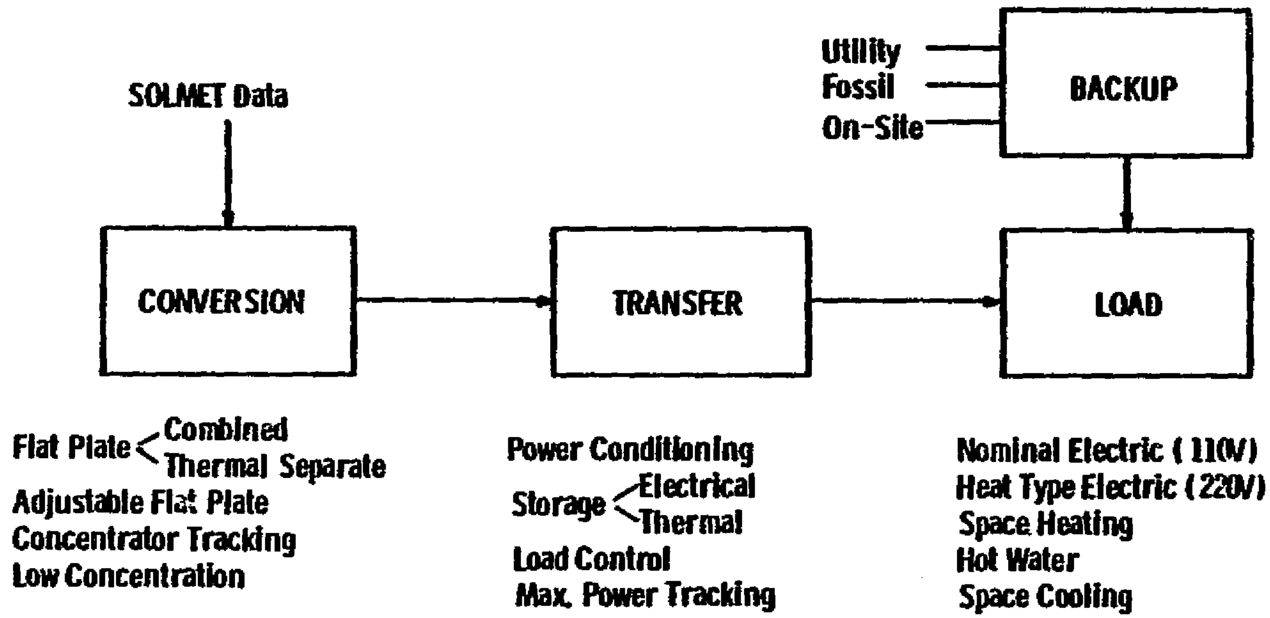
SESSION II COST/ECONOMICS

VIEWGRAPHS

PRESENTED BY E. F. FEDERMANN NOVEMBER 8, 1978

WESTINGHOUSE RESEARCH & DEVELOPMENT CENTER
PITTSBURGH, PENNSYLVANIA 15235

Dwg. 6451A54


SOLMET Data
CONVERSION
TRANSFER
LOAD
BACKUP
Utility
Fossil
On-Site
Flat Plate
Combined
Thermal Separate
Adjustable Flat Plate
Concentrator Tracking
Low Concentration
Power Conditioning
Storage
Electrical
Thermal
Load Control
Max. Power Tracking
Nominal Electric (110V)
Heat Type Electric (220V)
Space Heating
Hot Water
Space Cooling

Dwg. 6445A96

COMPUTER SIMULATION COMPLEXITY LEVEL (CSCL)

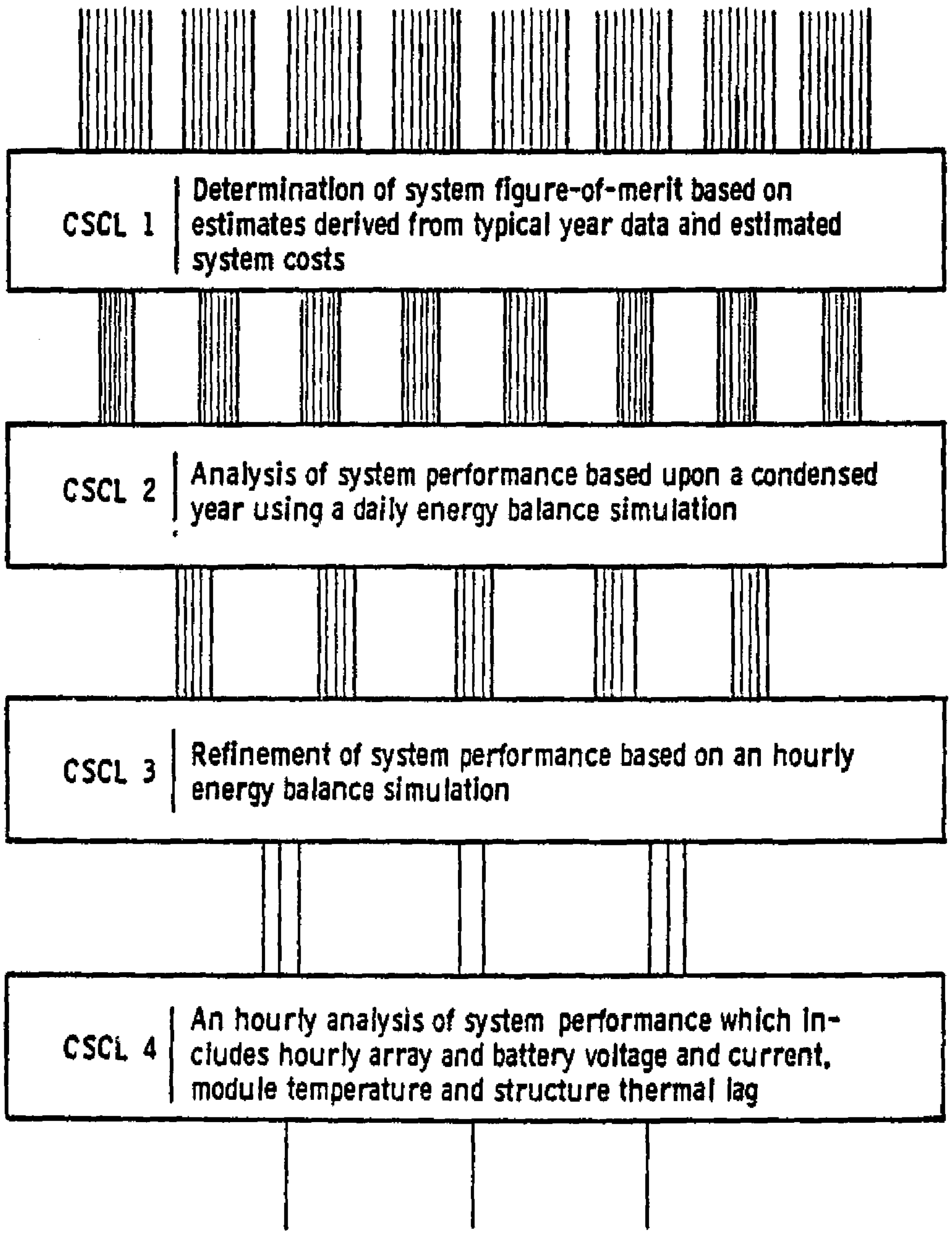


Fig. 5.1.2 – System rejection technique

SAMPLE FORMULATIONS

- COMBINED FLAT PLAT - ELECTRICAL OUTPUT:

  U_{DIR} and U_{DIF} from SOLMET

  Absorbed Energy = $.85\ F_E \times S \times U_{DIR} \cos\theta + .573\alpha\ U_{DIF}$

  $F_E = 1 - 0.225 \left(\frac{\theta}{\pi/2}\right)^2 \exp(1.414 \frac{\theta}{\pi/2})$

  $S = 1 - .08 \tan\theta$

  θ = Incidence angle

  $\alpha = (1 - 0.5\ U_{DIR})(1 - \frac{TILT}{\pi}) + \frac{1}{2} U_{DIR} \times \cos\theta$

  Photovoltaic Conversion = $e_n e_p e_t$ x Absorbed Energy

  $e_n e_t e_p$ are nominal, temperature, packing efficiencies

  e_n and e_t are calculated by the hour for CSCL4

- BATTERY DISCHARGE, USED ONLY IN CSCL 4

  For currents between 12.5 and 62.5 amperes:

  $V = \frac{62.5 - I}{50} (V_{12.5} - V_{62.5}) + V_{62.5}$

  $V_{12.5} = 1.936 + 0.1768\ C^{0.75} - 0.0943\ (C - 0.476)^2$

  $V_{62.5} = 1.810 + 0.2411\ C^{0.575} - 0.0966\ (C - 0.509)^2$

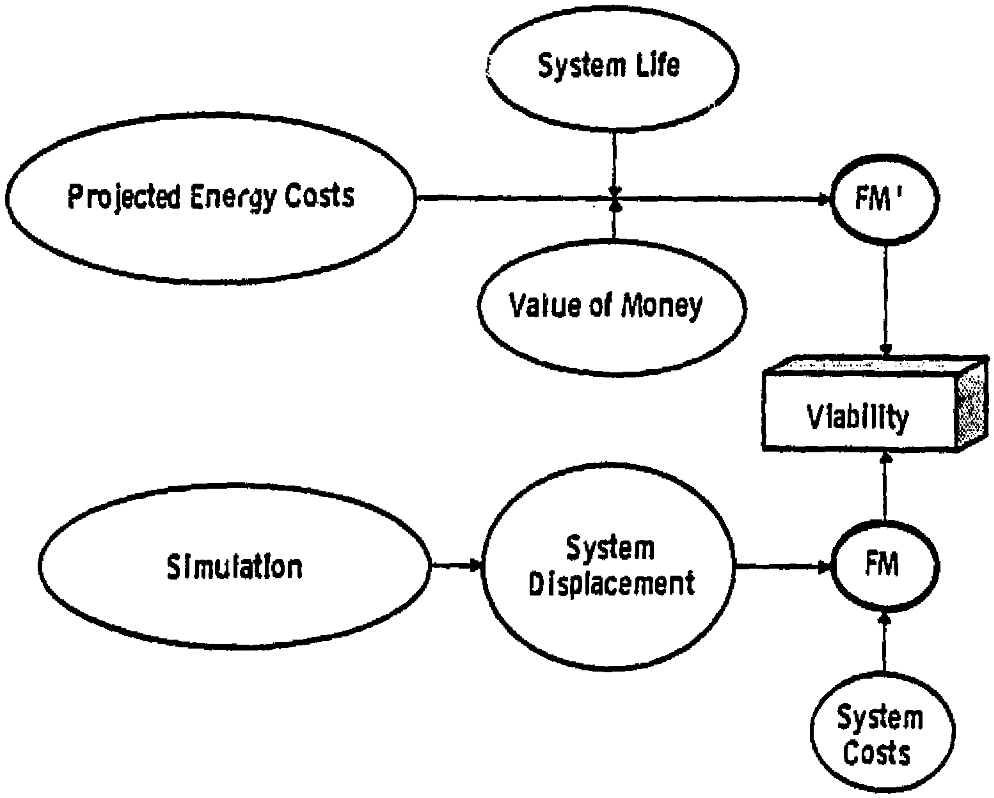
  where C = state of charge

- SIMPLIFIED SPACE-HEATING (H) USED IN CSCL 1, 2, 3:

  BOSTON: $H = 22040 - 380\ T \geq 0$

  where T = ambient temperature in degrees Fahrenheit

Dwg. 6439A19



$$F_M = \frac{\text{Present Value of All System Costs}}{\text{Annual System Displacement (kwh)}}$$

$$F_M' = M(\text{Composite Fuel Rate at Time of Installation})$$

Where $M = \frac{1 - \exp - (1 - e) N}{1 - e}$

N = System Life

e = Fuel Rate Escalation

I = Mortgage Interest

Fig. 4—Figure-of-merit

MAJOR ASSUMPTIONS

1. HIGH VOLUME PRODUCTION

   - COSTS START AT 200,000 CUMULATIVE RESIDENTIAL UNITS.

   - COSTS BASED ON APPROPRIATE LEARNING CURVE, LIMITED BY COST/# FOR SIMILAR MATURE APPARATUS.

2. GOVERNMENT PRECOMMERCIALIZATION PROGRAM

   - ONE POSSIBILITY - LONG TERM ASSURED PURCHASE OF ALL SUBSYSTEMS AT GRADUALLY REDUCING PRICES.

   - PRECOMMERCIALIZATION WOULD START AT THE $500/PEAK KILOWATT MODULE PRICE AND END IN FIVE TO SEVEN YEARS.

Curve 695686-A

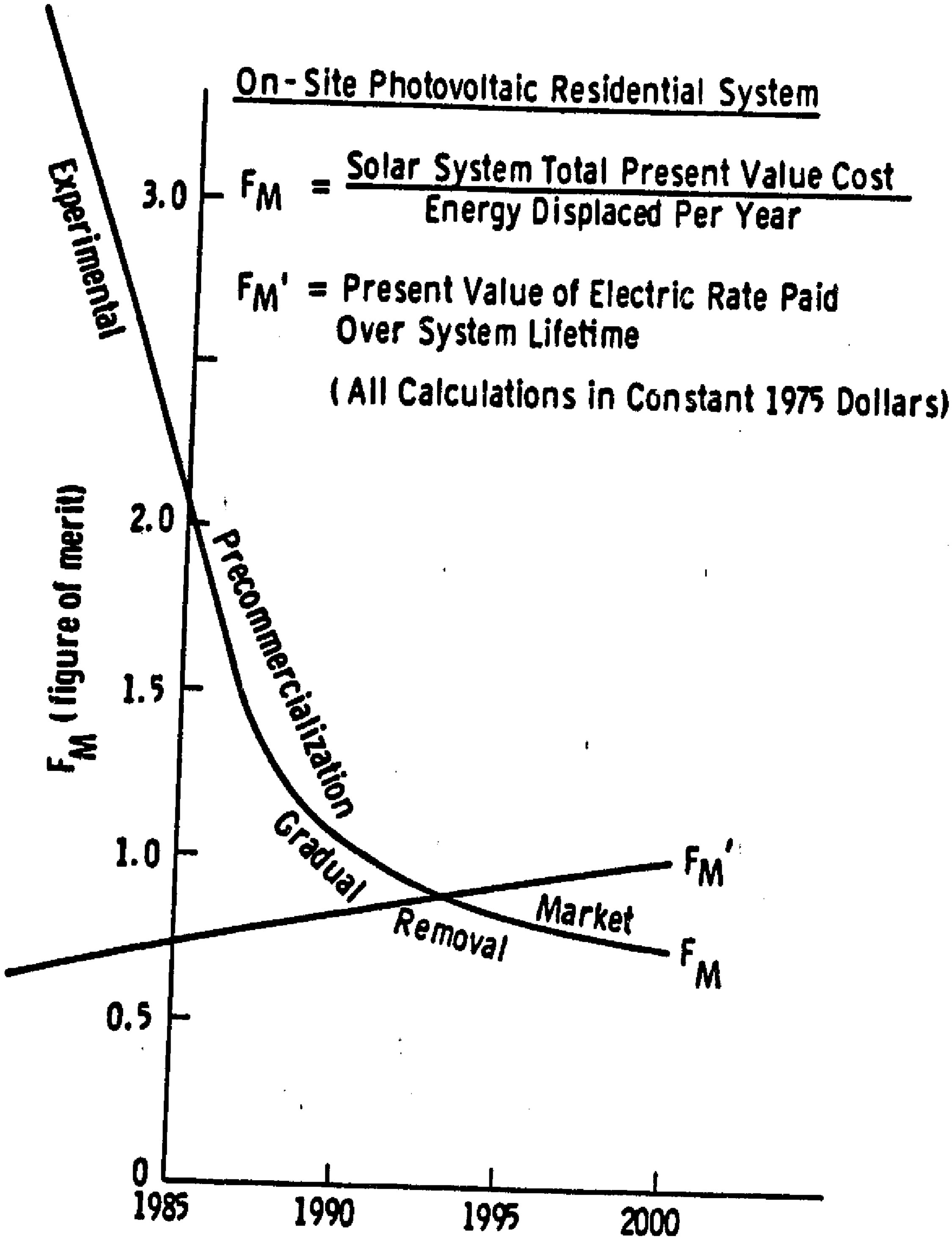


Fig. —Basis for viable cost estimates

Curve 697302-A

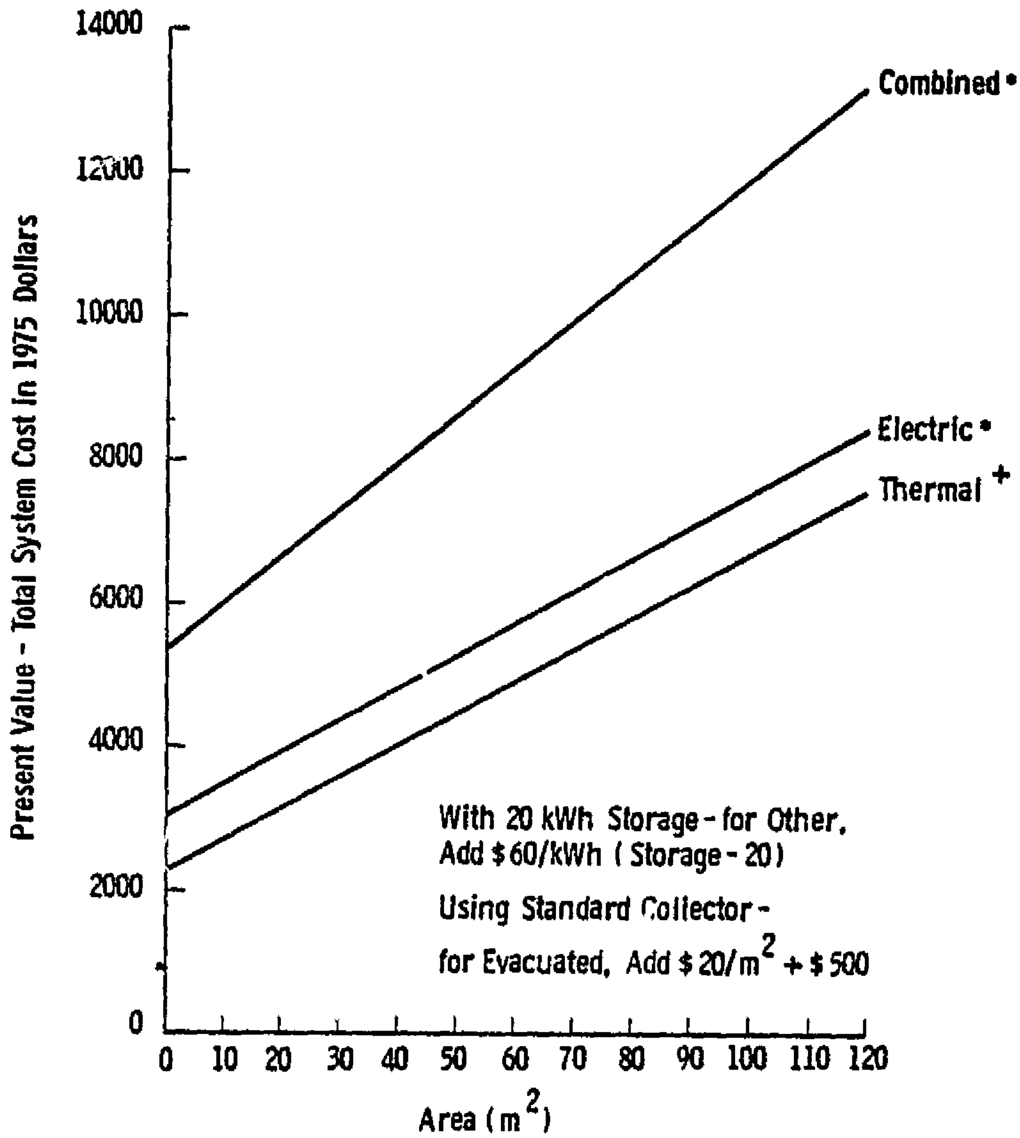


Fig. 5.1.6 — Simplified high volume cost for select systems

Federmann
m. - e.s. 9-7-78

Curve 697302-A

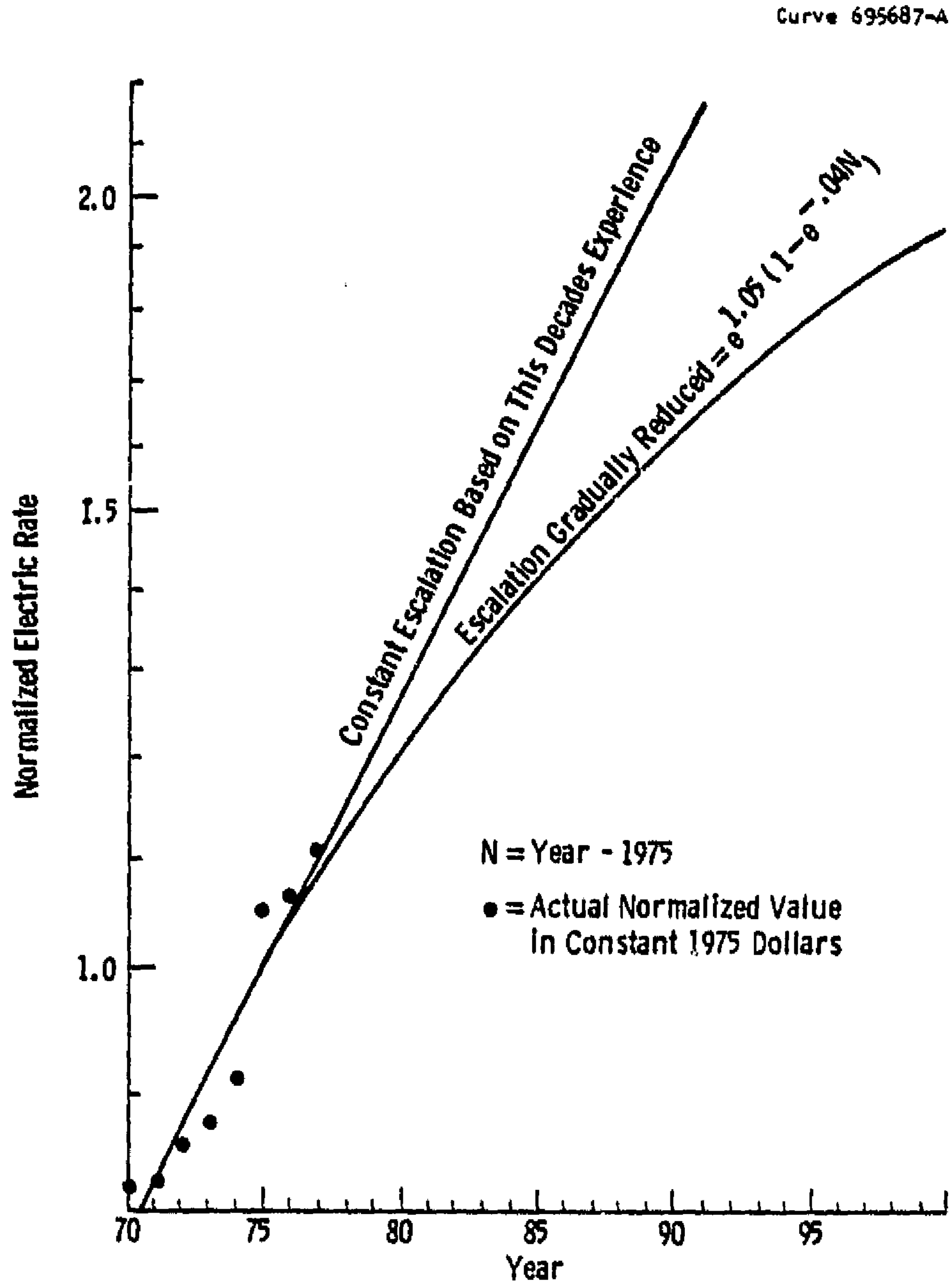


Fig. 2—Projected electric rate

E. Federmann
m. b. m. - l. r. 5-9-78

Curve 695687-A

AVERAGE SITE – RESIDENTIAL APPLICATION

$$\$/m^2 = (U I \mu)(rM)$$

$\$/m^2$ = Allowable overall system cost divided by insolation area
U = Utilization Factor < 1
I = Insolation received per square meter
μ = Overall system efficiency
(rM) = A multiplier determined by the value of money, electric rates and rate escalation
r = Electric rate at time of installation (1975 dollars)

$$M = \frac{1 - \text{Exp.}[-(m-e)N]}{(m-e)}$$

m = Discounted mortgage rate
e = Fuel escalation (Above Inflation)
N = System life

For Curve: I = 1700 kWh/m^2 μ = 0.10, (rM) = .94

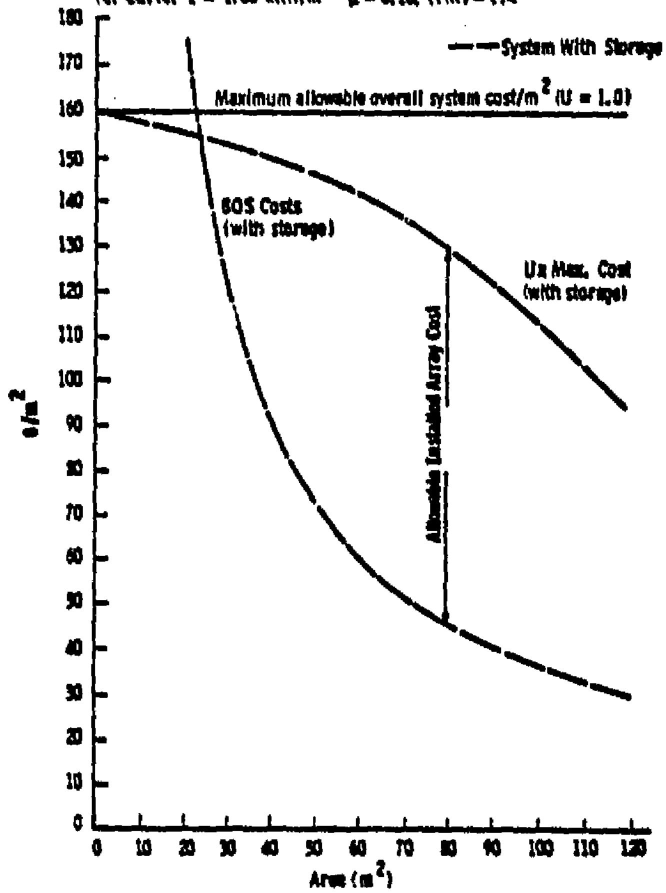


Fig. 5.1.7 – Allowable overall system costs

Curve [illegible]

AVERAGE SITE — RESIDENTIAL APPLICATION

$$\$/m^2 = (U I \mu)\,(rM)$$

$\$/m^2$ = Allowable overall system cost divided by insolation area
U = Utilization Factor < 1
I = Insolation received per square meter
μ = Overall system efficiency
(rM) = A multiplier determined by the value of money, electric rates and rate escalation
r = Electric rate at time of installation (1975 dollars)

$$M = \frac{1 - \mathrm{Exp.}[-(m-e)N]}{(m-e)}$$

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For Curve: I = 1700 kWh/m^2, μ = 0.10, (rM) = .94

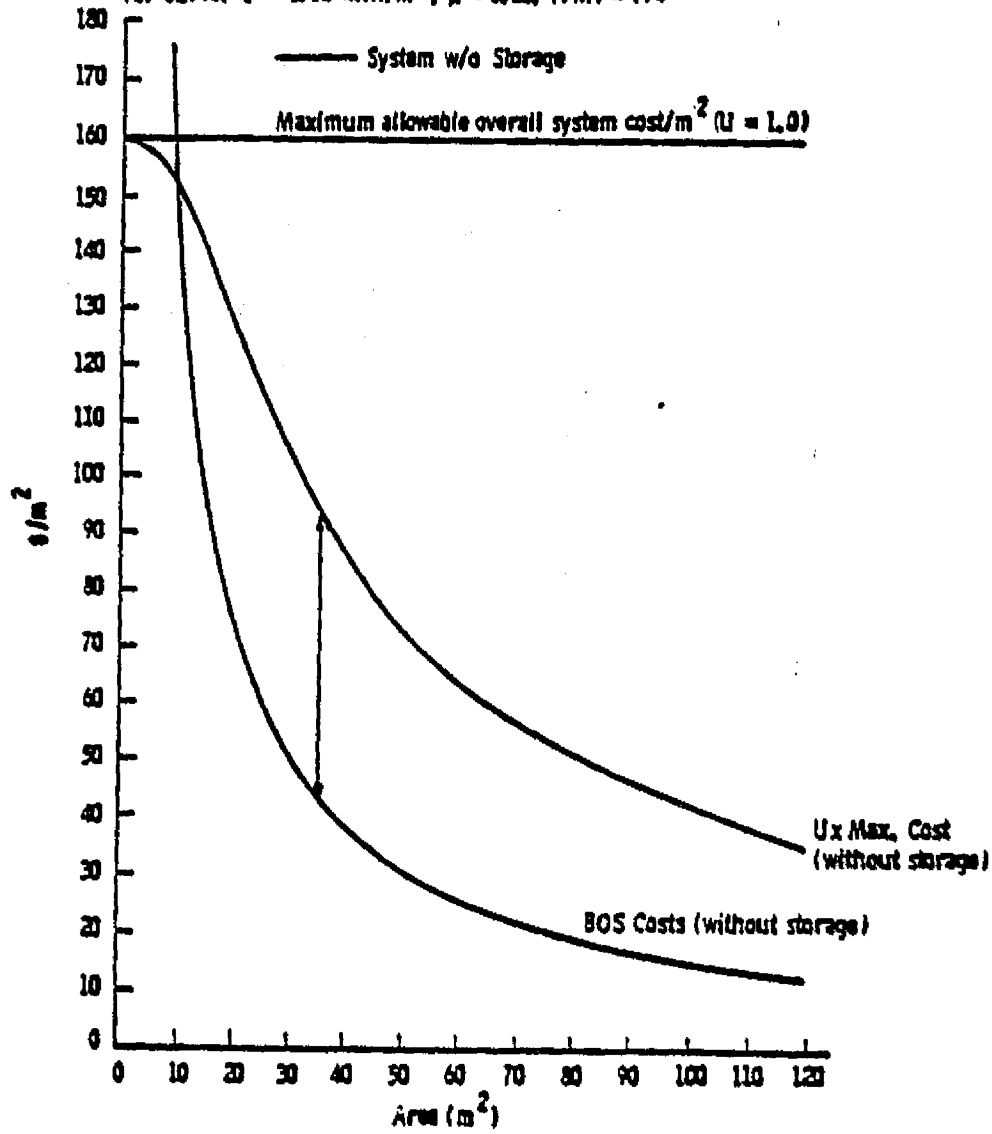

Fig. 5.1.7 — Allowable overall system costs

C. Borden
NOVEMBER 8, 1978

SELECT SYSTEMS FOR BOSTON

TYPE	AREA	STORAGE (KWH)	ENERGY DISPLACED (EQUIV.)	%	SOLAR FM	SYSTEM FM/FM
COMBINED	70-30T	20	11,900	74	.90	.95
SEPARATE						
AIR COOLED P.V.	50	20	12,500	76	.95	.98
EVAC. THERMAL	70					
COMBINED & PHASE CHANGE STORAGE	70	20	13,500	EST. 82	.85	.90

SELECT SYSTEMS FOR PHOENIX

TYPE	AREA	STORAGE (KWH)	ENERGY DISPLACED (EQUIV.)	%	SOLAR FM	SYSTEM FM/FM
ALL ELECTRIC	70	30	16,050	90	.45	.53

BASED ON HIGH VOLUME PRODUCTION ESTIMATED FOR THE YEAR 2000.

THE ALL ELECTRIC IS BY FAR THE SUPERIOR SYSTEM FOR THE PHOENIX SITE.

IN STRUCTURES DESIGNED FOR SOLAR ENERGY SYSTEMS FOR BOSTON, MOST PEOPLE WOULD NOT REQUIRE AIR-CONDITIONING.

T = ADDITIONAL THERMAL ONLY.

AREA IN m^2, ENERGY IN KWH/YR.

LOW-COST SOLAR ARRAY PROJECT

2-117

LIFETIME COST AND PERFORMANCE MODEL FOR PHOTOVOLTAIC POWER SYSTEMS

LOW-COST SOLAR ARRAY PROJECT

MOTIVATION FOR THE LIFETIME COST AND PERFORMANCE (LCP) MODEL

- TO PROVIDE A "BOTTOM-UP" DESCRIPTION OF ALL THE ACTIVITIES ASSOCIATED WITH INSTALLING, OPERATING, AND MAINTAINING A PHOTOVOLTAIC POWER PLANT IN TERMS OF COSTS AND ELECTRICAL PERFORMANCE OVER ITS LIFETIME

- TO PROVIDE A FRAMEWORK FOR MAKING TRADE-OFFS BETWEEN ALTERNATIVE INITIAL AND RECURRENT POLICY OPTIONS

- TO CREATE A GENERAL MODEL WHICH CAN EVALUATE PARAMETRICALLY A WIDE RANGE OF POWER PLANT DESIGNS AND APPLICATIONS

- TO FILL IN THE ANALYTICAL GAP BETWEEN THE SOLAR ARRAY MANUFACTURING INDUSTRY SIMULATION (SAMIS) AND THE UTILITY-OWNED SOLAR ELECTRIC SYSTEMS (USES) ECONOMIC MODEL

CB
11/8/78

THE LIFETIME COST AND PERFORMANCE (LCP) MODEL IS

- A MANAGEMENT TOOL USEFUL TO SYSTEM DESIGNERS AND OPERATORS FOR DECIDING BETWEEN ALTERNATIVE
  - SYSTEM CONFIGURATIONS
  - INSTALLATION ACTIVITIES
  - LEVEL OF EFFORT AND TIMING OF OPERATIONS/MAINTENANCE ACTIONS
  - REPLACEMENT OPTIONS
- STRUCTURED TO CAUSALLY RELATE THE IMPACT OF ALTERNATIVE INITIAL DESIGN AND RECURRENT POLICY DECISIONS ON BOTH COST AND ENERGY OUTPUT OVER THE LIFETIME OF A PHOTOVOLTAIC POWERPLANT
- DESIGNED TO MAKE TRADEOFFS ON THE BASES OF MINIMIZING BUSBAR ENERGY COST AND MAXIMIZING THE NET PRESENT VALUE OF THE INVESTMENT

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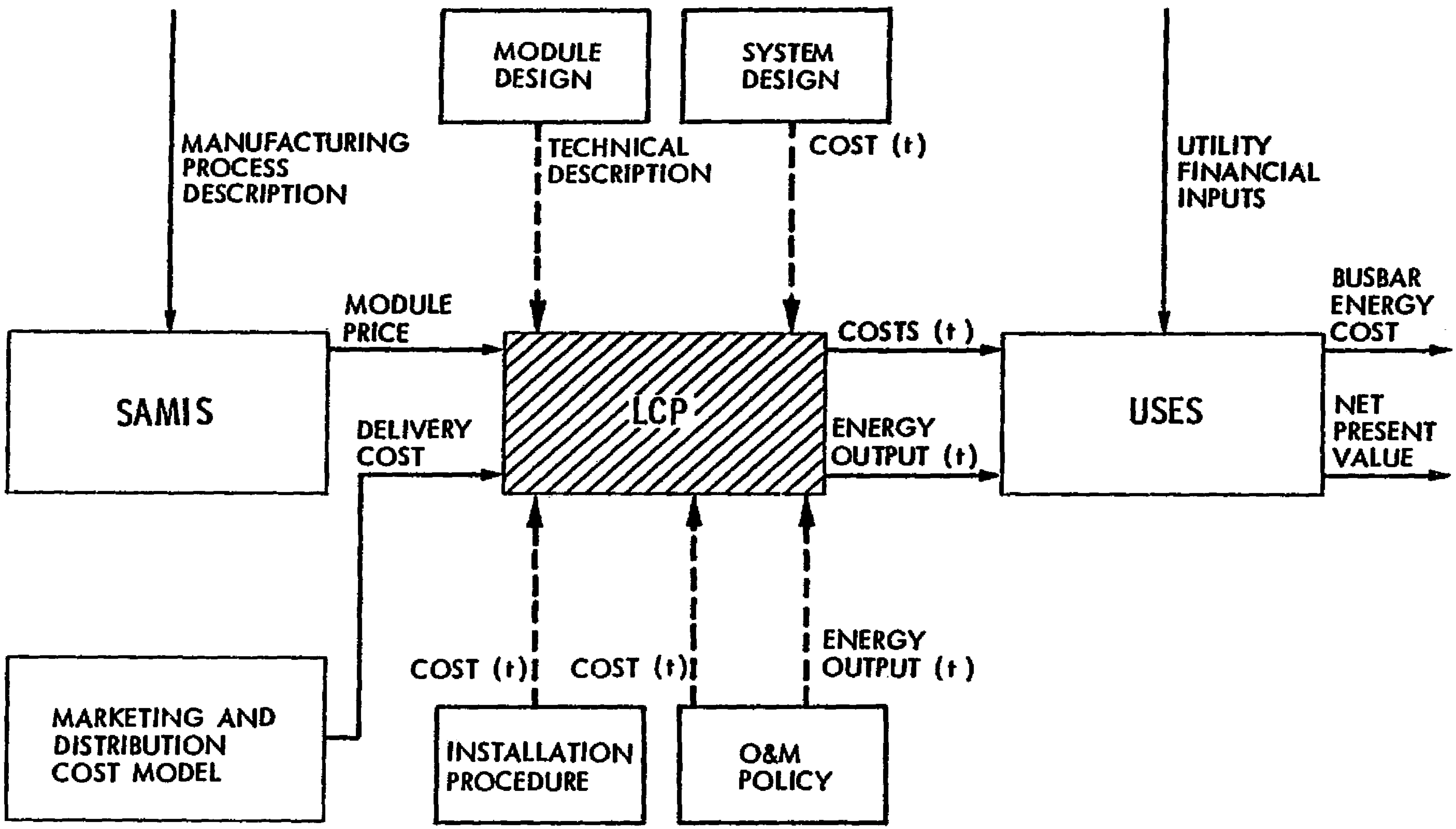
11/8/78


MODULE DESIGN
SYSTEM DESIGN
MANUFACTURING PROCESS DESCRIPTION
TECHNICAL DESCRIPTION
COST (t)
UTILITY FINANCIAL INPUTS
BUSBAR ENERGY COST
MODULE PRICE
COSTS (t)
SAMIS
LCP
USES
NET PRESENT VALUE
DELIVERY COST
ENERGY OUTPUT (t)
ENERGY OUTPUT (t)
COST (t)
COST (t)
MARKETING AND DISTRIBUTION COST MODEL
INSTALLATION PROCEDURE
O&M POLICY

LOW-COST SOLAR ARRAY PROJECT

CURRENT STATUS/PLANNED ACTIVITIES

- CURRENT STATUS
  - SOFTWARE DESIGN DOCUMENT COMPLETED (INITIAL VERSION)
  - EXTERNAL REVIEW/CRITIQUE BY THEODORE BARRY AND ASSOCIATES IS COMPLETED
  - COMPUTER CODING IS BEGINNING
- PLANNED ACTIVITIES
  - ANTICIPATE INITIAL RUNS OF THE COMPUTER MODEL IN THE FIRST QUARTER OF CALENDAR YEAR 1979
  - CONTINUING MODEL VALIDATION BOTH INTERNAL AND EXTERNAL TO JPL
  - IN THE FUTURE, LCP WILL EVALUATE RESIDENTIAL APPLICATIONS AND INTERFACE WITH A UTILITY GRID SIMULATION MODEL

CB
11/8/78

PENETRATION MODELING FOR NEAR AND INTERMEDIATE TERM PHOTOVOLTAIC APPLICATIONS

PRESENTED BY: DR. O. H. MERRILL
SCIENCE APPLICATIONS, INC.
NOVEMBER 8, 1978

SESSION II: COST/ECONOMICS

OVERVIEW

PURPOSE OF WORK: DEVELOP A RANGE OF MARKET PENETRATION ESTIMATES FOR PRESENT AND INTERMEDIATE TERM PV PRODUCTS.

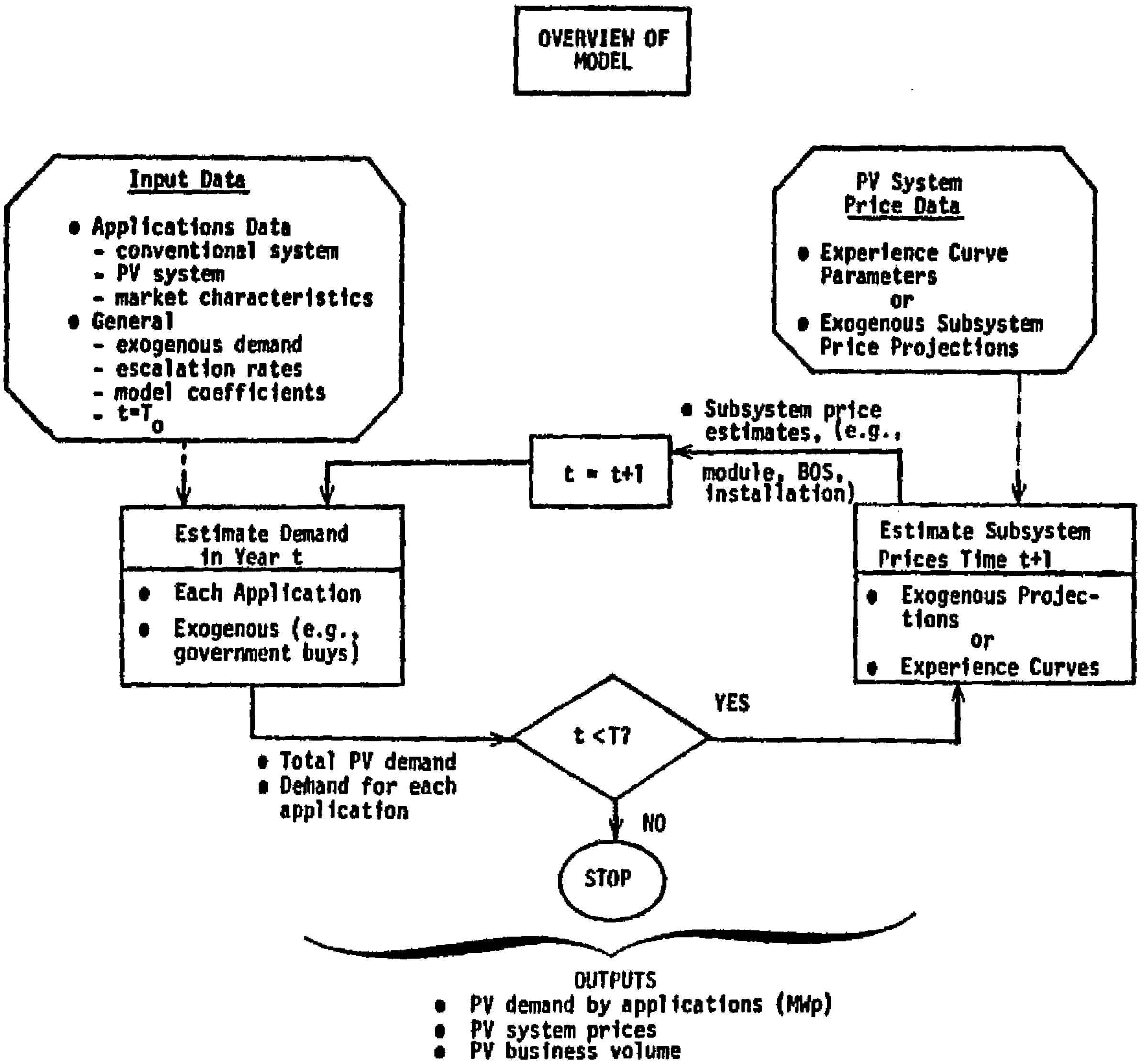
EXAMPLES OF APPLICATIONS CONSIDERED:

- MICROWAVE REPEATERS
- CATHODIC PROTECTION OF WELL CASINGS
- OFF-SHORE NAVAIDS
- EDUCATIONAL TV
- MICRO IRRIGATION
- DIGITAL WATCHES

LEVEL OF DETAIL: BROAD-BRUSH LOOK AT A LARGE NUMBER OF PV APPLICATIONS.

CONSIDERATIONS IN SELECTION OF MODEL:

- EASE OF APPLICATION
- PRECISION OF MODEL COMMENSURATE WITH PRECISION OF DATA
- EMPIRICAL BASIS FOR MODEL.


OVERVIEW OF MODEL
Input Data
• Applications Data
- conventional system
- PV system
- market characteristics
• General
- exogenous demand
- escalation rates
- model coefficients
- $t=T_0$
PV System Price Data
• Experience Curve Parameters
or
• Exogenous Subsystem Price Projections
• Subsystem price estimates, (e.g., module, BOS, installation)
t = t+1
Estimate Demand in Year t
• Each Application
• Exogenous (e.g., government buys)
Estimate Subsystem Prices Time t+1
• Exogenous Projections
or
• Experience Curves
t <T?
YES
NO
• Total PV demand
• Demand for each application
STOP
OUTPUTS
• PV demand by applications (MWp)
• PV system prices
• PV business volume

SUBSTITUTION MODEL

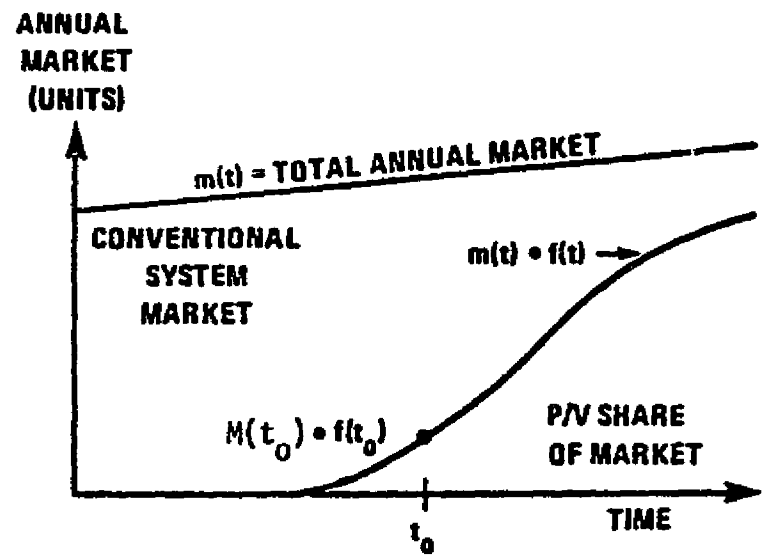
$$f(t) = \frac{\alpha \bullet \exp\left(\int_{t_0}^{t} \Phi(s)\, ds\right)}{1 + \alpha \bullet \exp\left(\int_{t_0}^{t} \Phi(s)\, ds\right)}$$

where:

$$\Phi(s) = a + b \bullet \Pi(s) + c \bullet \sigma(s)$$

and

$$\alpha = f(t_0) / (1 - f(t_0))$$



DEFINITION OF VARIABLES

$f(t)$ = MARKET SHARE FOR PHOTOVOLTAICS AT TIME t

$\Pi(s)$ = PROFITABILITY INDEX FOR P/V POWER SYSTEM AT TIME s

USER SPECIFIC PROFITABILITY MEASURES:

- RATIO OF EXPECTED PAYBACK PERIOD FOR A POTENTIAL USER TO ACTUAL PAYBACK PERIOD
- RATIO OF ROI FOR P/V PRODUCT TO INDUSTRY STANDARD

$\sigma(s)$ = RATIO OF INSTALLED COST OF P/V POWER SYSTEM TO TOTAL ASSETS OF AVERAGE FIRM AT TIME s

$m(t)$ = ANNUAL MARKET SIZE IN UNITS AT TIME t

OVERVIEW OF ASSUMPTIONS

- APPLICATIONS DESCRIPTION
  - ENERGY REQUIREMENTS
  - DESIGN INSOLATION
  - PV SYSTEM
    - -- SUBSYSTEM EFFICIENCIES
    - -- SUBSYSTEM COSTS
- COST OF CONVENTIONAL ALTERNATIVE(S)
  - MARKET DATA
    - -- SIZE
    - -- FRACTION AVAILABLE TO PV
    - -- GROWTH RATE
    - -- COST COMPARISON APPROACH (E.G., LCC, FIRST COST)
  - INITIAL PV PENETRATION
    - -- LEVEL
    - -- YEAR
- GENERAL ASSUMPTIONS
  - ESCALATION IN REAL COST OF CONVENTIONAL ENERGY
  - BOS COST TRENDS
  - PV MODULE COST TRENDS (OR EXPERIENCE CURVE PARAMETERS)

PRELIMINARY RESULTS FROM AN SAI STUDY OF "EXPORT POTENTIAL OF PHOTOVOLTAICS"

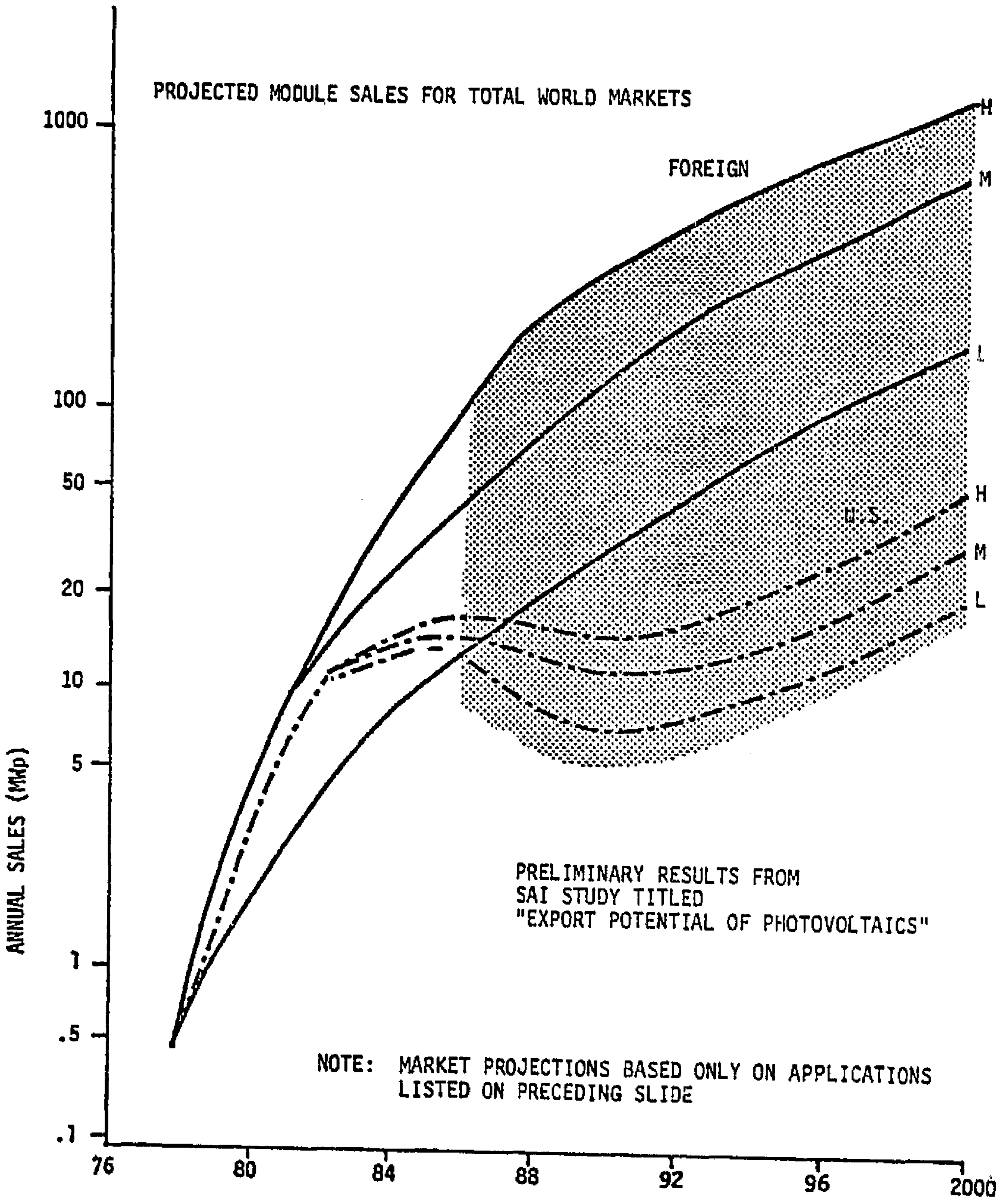
APPLICATIONS CONSIDERED:

FOREIGN

- COMMUNICATIONS EQUIPMENT
  - RADIO REPEATERS
  - MICROWAVE REPEATERS
  - TELEMETRY
  - MONITORING AND SENSING DEVICES
  - EDUCATIONAL TV/RADIO
  - BACKPACK RADIOS
  - EXTENDED RURAL TELEPHONES
- MARKING AND WARNING DEVICES
  - MARITIME NAVAIDS
- CORROSION PROTECTION
  - PIPELINES
  - WELLHEADS
- WATER PUMPING
  - MICRO-IRRIGATION
  - POTABLE/LIVESTOCK SYSTEMS
- GENERAL POWER SOURCES
  - VILLAGE/RESIDENTIAL SYSTEMS
  - REFRIGERATORS
- CONSUMER PRODUCTS
  - WATCHES, CALCULATORS, ETC.

U.S.

- COMMUNICATIONS EQUIPMENT
  - RADIO REPEATERS
  - MICROWAVE REPEATERS
  - TELEMETRY
  - MONITORING AND SENSING DEVICES
- MARKING AND WARNING DEVICES
  - OFF-SHORE PLATFORMS
  - MARITIME NAVAIDS
- CORROSION PROTECTION
  - PIPELINES
  - WELLHEADS
- WATER PUMPING
  - POTABLE/LIVESTOCK SYSTEMS
- GENERAL POWER SOURCES
  - (ONLY GOVERNMENT BUYS)
- CONSUMER PRODUCTS
  - WATCHES, CALCULATORS, ETC.


PROJECTED MODULE SALES FOR TOTAL WORLD MARKETS
FOREIGN
U.S.
H
M
L
H
M
L
ANNUAL SALES (MWp)
1000
100
50
20
10
5
1
.5
.1
76
80
84
88
92
96
2000
PRELIMINARY RESULTS FROM
SAI STUDY TITLED
"EXPORT POTENTIAL OF PHOTOVOLTAICS"
NOTE: MARKET PROJECTIONS BASED ONLY ON APPLICATIONS
LISTED ON PRECEDING SLIDE

SOURCES OF PROBLEMS/UNCERTAINTIES

- IDENTIFYING POTENTIAL APPLICATIONS
- MARKET DESCRIPTION UNCERTAINTIES
  - TOTAL ANNUAL MARKET
  - ANNUAL GROWTH RATE
  - FRACTION OF MARKET AVAILABLE TO PV
  - COST COMPARISON APPROACH
  - TIMING OF INITIAL PV PENETRATION
- CHARACTERISTICS OF INDIVIDUAL APPLICATIONS
  - INSOLATION VARIATIONS
  - LOAD PROFILE VARIATIONS
  - CONVENTIONAL ENERGY SYSTEM COSTS
- GENERAL SOURCES OF UNCERTAINTY
  - ECONOMIC CONDITIONS
  - SOCIAL FACTORS
  - TECHNOLOGY DEVELOPMENT RATES
  - FUTURE ENERGY POLICY
  - PRICE/PRODUCTION VOLUME RELATIONSHIPS
  - SUBSYSTEM COMPONENT COSTS
- PENETRATION MODELING
  - PRICE/NON-PRICE TRADE-OFFS
  - STRUCTURE AND INTERRELATIONSHIPS AMONG VARIABLES
  - TIME FOR INITIAL PENETRATIONS OF NEW MARKETS
  - EFFECTS OF OTHER NEW TECHNOLOGIES
  - LACK OF COMPREHENSIVE TREATMENT OF ALL APPLICATIONS
  - INTERRELATIONSHIPS AMONG MARKETS

KEY PROBLEMS ARE MARKET DEFINITION AND DATA PROBLEMS, NOT PENETRATION MODELING PROBLEMS

MIT PHOTOVOLTAIC MODEL

Thomas McCormack

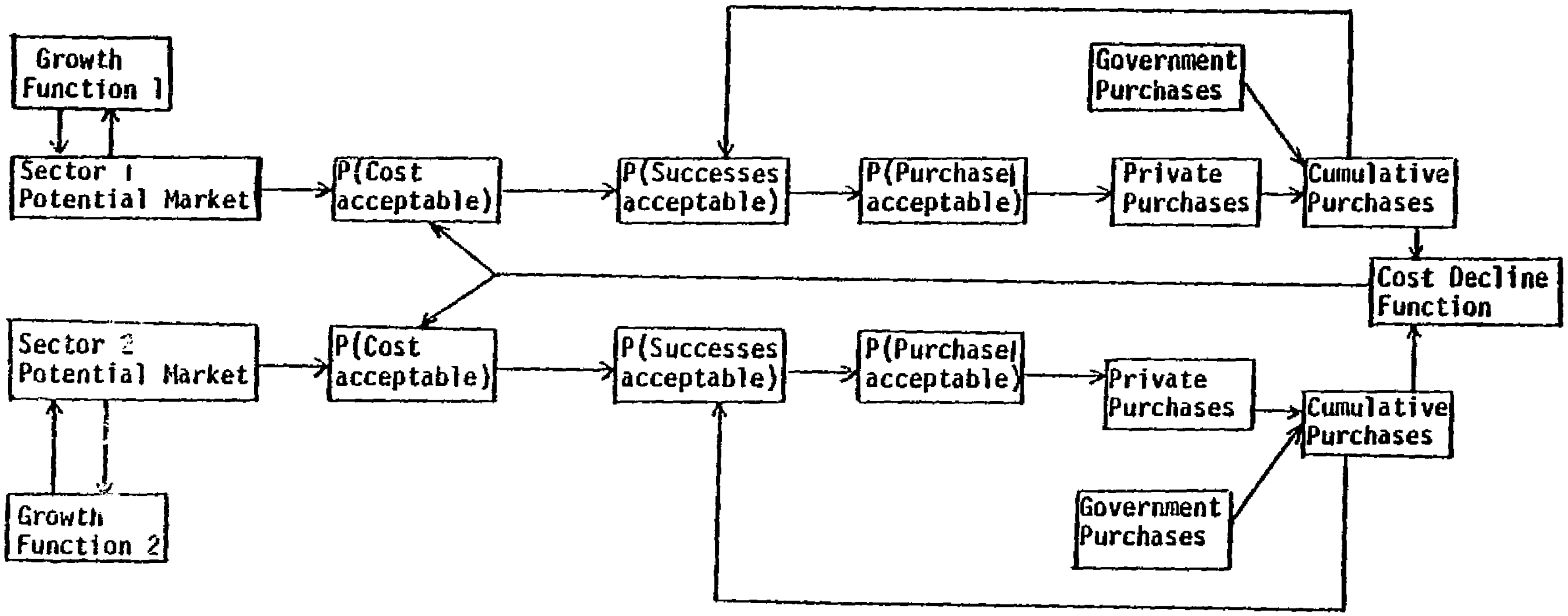
MIT/Energy Laboratory

MIT PV MODEL

BASIC CONCEPTS

* ACCEPTANCE IS ACCELERATED BY NON-ECONOMIC AS WELL AS ECONOMIC FACTORS
* INITIAL SYSTEM COSTS DECLINE ACCORDING TO A LEARNING CURVE
* NON-ECONOMIC PARAMETERS SHOULD BE EMPIRICALLY DETERMINED BY MARKET MEASUREMENTS
* THE DIFFUSION CURVE SHOULD BE AN OUTPUT BASED ON BEHAVIOR RATHER THAN AN INPUT

MIT PV MODEL



Growth Function 1
Sector 1 Potential Market
P(Cost acceptable)
P(Successes acceptable)
P(Purchase| acceptable)
Private Purchases
Government Purchases
Cumulative Purchases
Cost Decline Function
Sector 2 Potential Market
P(Cost acceptable)
P(Successes acceptable)
P(Purchase| acceptable)
Private Purchases
Cumulative Purchases
Government Purchases
Growth Function 2

MARKET SURVEY RESULTS

THREE SURVEYS COMPLETED:

- NEBRASKA AGRICULTURAL IRRIGATION

- NEBRASKA RESIDENTIAL

- BOSTON SUN DAY RESIDENTIAL

KEY FACTORS ASSOCIATED WITH PV PREFERENCE WERE:

- FOR THE GENERAL POPULATION, PRIMARILY TECHNOLOGICAL/ ECONOMIC CONCERNS, SECONDARILY ECOLOGICAL/ENVIRONMENTAL CONCERNS
- FOR THE EARLY INNOVATORS, PRIMARILY ECOLOGICAL/ ENVIRONMENTAL CONCERNS

SUN DAY INNOVATORS COMPARED TO NEBRASKA HOMEOWNERS

- STRONG DIFFERENCES IN OVERALL PREFERENCE, CONFIDENCE IN PV AND RESISTANCE TO HIGH INITIAL COST, BUT
- LITTLE DIFFERENCE IN EXPRESSED ATTITUDES OR GROUP DEMOGRAPHICS TO EXPLAIN INNOVATIVENESS

INITIAL MODEL RUNS

OBJECTIVE: INVESTIGATE ALLOCATION OF GOVERNMENT DEMONSTRATION RESOURCES OVER SECTORS AND OVER TIME

3 SECTORS AND 10 YEARS IN MODEL

- AGRICULTURAL IRRIGATION
- DISPERSED RESIDENTIAL POWER
- CENTRAL POWER STATIONS

8 IDENTICAL REGIONS FOR AGRICULTURAL AND RESIDENTIAL SECTORS

MODEL PARAMETER ASSUMPTIONS

SYSTEM COSTS DECLINE IN AN EXPONENTIAL LEARNING CURVE WITH A DOUBLING CONSTANT OF .70

INITIAL PV SYSTEM COST $10/WATT

AVERAGE INSTALLATION SIZE:

- 10 KW FOR IRRIGATION
- 9 KW FOR RESIDENTIAL
- 500 MW FOR CENTRAL POWER

PARAMETERS DETERMINED EMPIRICALLY FOR EACH SECTOR

- DISTRIBUTION OF "PERCEPTUAL" BREAK-EVEN COST
- DISTRIBUTION OF NUMBER OF SUCCESSFUL INSTALLATIONS NECESSARY FOR ACCEPTANCE
- PROBABILITY OF PURCHASE GIVEN ACCEPTABILITY

RUN RESULTS

ALLLOCATION STRATEGY HAS A SIGNIFICANT EFFECT ON RATE AND LEVEL OF ADOPTION. IT IS OPTIMAL TO ALLOCATE RESOURCES IN SEQUENCE FROM THE HIGHEST TO THE LOWEST BREAK-EVEN COST SECTOR AND UNIFORMLY ACROSS REGIONS.

SENSITIVITY OF RESULTS:

- VERY SENSITIVE TO LEARNING CURVE PARAMETER
- NOT SENSITIVE TO ASSUMPTIONS ABOUT SUCCESSFUL INSTALLATIONS NECESSARY FOR ACCEPTANCE

CONCLUSIONS

* MODEL IS IN INITIAL BUT WORKABLE STATE
* CAN BE USED TO TEST/ASSESS POLICY ALTERNATIVES
* FIELD CALIBRATION IS AN INTEGRAL PART OF THE PROCESS
* INITIAL RESULTS INDICATE IMPORTANCE OF
    - CONCENTRATION OF DEMONSTRATION RESOURCES
    - COST DECLINE INFORMATION

NEXT STEPS

* CALIBRATE WITH BUILDER/DEVELOPERS
* GENERALIZE MODEL
  - OPTIMIZATION CAPABILITY
  - EXPLICITLY INCLUDE COMPETING TECHNOLOGIES

ANALYSIS METHODOLOGY:
PHOTOVOLTAIC CENTRAL STATION POWER PLANTS

S. L. Leonard

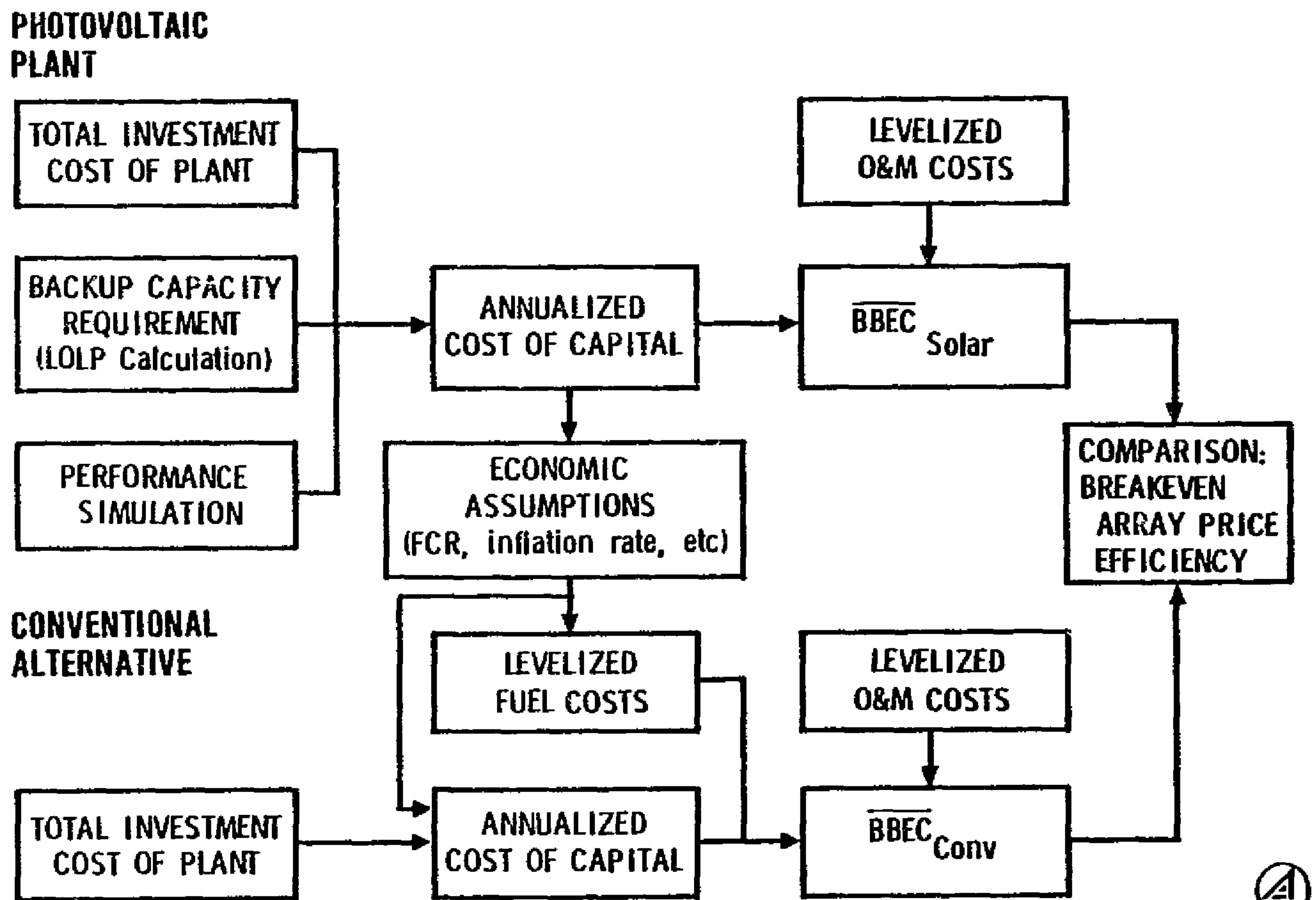
The Aerospace Corporation
El Segundo, California

Presented at
U.S. Department of Energy
PHOTOVOLTAICS TECHNOLOGY DEVELOPMENT AND APPLICATIONS PROGRAM REVIEW

Arlington, Virginia
November 7-9, 1978

H 8258

Photovoltaic Central Station Plant Analysis



Assumptions

- BASIC ECONOMIC PARAMETERS
  - DISCOUNT RATE: 8% GENERAL INFLATION RATE: 5%
  - FIXED CHARGE RATE: 15% PHOTOVOLTAIC SYSTEM LIFE: 30 YEARS
- PHOTOVOLTAIC SYSTEM COST
  - INVESTMENT COST
    - BASIC PLANT COST

SOLAR	CONVENTIONAL
ARRAY (flat plate): VARIABLE	LAND AND LAND PREP: \$500/ACRE
CONCENTRATOR CELL ASSEMBLY (AlGaAs/GaAs): \$10,000/m^2	BUILDING/FACILITIES: \$11/kW
SUPPORT STRUCTURE (flat plate): \$15.2/m^2	POWER CONDITIONING: \$70/kW
HELIOSTATS (central receiver): \$60/m^2	ELECTRIC PLANT EQUIP: \$16/kW
TOWER (central receiver): \$2.8 PER m^2 OF COLLECTOR	MISC PLANT EQUIP: \$6/kW
PARABOLIC TROUGH: \$64/m^2	ELECTRIC STORAGE (if used): \$40/kWh
PARABOLIC DISH: \$122/m^2	
DC WIRING: VARIABLE (depends on concept)	

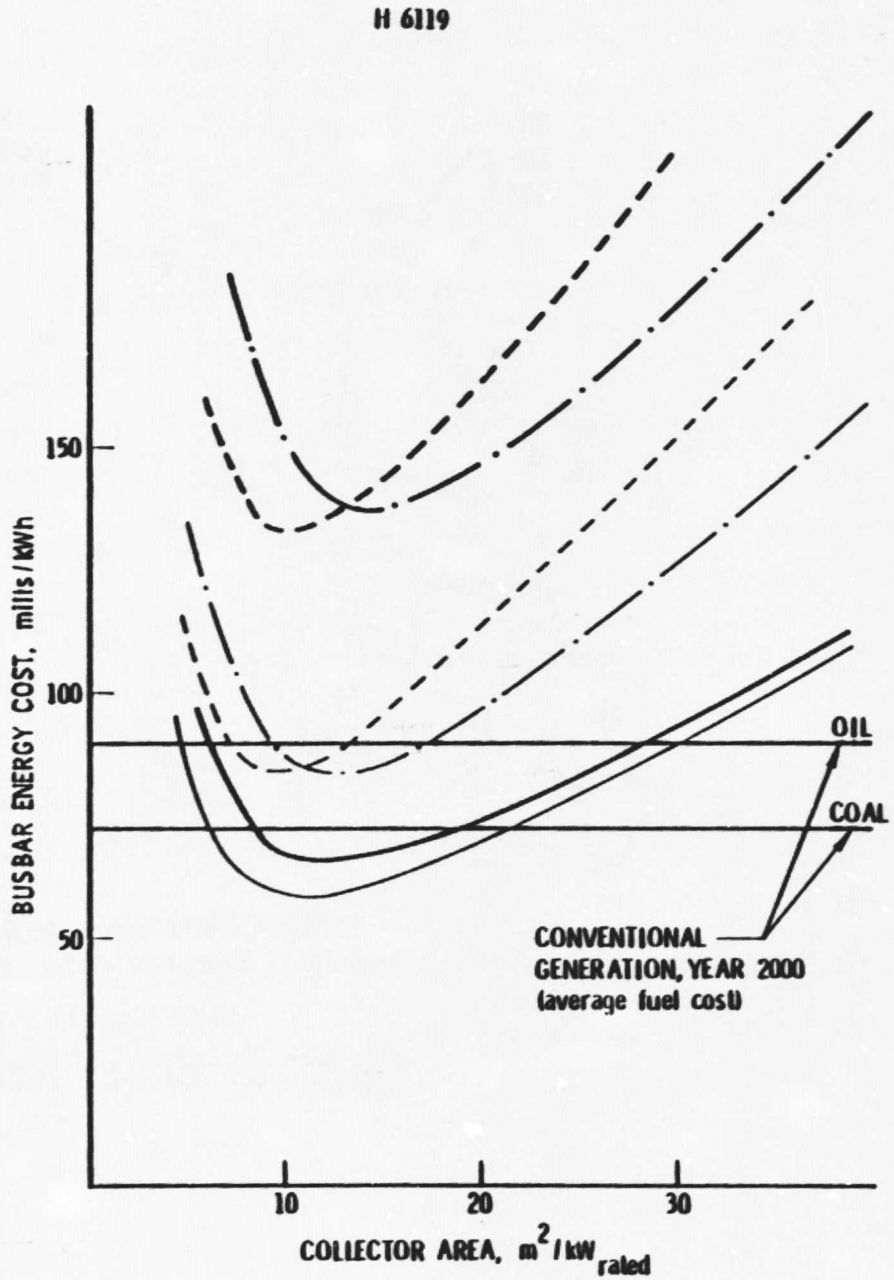
    - SPARES, CONTINGENCIES: 8% OF BASIC PLANT COST
    - INDIRECT COSTS: 10% OF SOLAR ELEMENT COST PLUS 52% OF CONVENTIONAL ELEMENT COST
    - INTEREST DURING CONSTRUCTION: 12.8% (8% rate, 4 year construction period)
    - BACKUP CAPACITY – \$140/kW (gas turbine)
  - OPERATION AND MAINTENANCE – 3 mills/kWh
- COST OF ALTERNATIVE CONVENTIONAL SYSTEM
  - INVESTMENT COST: \$550/kW (coal); \$350/kW (oil)
  - OPERATION AND MAINTENANCE (except fuel): 3 mills/kWh
  - FUEL: VARIABLE, BASED ON SHERMAN CLARK ASSOCIATES PROJECTIONS (by state); AVERAGE REAL ESCALATION RATE ~ 2.6% (coal)

Busbar Energy Cost

FLAT-PLATE vs CONCENTRATING PHOTOVOLTAIC POWER PLANTS WITHOUT STORAGE (1975 dollars)

LOCATION:	MIAMI, FL
ARRAY EFFICIENCY (20°C)	
SILICON: (Flat Plate, NS Trough)	0.135
AlGaAs/GaAs: (Central Receiver)	0.22
FIXED CHARGE RATE:	0.15
LEVELIZED O AND M COST:	3 mills/kWh
ARRAY PRICE (Flat Plate):	$\$200/kW_{pk}$

COLLECTOR TYPE	INSOLATION DATA	
	OLD DATA (1963)	REVISED DATA (1953)
FLAT PLATE	————	————
NS TROUGH	—·—·—	—·—·—
CENTRAL RECEIVER	- - - - -	- - - - -



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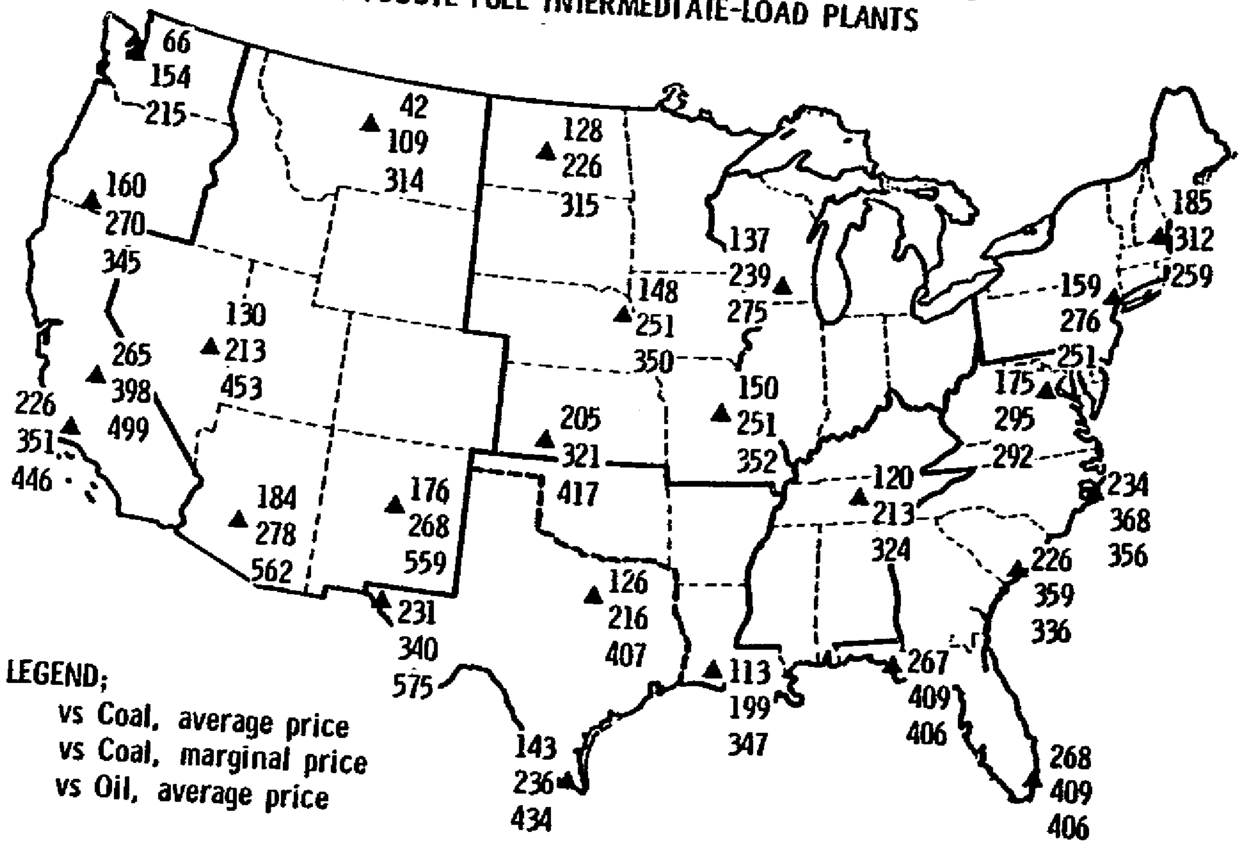
Breakeven Array Prices in 2000

1975 DOLLARS PER kWpk

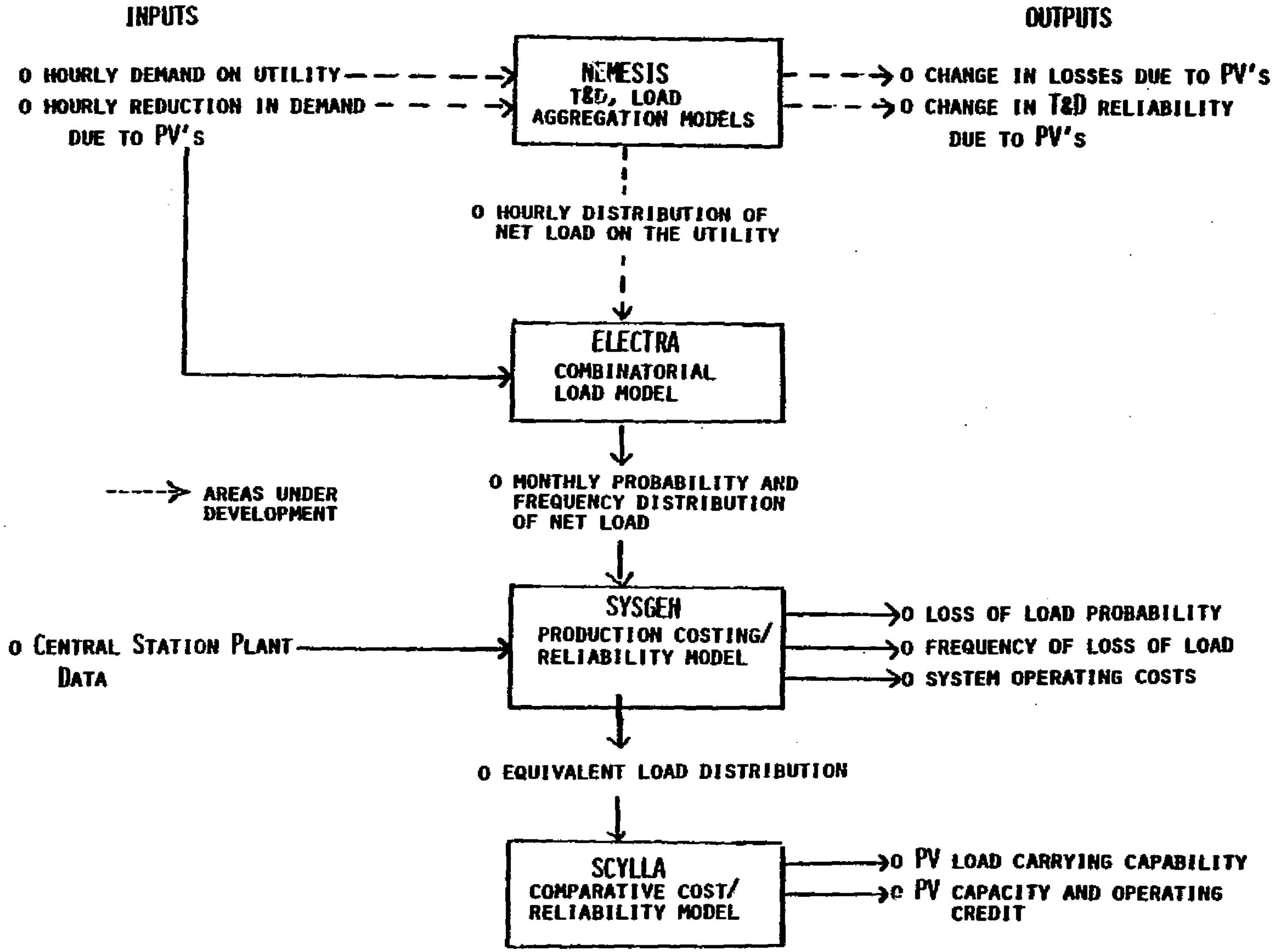
PHOTOVOLTAIC CENTRAL STATION POWER PLANTS vs
NEW FOSSIL-FUEL INTERMEDIATE-LOAD PLANTS



PHOTOVOLTAIC UTILITY WORTH

Susan Finger

MIT/Energy Laboratory


INPUTS
OUTPUTS
O HOURLY DEMAND ON UTILITY
O HOURLY REDUCTION IN DEMAND DUE TO PV's
NEMESIS
T&D, LOAD AGGREGATION MODELS
O CHANGE IN LOSSES DUE TO PV's
O CHANGE IN T&D RELIABILITY DUE TO PV's
O HOURLY DISTRIBUTION OF NET LOAD ON THE UTILITY
ELECTRA
COMBINATORIAL LOAD MODEL
AREAS UNDER DEVELOPMENT
O MONTHLY PROBABILITY AND FREQUENCY DISTRIBUTION OF NET LOAD
SYSGEN
PRODUCTION COSTING/ RELIABILITY MODEL
O CENTRAL STATION PLANT DATA
O LOSS OF LOAD PROBABILITY
O FREQUENCY OF LOSS OF LOAD
O SYSTEM OPERATING COSTS
O EQUIVALENT LOAD DISTRIBUTION
SCYLLA
COMPARATIVE COST/ RELIABILITY MODEL
O PV LOAD CARRYING CAPABILITY
O PV CAPACITY AND OPERATING CREDIT

PHOTOVOLTAIC UTILITY WORTH ASSUMPTIONS

- o EPRI SYNTHETIC UTILITIES 1975 SCALED DOWN SYSTEMS
- o 1975 HOURLY WEATHER FROM SOLMET TAPES
- o 1975 HOURLY LOAD DATA FOR SOLMET CITIES
- o 1975 REGIONAL FUEL COSTS FROM FPC
- o 3% REAL DISCOUNT RATE
- o 5% FOSSIL FUEL ESCALATION RATE
- o 2% NUCLEAR FUEL ESCALATION RATE
- o 2% OPERATING AND MAINTENANCE COST ESCALATION RATE

PHOTOVOLTAIC UTILITY WORTH RESULTS

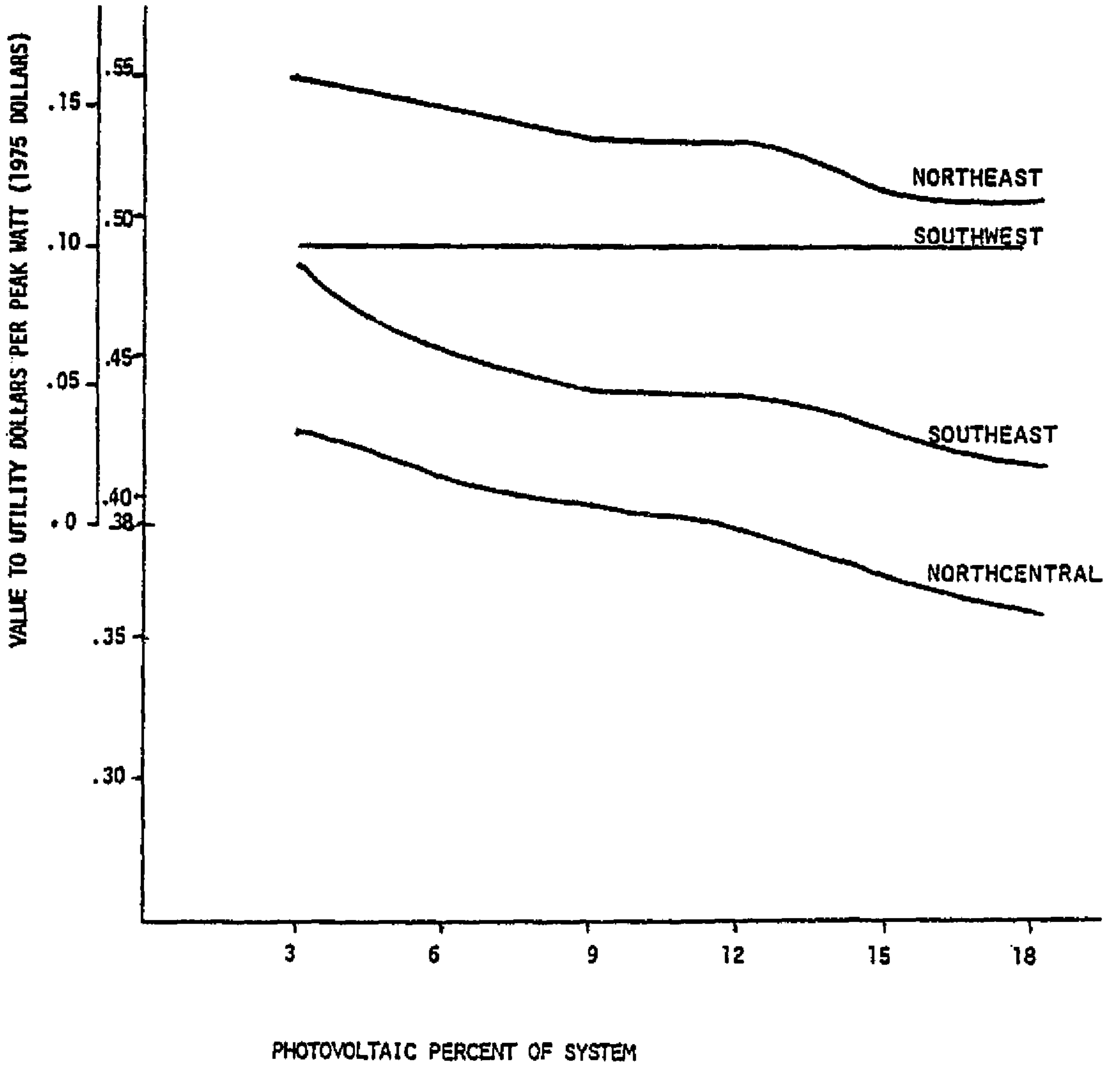
OPERATING AND CAPITAL COST SAVINGS TO UTILITY DUE TO PHOTOVOLTAICS
DOLLARS PER PEAK WATT (1975 DOLLARS)

PHOTOVOLTAIC PERCENT OF INSTALLED CAPACITY	SOUTHEAST	NORTHEAST	SOUTHWEST	NORTHCENTRAL
3%	$ .48	$ .55	$ .49	$ .43
6%	.45	.54	.49	.41
9%	.44	.53	.49	.40
12%	.44	.53	.49	.38
15%	.43	.52	.49	.37
18%	.42	.52	.49	.36

BALANCE OF SYSTEM COSTS (SERI) = $.38 /PEAK WATT

PHOTOVOLTAIC UTILITY WORTH RESULTS

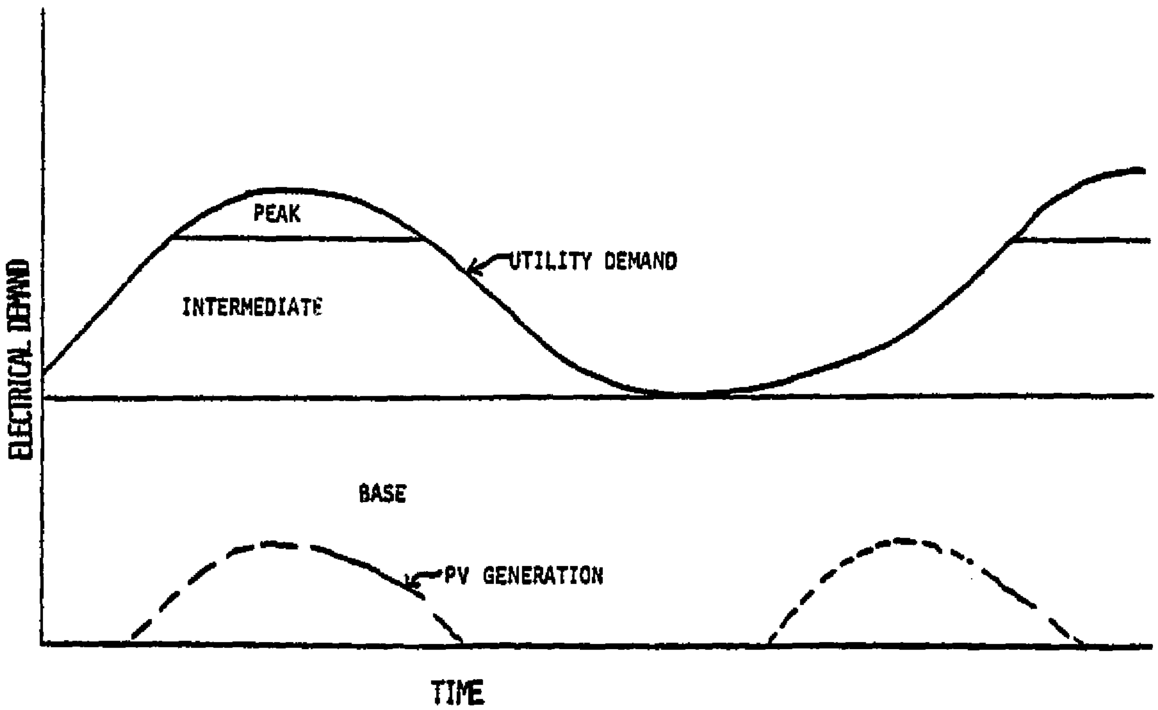
VALUE OF PHOTOVOLTAICS TO UTILITIES DUE TO OPERATING
AND CAPITAL SAVINGS
1975 DOLLARS



PHOTOVOLTAIC UTILITY WORTH

SENSITIVITY

- o CORRELATION OF SOLAR PEAK WITH UTILITY PEAK
- o AVAILABILITY OF STORAGE
- o SYSTEM LOAD FACTOR



THE SETTING OF PROGRAM PRICE GOALS: BACKGROUND AND ALTERNATIVE APPROACHES

PAUL R. CARPENTER
JEFFREY L. SMITH

JET PROPULSION LABORATORY

NOVEMBER 8, 1978

DISCUSSION OUTLINE:

1. BACKGROUND TO \$0.50/WATT$_{(P)}$ PROGRAM PRICE GOAL

   - COINCIDENT QUANTITY GOAL: 500 MW INSTALLED
   - SUBSIDIARY CONDITIONS: 10% EFFICIENCY, 20 YR LIFETIME

2. BENEFITS OF \$0.50/W$_P$ GOAL TO PROGRAM

   - HELPS FOCUS TECHNOLOGY DEVELOPMENT PROGRAM (LSA)
   - A TOOL TO MONITOR TASK PROGRESS AND PROVIDE TASK DIRECTION (PRICE ALLOCATION GUIDELINES)
   - A VERY EFFECTIVE COMMUNICATION DEVICE TO THE PUBLIC "HERE IS OUR OBJECTIVE AND THIS IS HOW WE PLAN TO GET THERE"

3. PURPOSE OF PROGRAM PRICE GOALS

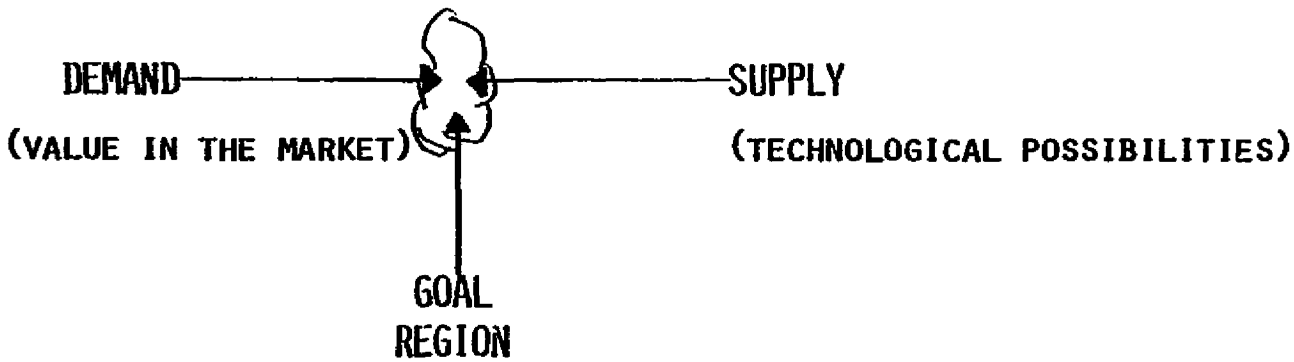
- EXTERNAL - COMMUNICATION OF PROGRAM OBJECTIVES TO THE OUTSIDE WORLD
- INTERNAL - MANAGEMENT TOOL FOR PLANNING AND CONTROL OF TECHNOLOGY DEVELOPMENT AND APPLICATIONS

4. HOW SPECIFIC SHOULD THEY BE?

- SYSTEM GOALS VS. MODULE (ARRAY PRICE) GOALS
- ONCE WE MOVE TOWARD SYSTEM GOALS--SEVERAL SPECIFICITY PROBLEMS ARISE
  - MODULE VS. SYSTEM WATTS
  - APPLICATION CHOICE
  - TECHNOLOGY CHOICE
- REPRESENTATION: ENERGY COST ($/KWH) OR SYSTEM COST ($/Wp)?

5. CHOOSING NUMBERS

- A CONVERGENCE BETWEEN WHERE WE NEED TO BE COMPETITIVE AND WHERE WE THINK THE TECHNOLOGY CAN GO



PV PROGRAM GOALS AND THE CONSUMER

D. Bottaro

MIT/Energy Laboratory

D BOTTARO 11/9/78
MIT/ENERGY LAB

PV PROGRAM GOALS AND THE CONSUMER

OVERALL CONCERN IS WHETHER GOALS ARE STATED IN TERMS MEANINGFUL TO THE CONSUMER.

PRICE GOALS AND THE PRODUCT:

- FOR TOTAL SYSTEM WHICH CONSUMER WILL BUY, NOT JUST MODULE
- FOR A PRODUCT DESIGNED APPROPRIATELY FOR CONSUMER'S USE
- FOR A PRODUCT WITH SYSTEM PRICE ACCESSIBLE TO MOST CONSUMERS, NOT FOR A CADILLAC
- FOR A PRODUCT WITH A SENSIBLE NET ENERGY FLOW, TAKING INTO ACCOUNT THE VALUES OF THE ENERGY CONSUMED AND PRODUCED

PRICE GOALS AND THEIR CALCULATION:

- APPROPRIATE UNITS FOR COMPARING TO AL TERNATIVES MUST BE AT LEAST DERVIABLE
- LIFETIME MUST BE TAKEN INTO ACCOUNT AND OPTIMIZED
- LIFECYCLE COSTS ARE TO BE MINIMIZED, INCLUDING:
  - REPLACEMENT OF COMPONENTS
  - REPAIR OF COMPONENTS AND SYSTEM
  - MAINTENANCE OF SYSTEM AND COMPONENTS
- EXTERNAL COSTS AND BENEFITS ARE CONSIDERED:
  - INJURIES TO USERS AND WORKERS
  - SUBSIDIES FOR OTHER POWER SOURCES
  - ENVIRONMENTAL EFFECTS

PRICE GOALS AND THE MARKET:

- GOALS CONDUCIVE TO A COMPETITIVE MARKET, NOT IMPLICITLY ASSUMING HIGH HORIZONTAL CONCENTRATION AND VERTICAL INTEGRATION
- COMPATIBILITY WITH EXISTING COMPLEMENTARY TECHNOLOGIES
- INCLUSION OF DEVELOPMENT OF ALL PHASES OF INDUSTRY, NOT JUST PRODUCTION:
  - WHOLESALERS, RETAILERS
  - INSTALLERS
  - SERVICE

CONCLUSIONS AND RECOMMENDATIONS

Richard D. Tabors

MIT/Energy Laboratories

MARKET/ECONOMICS WORKSHOP

Conclusions & Recommendations

Part I Models

1) There is a need to standardize the system configuration input assumptions as well as the physical (solar insolation) assumptions to allow for comparability between models developed by different research groups.

2) There are a set of information requirements which, as a minimum, should be the output of each modeling activity focused on a sector, be it residential, central power, institutional, etc.

3) In the near term additional attention is required on the relationship between photovoltaic power systems utilization in specific sectors. As an example, the relationship between large scale adoption in the residential sector and the operation and expansion of electric utilities.

4) Additional information and analysis is required to evaluate the influence of future rate structures upon the potential adoption of Photovoltaic power systems and conversely, the impact that significant penetration of privately owned Photovoltaic power systems may have upon the utility rate structure.

5) There is a need for more performance information (live data) that can be used to confirm the usefulness of the models under development.

6) Coordinating activities currently underway should be maintained and increased to minimize unnecessary duplication of effort.

7) There is currently a set of residential and utility Photovoltaic models available. These offer several analytic approaches. Little, if any, advantage can be gained from additional de novo efforts in residential or utility economic modeling of Photovoltaic power systems.

MARKET/ECONOMICS WORKSHOP

Conclusions and Recommendations

Part II Goals

1) Program goals need to be set in a hierarchy which are internally consistent.

2) The goals set within the program should take into account those variables over which governmental RD&D policy can have an impact. While other goals may be of insignificance, these will be more or less independent of federal governmental policy.

3) Goals should be specific to a given audience while remaining internally consistent. An example of such goals would be for both flat plate and concentrating systems.

BIBLIOGRAPHY OF MODELING REPORTS ON PHOTOVOLTAIC RESIDENTIAL AND UTILITY SYSTEMS

BIBLIOGRAPHY OF MODELING REPORTS ON PHOTOVOLTAIC RESIDENTIAL AND UTILITY SYSTEMS*

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* This Bibliography has been prepared by Richard D. Tabors of the MIT Energy Laboratory at the request of some workshop participants. While an effort has been made to collect relevant documentation NO GUARANTEE OF COMPLETENESS IS IMPLIED IN THIS LISTING.

SESSION III

CONCENTRATOR AND FLAT PANEL TECHNOLOGY

ALTERNATIVE FOR 50¢/WATT

R. G. Ross

Jet Propulsion Laboratory

AND

B. D. Shafer

Sandia Laboratories

DESIGN ALTERNATIVES FOR COST EFFECTIVE SOLAR ARRAYS

R. G. ROSS, JET PROPULSION LAB

NOVEMBER 8, 1978

RGR
11/8/78

DESIGN ALTERNATIVES FOR COST EFFECTIVE SOLAR ARRAYS

AGENDA

1:30 pm WEDNESDAY 11/8

• A FRAMEWORK FOR ARRAY COST COMPARISONS	R. Ross JPL
• COST ELEMENTS OF FLAT-PLATE ARRAYS	R. Ross JPL
• PROGRESS TOWARD 50¢/WATT FLAT-PLATE MODULES	W. Callaghan JPL

3:30 am WEDNESDAY 11/8

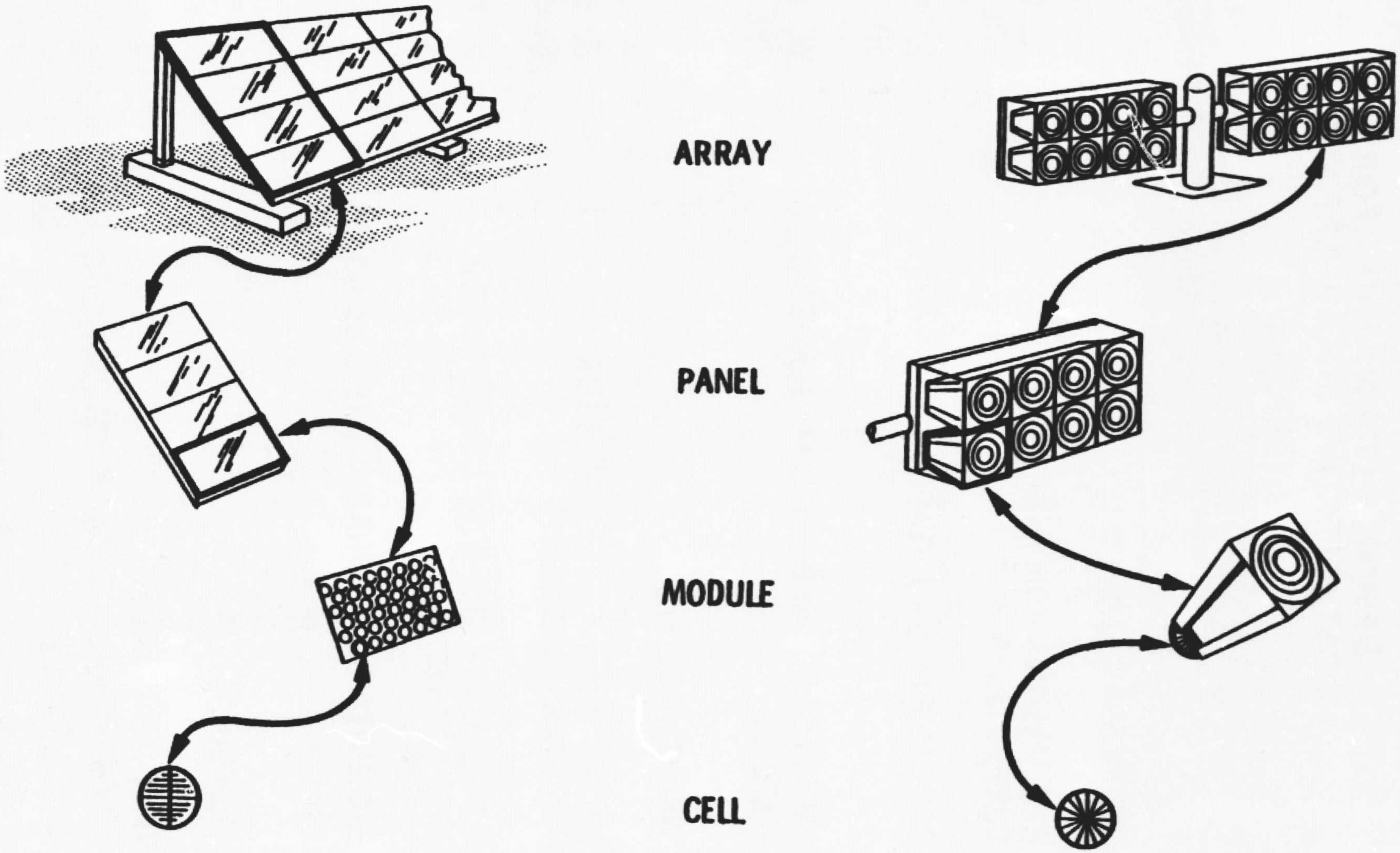
• DOLLAR PER m^2 COST GOALS FOR CONCENTRATOR ARRAYS	B. D. Shafer Sandia
• A STRAWMAN LOW-COST CONCENTRATOR ARRAY DESIGN	B. D. Shafer Sandia
• PROJECTED CONCENTRATOR COSTS vs GOALS	B. D. Shafer Sandia

8:30 am THURSDAY 11/9

OPEN DISCUSSION

LOW-COST SOLAR ARRAY PROJECT

ARRAY NOMENCLATURE



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11/7/78

LOW-COST SOLAR ARRAY PROJECT
OVERALL ARRAY GOAL

- LIFE-CYCLE ENERGY COST COMPETITIVE WITH ALTERNATE ENERGY SOURCES

$$\text{LIFE-CYCLE DC ENERGY COST} = \frac{\begin{pmatrix}\text{INITIAL COST}\\ \text{PER SQ METER}\end{pmatrix} + \begin{pmatrix}\text{L-C O\&M COST}\\ \text{PER SQ METER}\end{pmatrix}}{\begin{pmatrix}\text{ARRAY}\\ \text{EFFICIENCY}\end{pmatrix} \times \begin{pmatrix}\text{ANNUAL}\\ \text{ENERGY}\\ \text{INPUT}\end{pmatrix} \times \begin{pmatrix}\text{L-C ENERGY}\\ \text{FRACTION}\end{pmatrix}^{*}}$$

$\leq$ 5 ¢/kW-hr (ARRAY ONLY)

*EQUALS THE PRESENT VALUE OF AN ANNUITY OF ONE (1/FCR) FOR AN ARRAY WITH NO DEGRADATION OVER LIFE

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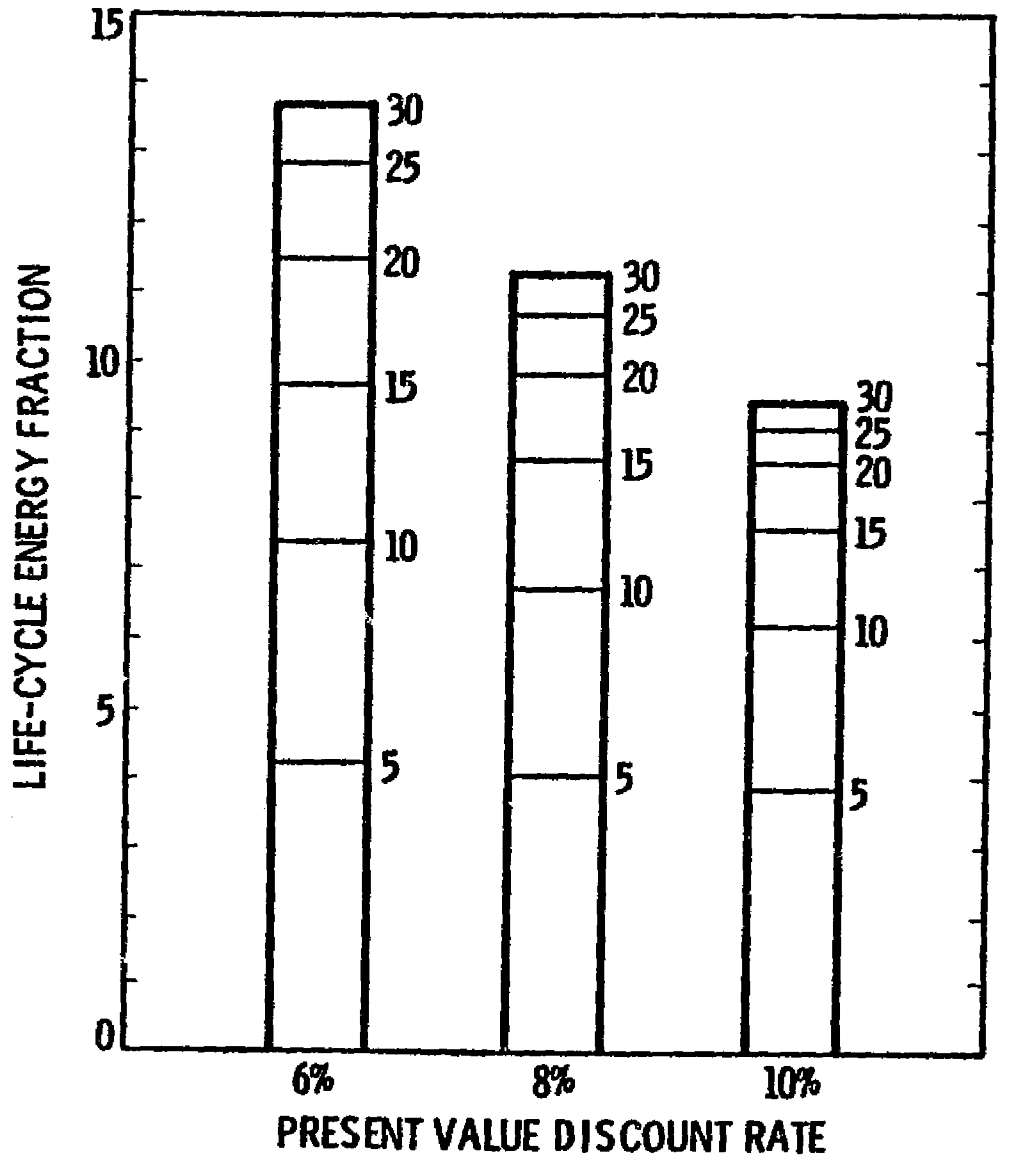
11/7/78

LOW-COST SOLAR ARRAY PROJECT

LIFE-CYCLE ENERGY FRACTION

(NO DEGRADATION WITH TIME)



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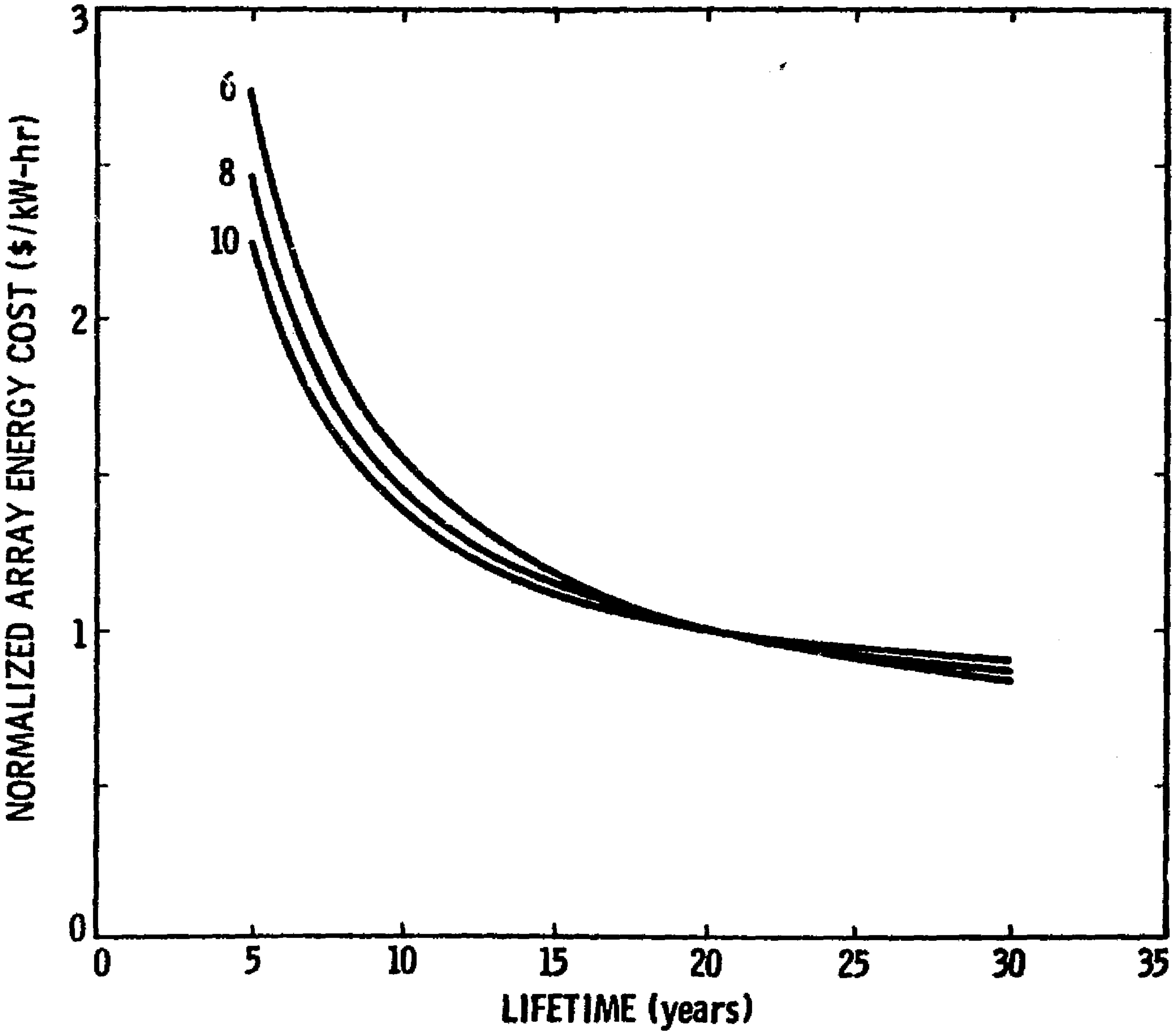
LOW-COST SOLAR ARRAY PROJECT

ARRAY COST SENSITIVITY TO MODULE LIFE



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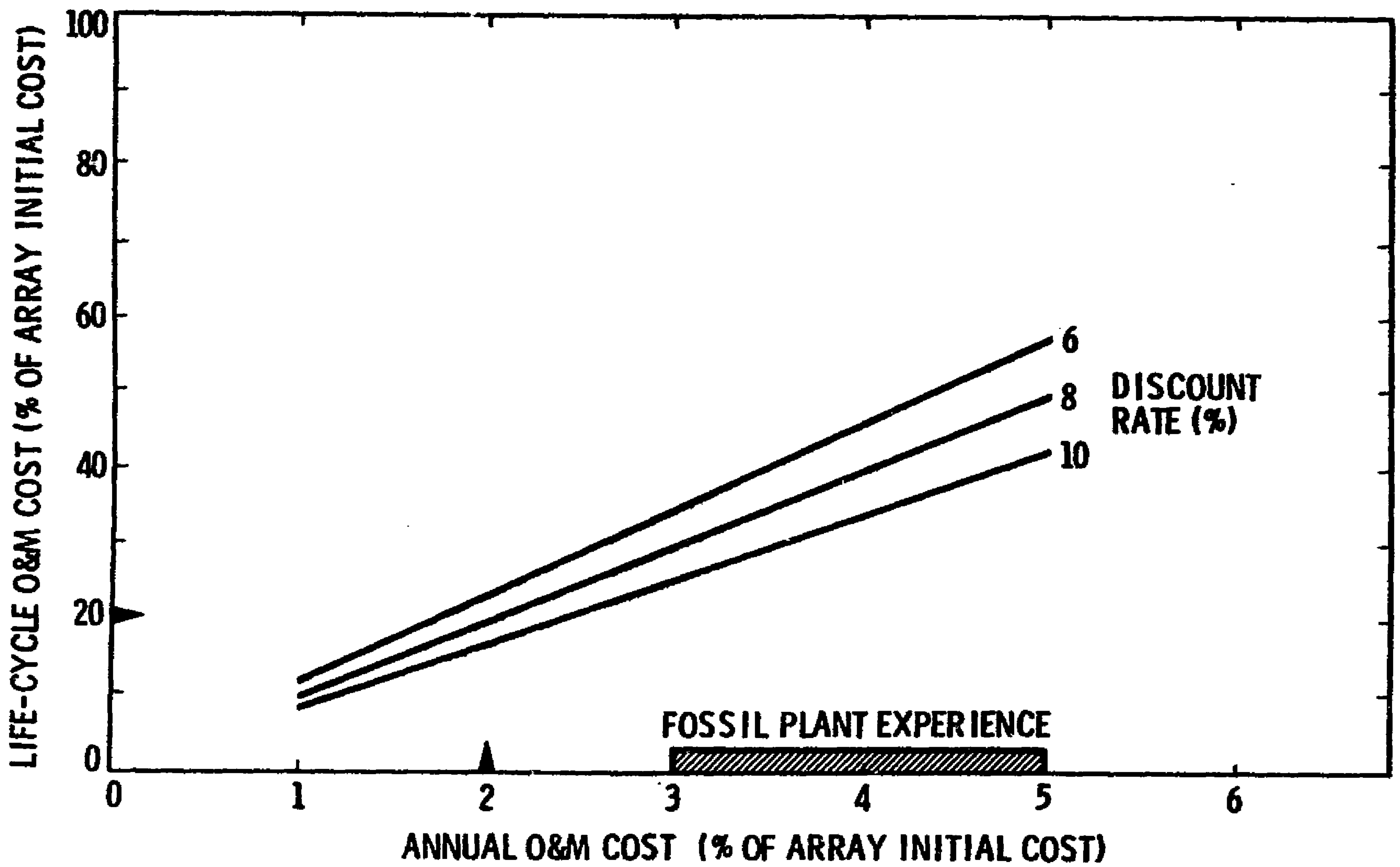
LOW-COST SOLAR ARRAY PROJECT

OPERATION AND MAINTENANCE COST IMPLICATIONS

(20-year LIFE)



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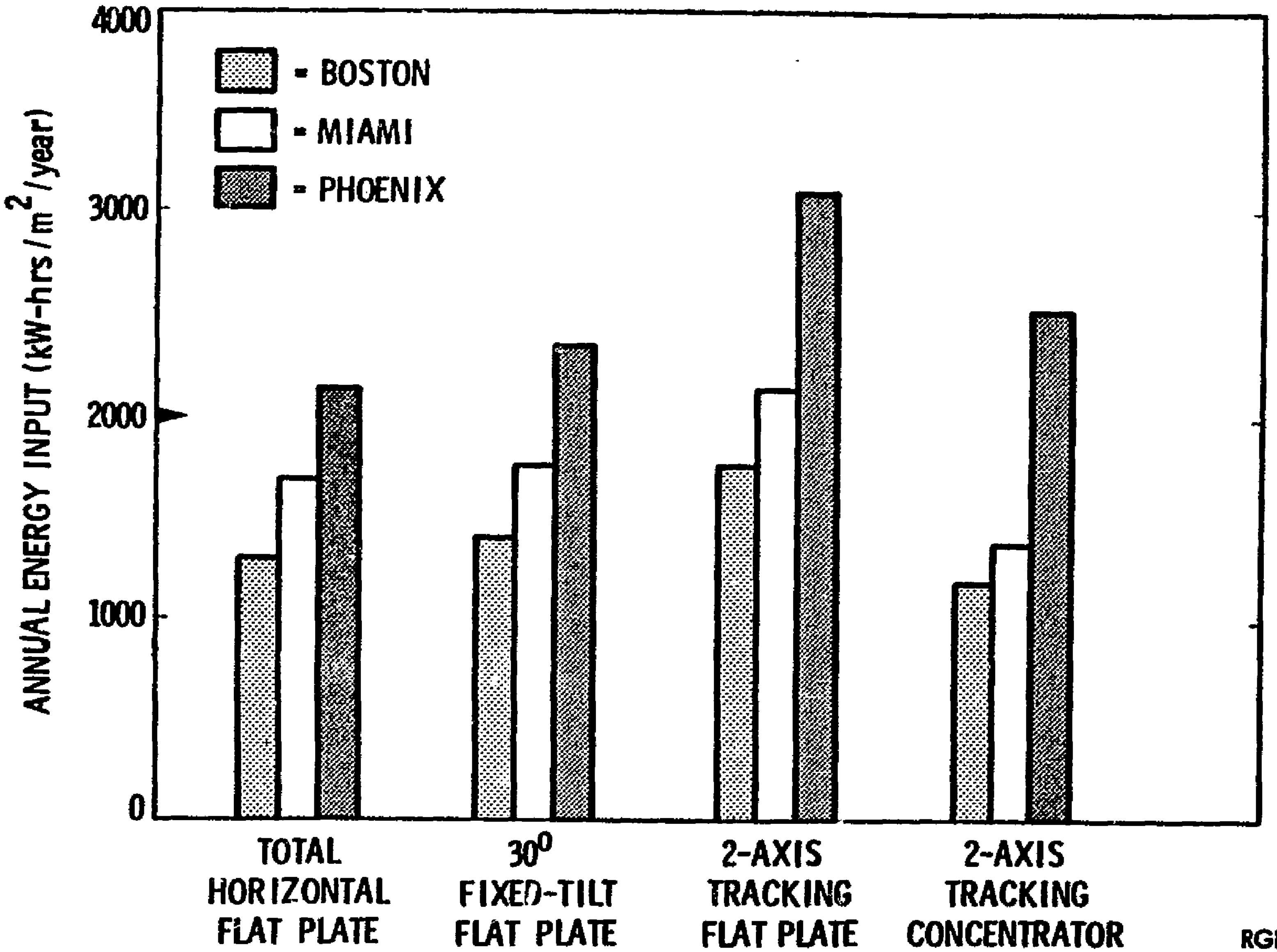
LOW-COST SOLAR ARRAY PROJECT

ANNUAL ENERGY INPUT VERSUS SITE LOCATION AND ARRAY ORIENTATION



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LOW-COST SOLAR ARRAY PROJECT
ARRAY POWER-COST GOAL
(1975 DOLLARS)

GIVEN:

$$\text{LIFE-CYCLE DC ENERGY COST} = \frac{\begin{pmatrix}\text{INITIAL COST}\\ \text{PER SQ METER}\end{pmatrix} + \overbrace{\begin{pmatrix}\text{L-C O\&M COST}\\ \text{PER SQ METER}\end{pmatrix}}^{\text{20\% OF INITIAL COST}}}{\begin{pmatrix}\text{ARRAY}\\ \text{EFFICIENCY}\end{pmatrix} \times \underbrace{\begin{pmatrix}\text{ANNUAL}\\ \text{ENERGY}\\ \text{INPUT}\end{pmatrix}}_{2000} \times \underbrace{\begin{pmatrix}\text{L-C ENERGY}\\ \text{FRACTION}\end{pmatrix}}_{10}} \approx 0.05 \left(\frac{\$}{\text{kW-hr}}\right)$$

THEREFORE:

$$\text{INITIAL COST PER } kW_{pk} = \frac{0.05 \times 2000 \times 10}{1.2}$$

$$= \boxed{750 \text{ TO } 1000 \ \$/kW_{pk}}$$

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LOW-COST SOLAR ARRAY PROJECT

ARRAY INITIAL COST VARIABLES

- ENVIRONMENT DURABILITY
  - WIND LEVEL
  - HAIL
  - SNOW AND ICE
  - SALT SPRAY
  - TROPICAL CONDITIONS
- SYSTEM DC VOLTAGE LEVEL
  - VOLTAGE ISOLATION
  - TERMINATION DESIGN
- SITE CONDITIONS
  - SOIL CONDITIONS
  - INTERFACES WITH EXISTING STRUCTURES
  - REMOTENESS

RR
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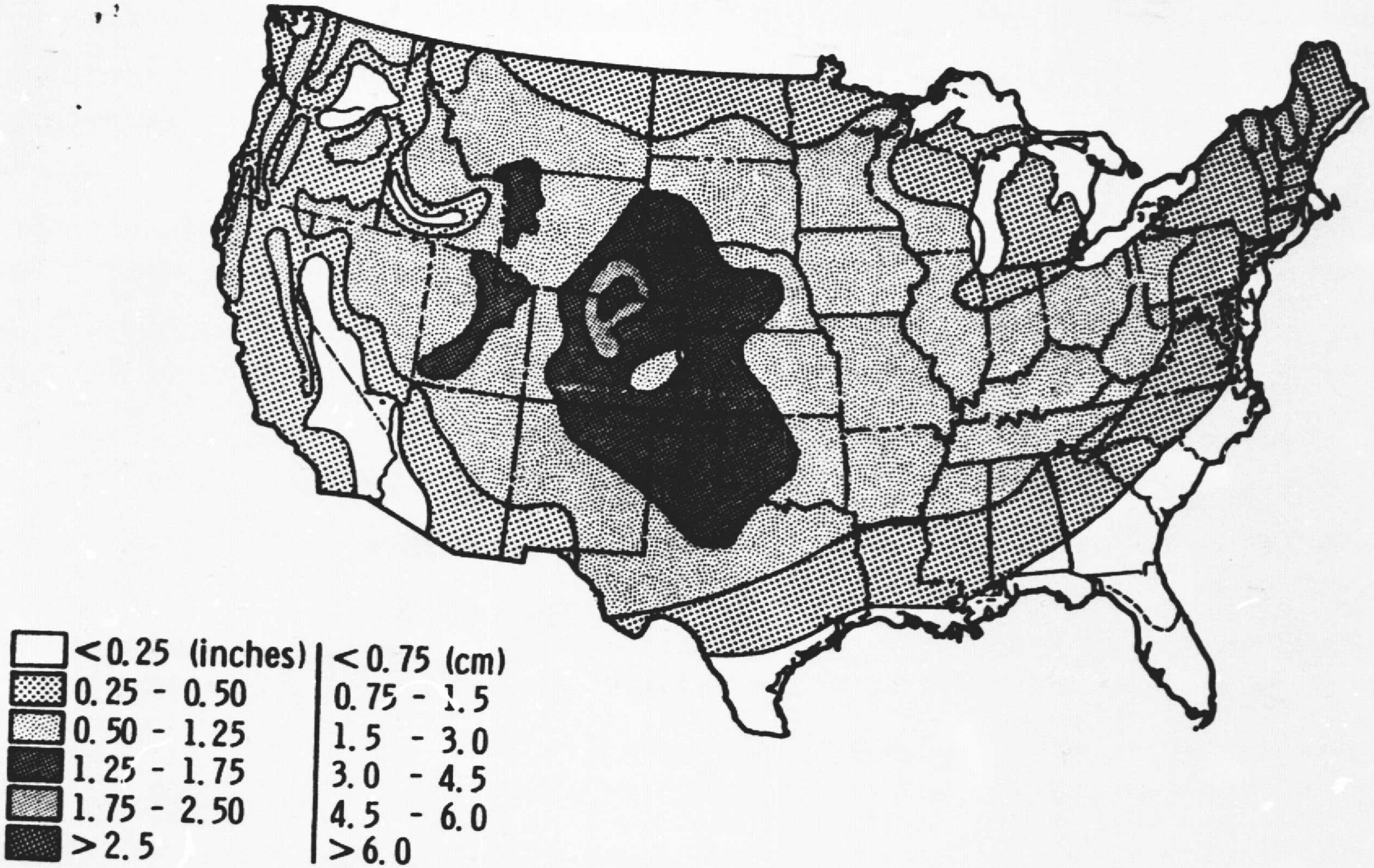
LOW-COST SOLAR ARRAY PROJECT

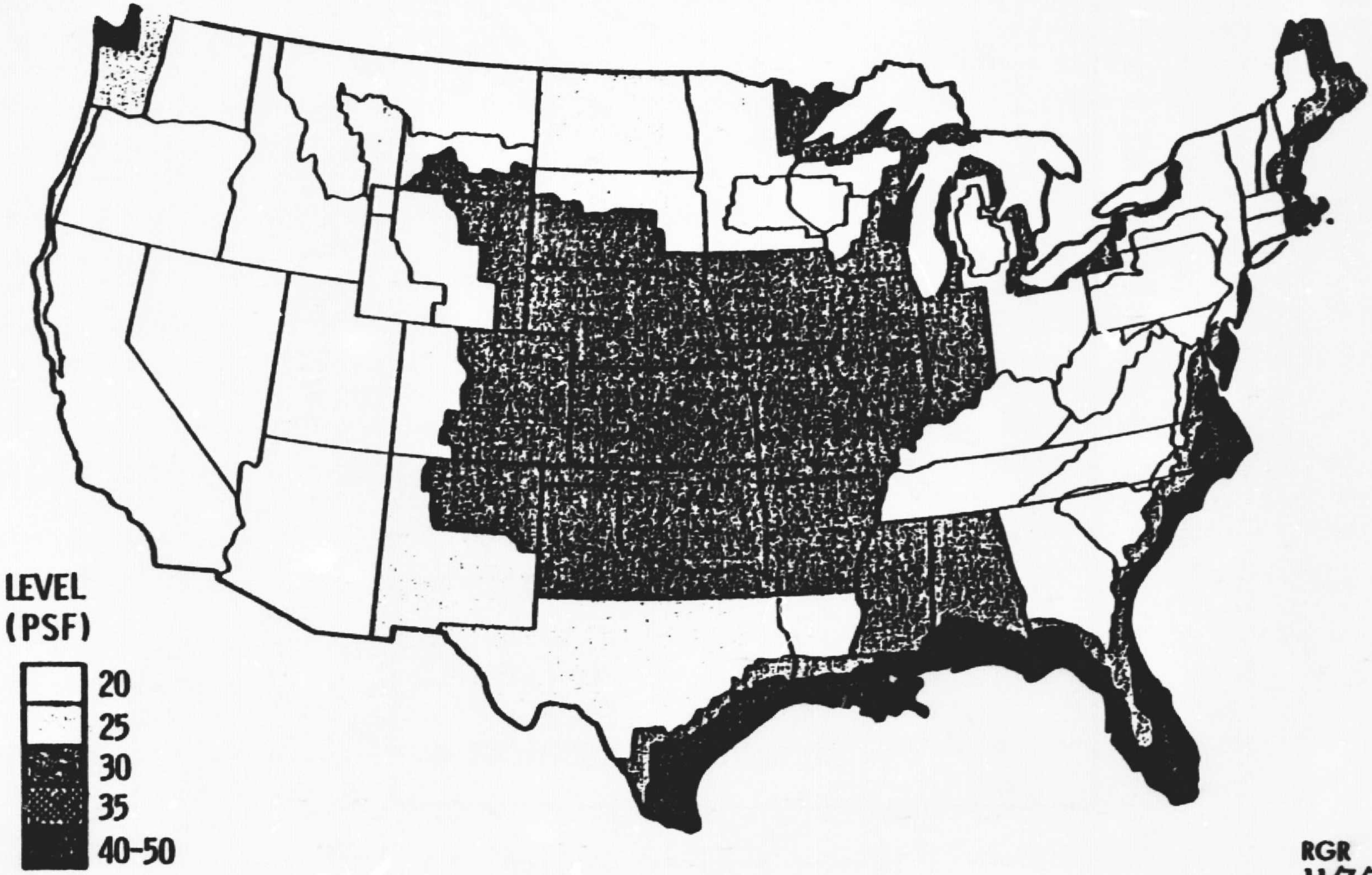
HUD MINIMUM HAIL LOAD REQUIREMENTS FOR SOLAR THERMAL COLLECTORS (HAILSTONE DIAMETER)



LOW-COST SOLAR ARRAY PROJECT

MINIMUM WIND LOADING LEVELS

(UNIFORM BUILDING CODE)



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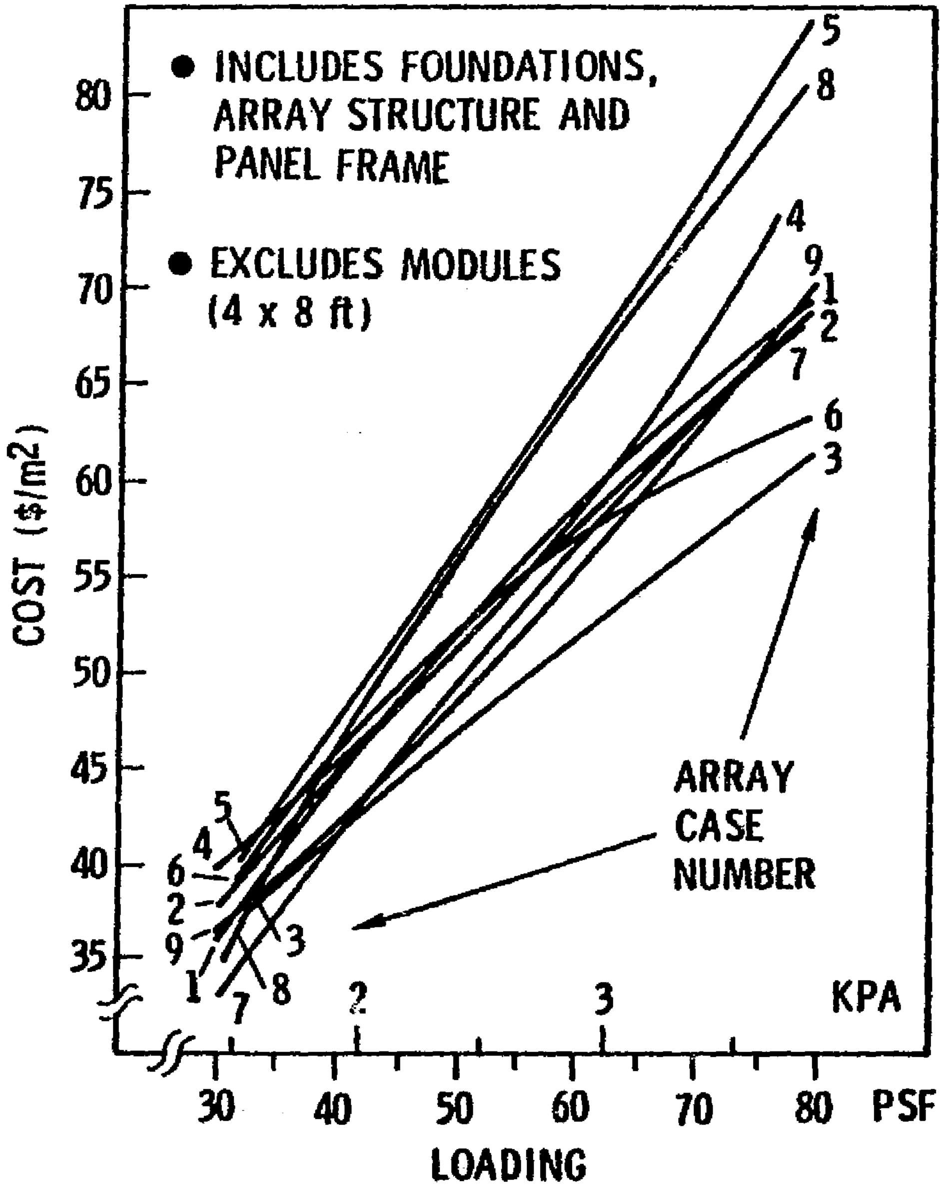
LOW-COST SOLAR ARRAY PROJECT

STRUCTURES COST

(1975 $'s)



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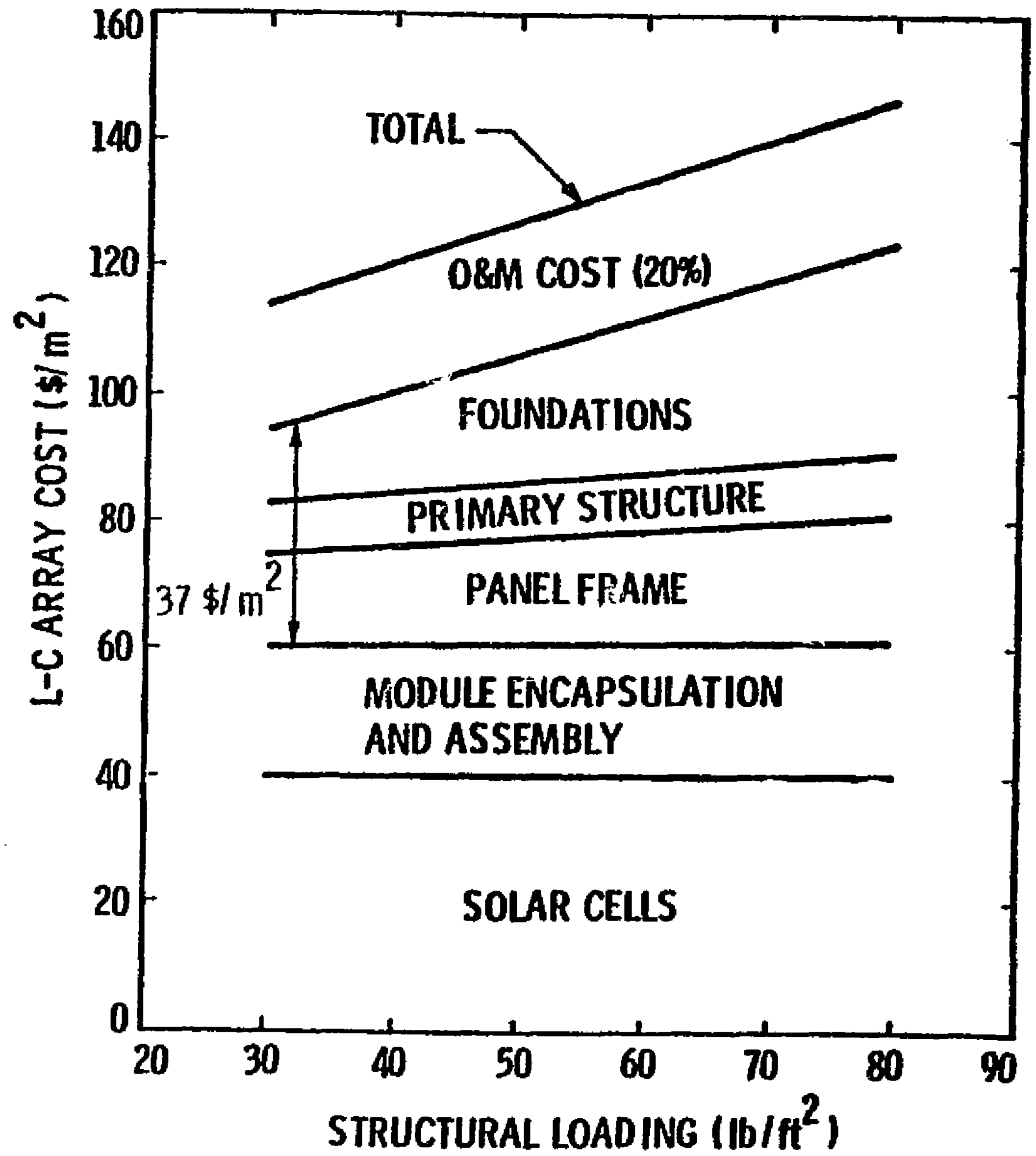
LOW-COST SOLAR ARRAY PROJECT

TYPICAL FLAT-PLATE ARRAY COST BREAKDOWN

(1975 DOLLARS)



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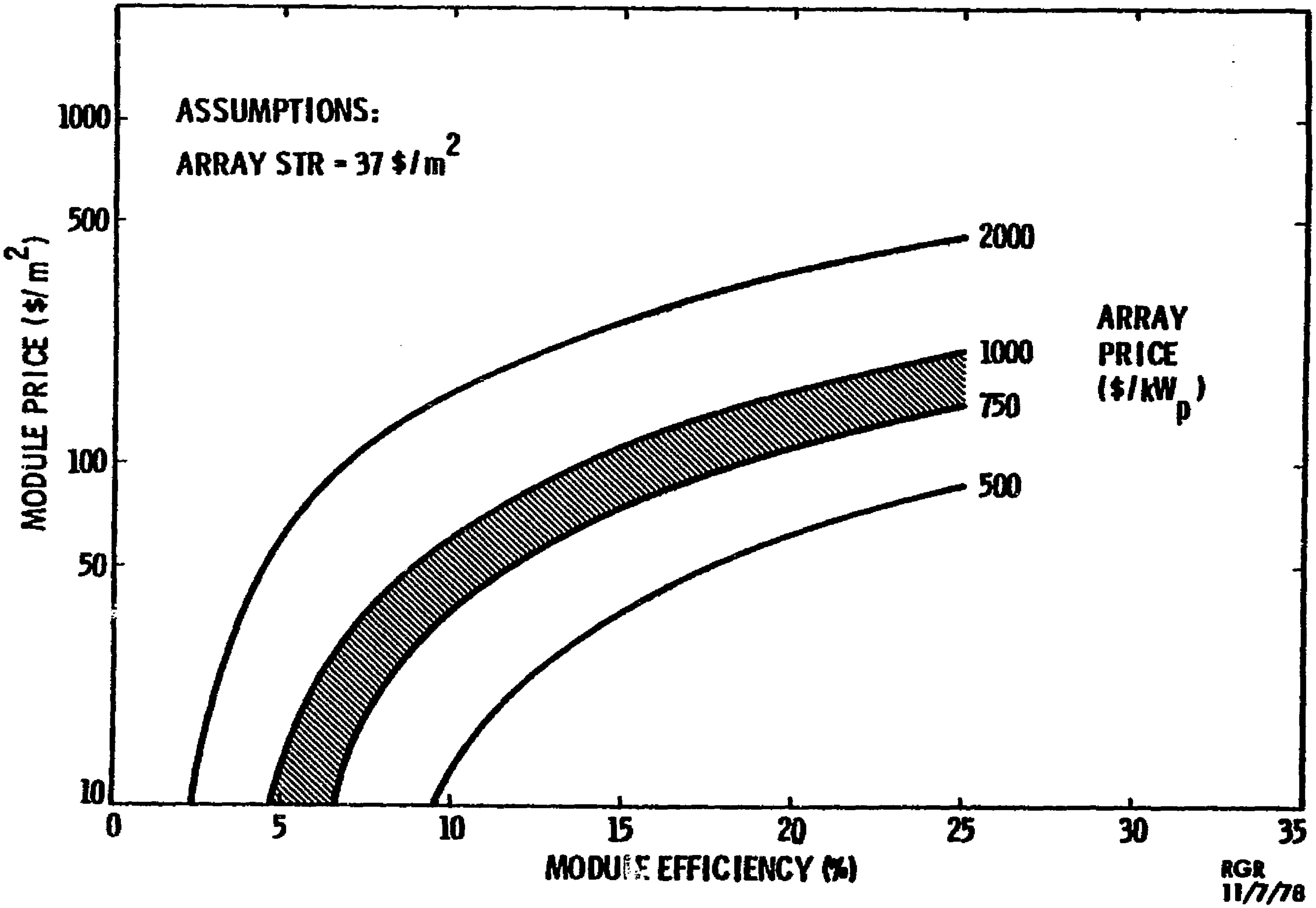
LOW-COST SOLAR ARRAY PROJECT

MODULE PRICE/EFFICIENCY GOAL SPACE

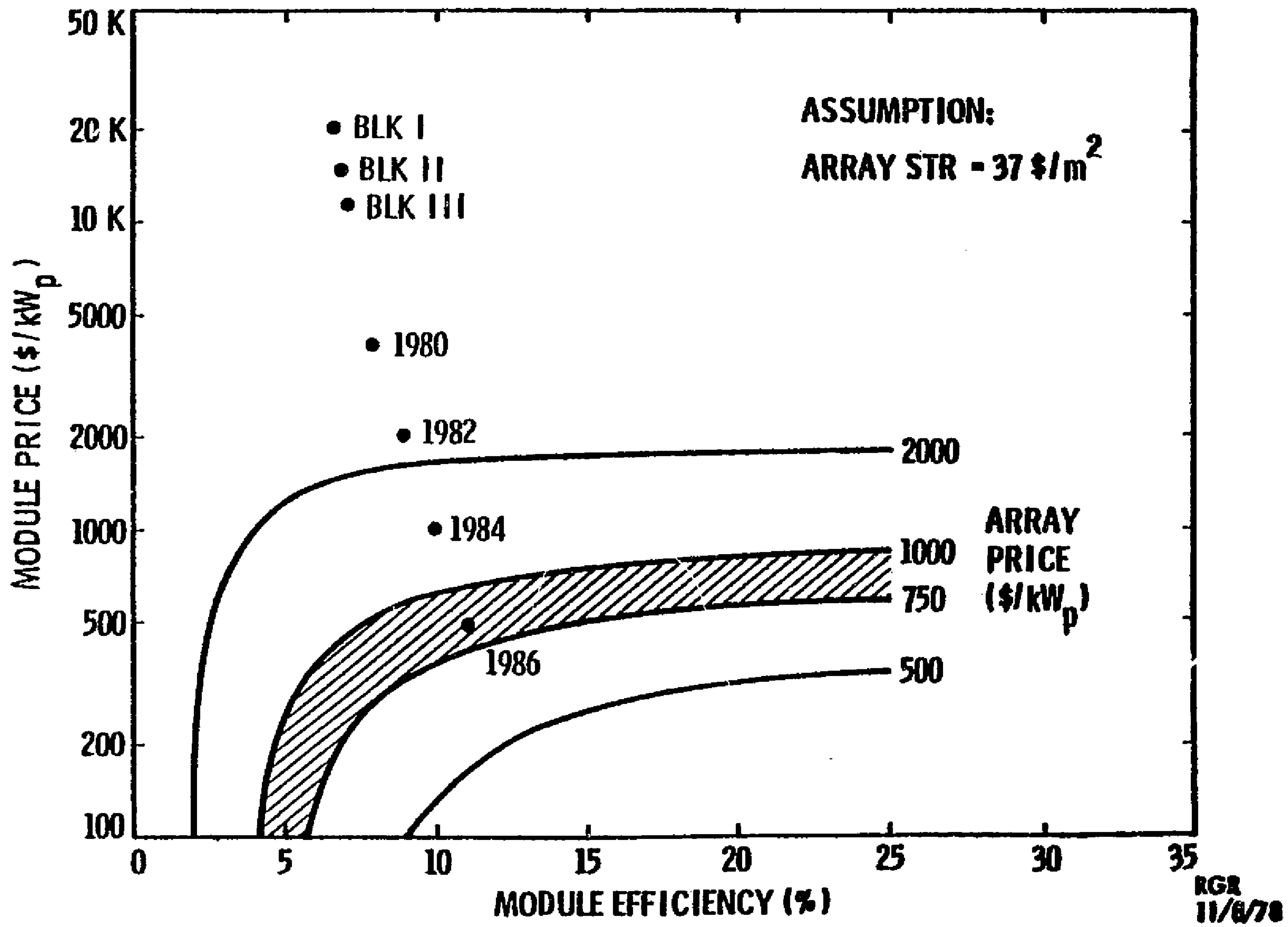
(100 mW/cm^2, 28°C, 1975 DOLLARS)



LOW-COST SOLAR ARRAY PROJECT

MODULE PRICE/EFFICIENCY GOAL SPACE

(100 mW/cm², 28°C, 1975 DOLLARS)



PROJECT SUMMARY

- TECHNICAL TASK PRICE ALLOCATION
  - CONCEPT
  - UPDATES
- BRIEF TECHNICAL TASK STATUS
- ECONOMICS OF TECHNICAL PROCESS ACHIEVEMENT
  - COST STANDARDS (SAMICS)
  - CREDIBILITY
  - THE $0.50/W$_{pk}$ PROCESS EXAMPLE

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II. PRICE ALLOCATION GUIDELINES

Table 1. Ingot Technology

Efficiency (%)		1978	1980	1982	1984	1986
Encapsulated Cell		11.5	13	14	15	16.9
Module		8.6	10.1	11.2	12.8	14.4
		Guidelines				Goals
Silicon	\$/kg	65	60	40	17	10
	\$/Wpk	1.42	1.10	0.47	0.19	0.095
Sheet (value added)	$\$/m^2$ sheet	214	129	90	54	18
	\$/Wpk	2.33	1.24	0.72	0.38	0.112
Cells (value added)	$\$/m^2$ cell	200	120	52	30	22
	\$/Wpk	1.74	0.92	0.37	.20	0.130
Encapsulaton Materials	$\$/m^2$ module	30	25	15	10	8
	\$/Wpk	0.35	0.25	0.13	0.08	0.055
Module (value added)	$\$/m^2$ module	100	50	34	20	15.5
	\$/Wpk	1.16	0.49	0.31	0.15	0.108
Totals	$\$/m^2$ module	602	404	224	128	72
	\$/Wpk	7.00	4.00	2.00	1.00	0.50

C-6

LOW-COST SOLAR ARRAY PROJECT
SILICON MATERIAL TASK
OVERVIEW
ASSUMES 1000 MT/YR PRODUCTION CAPACITY

	PROCESS	TOTAL PRODUCT COST $/kg
BMI	REDUCTION OF $SiCl_4$ IN FBR	7.80 - 10.98
UNION CARBIDE	CONVERSION $SiHCl_3$ TO SiH_4, DEPOSITION OF Si IN FSR OR FBR	(7.80)*/6.90*
MOTOROLA	Si REFINING USING SiF_2	9.50
WESTINGHOUSE	REDUCTION OF $SiCl_4$ BY NA IN ARC HEATER REACTOR	9.42
DOW CORNING	PURER SiO_2 + C IN REFINED ARC FURNACE AND UNIDIRECTIONAL SUBDIFICATION	7.40
	REDUCTION OF SILICON HALIDES BY ALKALI METALS USING FLAME CHEMISTRY	
	REDUCTION OF SiF_4 BY NA AND SUBSEQUENT Si PURIFICATION	6.20
	REDUCTION OF BROMOSILANES IN HIGH VELOCITY REACTOR	

*UNION CARBIDE CALCULATION ASSUMING 15% ROI

**LAMAR UNIVERSITY CALCULATION OF TOTAL PRODUCT COST

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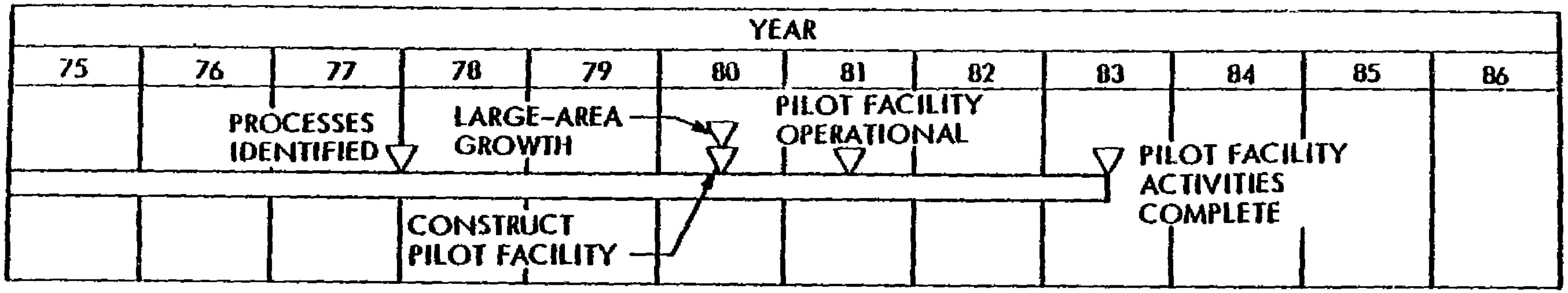
LOW-COST SOLAR ARRAY PROJECT
LARGE AREA SILICON SHEET TASK
STATUS-NOVEMBER 1978



INGOT TECHNOLOGY

- ADVANCED Cz GROWTH
  - ADV. Cz GROWTH MACHINES BUILT
  - MELT REPLENISHMENT DEMONSTRATED
  - MULTIPLE INGOT GROWTH DEMONSTRATED (12 cm DIAM., 4 INGOTS, 50 kg TOTAL)
- CASTING BY HEAT EXCHANGE METHOD
  - 2.5 kg SHAPED INGOT CAST (> 80% SINGLE CRYSTAL)
- WAFERING
  - 1000 BLADE PROTOTYPE MBS SAW BUILT AND TESTING IN PROGRESS (10 cm DIA, 300 μ WAFER, 200 μ KERF, > 95% YIELD)
  - 300 WIRE MW PROTOTYPE SAW BUILT AND TESTING IN PROGRESS (10 cm DIA, 250 μ WAFER, 250 μ KERF, > 97% YIELD)

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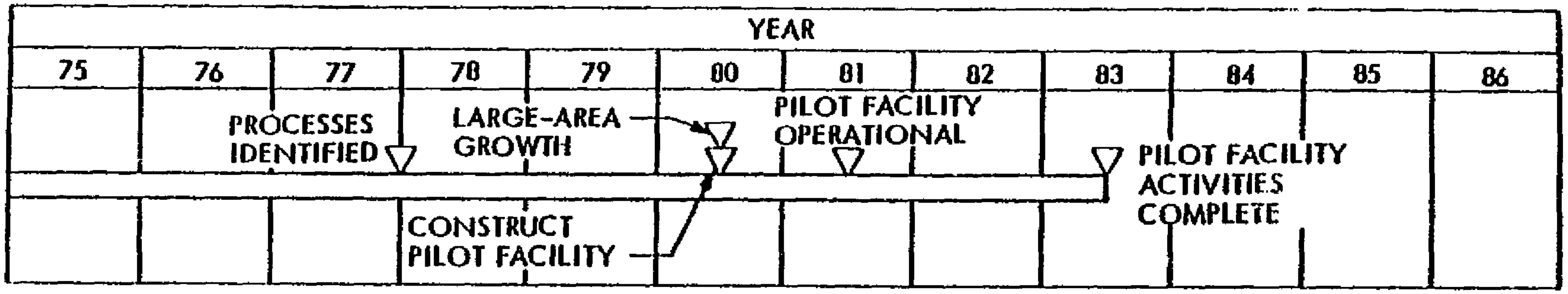
LOW-COST SOLAR ARRAY PROJECT
LARGE AREA SILICON SHEET TASK
STATUS-NOVEMBER 1978



SHAPED RIBBON TECHNOLOGY

- SIMULTANEOUS GROWTH OF 5 EFG RIBBONS EACH 5 cm WIDE AT 5 cm/min IS ROUTINELY ACHIEVABLE
- CONSIDERABLE PROGRESS IN MINIMIZING THE CONTAMINATION-RELATED EFFECTS ON EFG CELLS (> 9% EFFICIENCY)
- 13 cm^2/min AREA GROWTH RATE HAS BEEN ACHIEVED FOR WEB-DENDRITIC RIBBONS
- 15.5% EFFICIENCY WEB-DENDRITIC CELLS HAVE BEEN DEMONSTRATED (6.4 cm^2 AREA)
- 55 cm^2/min AREA GROWTH RATE HAS BEEN ACHIEVED FOR RTR RIBBONS WITH CVD POLY FEEDSTOCK
- 6% EFFICIENCY RTR CELLS HAVE BEEN DEMONSTRATED (4 cm^2 AREA)

SUPPORTED FILM TECHNOLOGY

- 4.5 cm^2 SOC CELLS HAVE BEEN FABRICATED WITH >7% EFFICIENCY (SLOTTED MULLITE SUBSTRATE, BACK SIDE CONTACT)
- 12% EPI CELLS ON METALLURGICAL GRADE SI SUBSTRATES HAVE BEEN DEMONSTRATED

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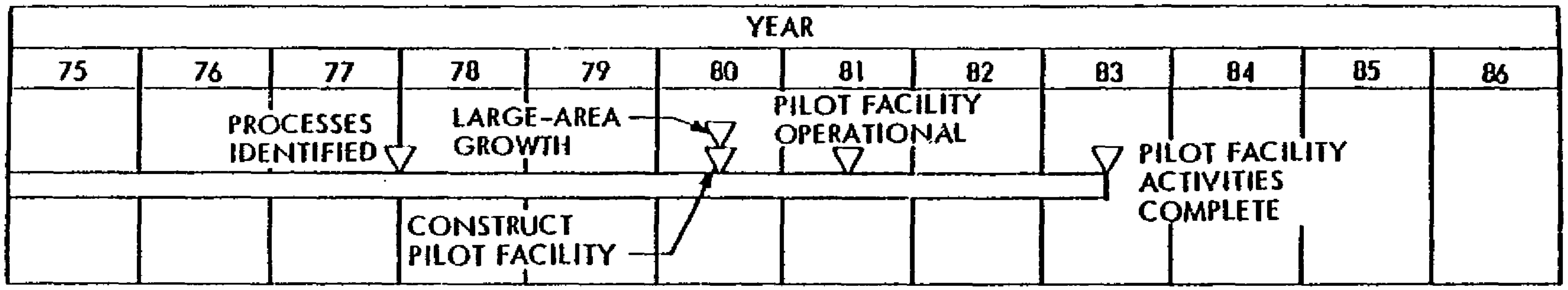
LOW-COST SOLAR ARRAY PROJECT
LARGE AREA SILICON SHEET TASK
PLANS UP TO APRIL 1979



INGOT TECHNOLOGY

- DEMONSTRATE GROWTH OF 100 kg Cz INGOT (10 cm DIA. AT 10 cm/hour WITH MELT REPLENISHMENT)
- ACHIEVE GROWTH OF 8 kg SHAPED HEM INGOT
- ACHIEVE WAFERING GOAL OF 25 SLICES/cm OF 10 cm DIA. INGOT

SHAPED RIBBON TECHNOLOGY

- DEMONSTRATE SIMULTANEOUS GROWTH OF EFG RIBBONS, 10 cm WIDE AT 5 cm/min (250 cm^2/min)
- ACHIEVE 25 cm^2/min AREA GROWTH RATE FOR WEB-DENDRITIC RIBBONS
- DEMONSTRATE >10% EFFICIENCY RTR CELLS AND ACHIEVE 100 cm^2/min AREA GROWTH RATE

SUPPORTED FILM TECHNOLOGY

- DEMONSTRATE >10% EFFICIENCY SOC CELLS
- DEMONSTRATE ROUTINE UTILIZATION OF HIGH THROUGHPUT EPI REACTOR

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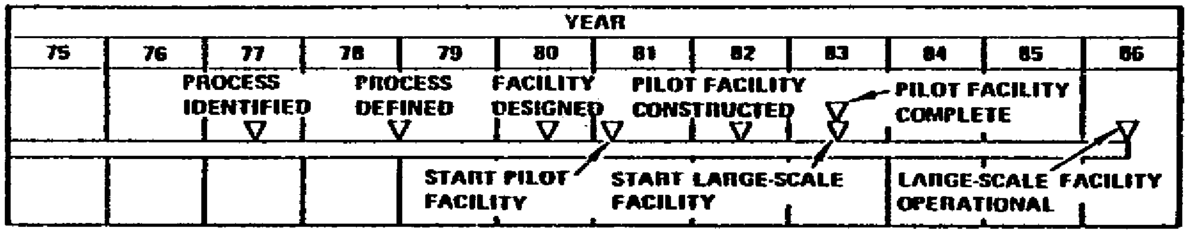
LOW-COST SOLAR ARRAY PROJECT

GENERAL PLAN

PRODUCTION PROCESS AND EQUIPMENT



PHASE II PROCESS DEVELOPMENT

- LOCKHEED
- MBA
- RCA
- SENSOR TECHNOLOGY
- SOLAREX
- TEXAS INSTRUMENTS
- WESTINGHOUSE
- MOTOROLA
- SPECTROLAB

SPECIAL PROCESS STUDIES

- SPIRE
- OCLI
- MOTOROLA
- SOLAREX
- B. ROSS
- KINETIC COATINGS

NEAR TERM COST REDUCTION

- ARCO
- KULICKE AND SOFFA
- SOLLOS
- MOTOROLA
- RCA
- SENSOR TECHNOLOGY

< $500/kW$_{pk}$ STRAWMAN FACTORY

	VALUE ADDED $/W
SILICON* PREPARATION	0.043
SHEET FABRICATION	0.134
CELL FABRICATION	0.119
MODULE FABRICATION	0.164
TOTALS	0.460

*BASED ON 10 $/kg SILICON

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LOW-COST SOLAR ARRAY PROJECT

ENCAPSULATION TASK STATUS

MATERIAL SYSTEMS	EST. COST	¢/W_{pk}	STATUS
1982 CANDIDATE (TYPICAL) SODA-LIME GLASS, LOW IRON, TEMPERED, \$7.00/m^2 SAFLEX PVB, - 3.00/m^2 MYLAR OR TEDLAR FILM, - 1.00/m^2 STEEL FRAME, - \$4.00	\$15.00/m^2	@ 11% 13¢	IN PRODUCTION MODULES GOING THROUGH FIELD TESTING
1986 CANDIDATES (TWO BASIC DESIGNS)		@13%	
SODA-LIME GLASS, ANNEALED, AR-COATED, \$3.50/m^2 EHTYLENE VINYLACETATE POTTANT, 1.00/m^2 ALUMINUM FOIL BACK COVER, 0.30/m^2 FRAME (OPTIONAL) 3.00/m^2	4.80/m^2 + 3.00/m^2	3.7¢ TO 6.0¢	MINI-MODULE FAB AND TEST (LIFE AND FAILURE MODES UNKNOWN)
HARDBOARD SUBSTRATE (WEATHERIZED) \$1.70/m^2 ETHYLENE VINYLACETATE, 1.00/m^2 ACRYLIC UV SCREEN AND SOILING COVER 0.30/m^2 FRAME (OPTIONAL) 3.00/m^2	3.00/m^2 + 3.00/m^2	2.3¢ TO 4.6¢	MINI-MODULE FAB AND TEST (UNKNOWN UV DEGREDATION RATE) UV SCREENS BEING DEVELOPED
1986 MATERIAL AND PROCESS OPTIONS R&D			
ELECTROSTATIC BONDING TO GLASS ELASTOMERIC ACRYLIC POTTANTS FUSED GLASS HERMETIC ENCAPSULATION ION-PLATED FILMS GLASS REINFORCED CONCRETE SUBSTRATE			DEVELOPMENTS UNDER CURRENT AND PLANNED R&D CONTRACTS

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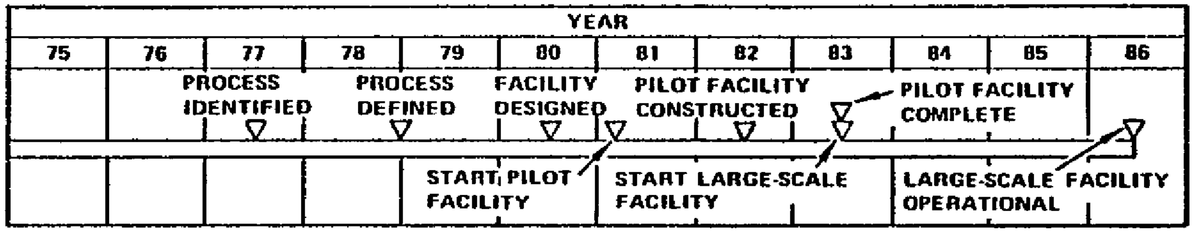
LOW-COST SOLAR ARRAY PROJECT

STATUS-OCTOBER 1979

PRODUCTION PROCESS AND EQUIPMENT



PHASE II PROCESS DEVELOPMENT

$500/kW$_{pk}$ STRAWMAN FACTORY

- ACHIEVABLE USING PROCESSES UNDER DEVELOPMENT
- GOAL MAY BE EXCEEDED

SEQUENCE DEVELOPMENT EFFORT STARTING

- PROCESSES SELECTED FOR USE IN SEQUENCES
- SEQUENCE OPTIONS AVAILABLE USING ALTERNATE KEY PROCESSES
- DEVELOPED PROCESSES ARE BEING VERIFIED

SPECIAL PROCESS STUDIES

- LARGE SCALE ION IMPLANTER DESIGN COMPLETED
- HIGH EFFICIENCY P/N CELLS/MODULES

METALLIZATION DEVELOPMENTS

- WORKSHOP HELD TO BRING IN NEW APPROACHES
- CONCERN OVER ENVIRONMENTAL/ENCAPSULATION REQUIREMENTS
- WORK ON THICK FILM METAL INKS WITHOUT FRIT
- PURSUING FURTHER REDUCTIONS IN PLATING SYSTEMS COSTS

NEAR TERM PRICE REDUCTION CONTRACTS

- SUPPORTED PROJECT IN RFP, PROPOSAL EVALUATION, AND CONTRACT MONITORING

PHASE III

- FIRST GENERATION SPRAY EQUIPMENT OPERATIONAL FOR JUNCTION FORMATION

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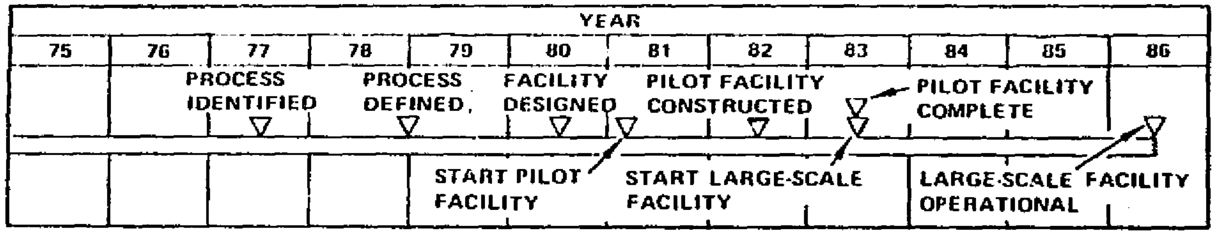
LOW-COST SOLAR ARRAY PROJECT

ANTICIPATED STATUS-APRIL 1979

PRODUCTION PROCESS AND EQUIPMENT



- WORK TOWARD 4c/WATT METALLIZATION SYSTEMS
- CONTINUE PROCESS SEQUENCE DEVELOPMENT
- BROADEN TECHNOLOGY TRANSFER
- DEVELOPMENT OF AUTOMATED ASSEMBLY EQUIPMENT
- MATERIAL HANDLING STUDIES

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LOW-COST SOLAR ARRAY PROJECT

SAMICS PROGRESS

- SEPTEMBER, 1977
  1) RELEASE OF IPEG (INTERIM PRICE ESTIMATION GUIDELINES)
  2) RELEASE OF SAMICS (COSTING STANDARDS)
- DECEMBER, 1977

  SAMICS/IPEG USED FOR THE "2\$/W_{pk} STRAWMAN"
- APRIL, 1978 RELEASE OF SAMIS III (INDUSTRY SIMULATION MODEL)
- FROM APRIL THROUGH AUGUST, 1978
  1) SAMIS III DEVELOPMENT AND VALIDATION
  2) EXPANSION OF THE SAMIS DATA BASE (NEARLY 200 FORMAT A's)
  3) SAMIS III IS REPLACING IPEG AT JPL
- AUGUST, 1978 SAMIS III USED FOR "\$0.50/W_{pk} STRAWMAN"

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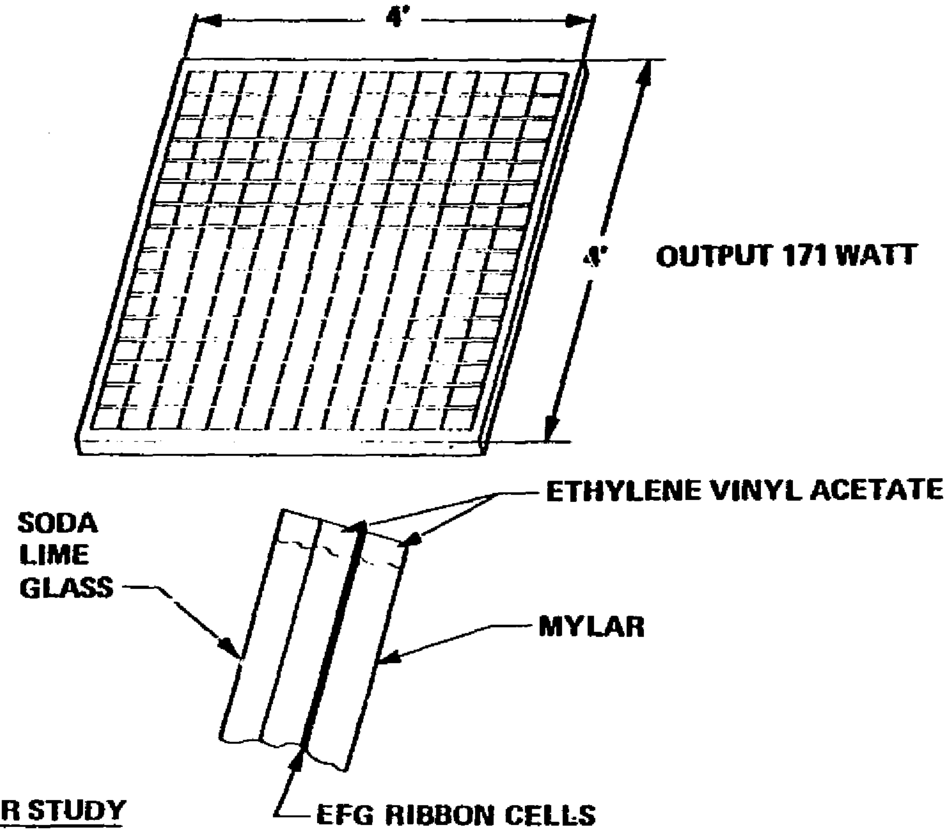
LOW-COST SOLAR ARRAY PROJECT

<$500/KWpk STRAWMAN FACTORY

PRODUCT DESIGN



NOMINAL TECHNOLOGIES SELECTED FOR STUDY

TECHNICAL AREA	NOMINAL APPROACH
POLYSILICON PRODUCTION	LOW COST SILANE AND FREE SPACE REACTOR (U.C.)
SILICON SHEET PRODUCTION	EDGE-DEFINED, FILM FED GROWTH (MOBIL TYCO)
SOLAR CELL AND ARRAY PRODUCTION	ION IMPLANTATION, ETC.
ENCAPSULATION	GLASS - ETHYLENE VINYL ACETATE | CELLS | ETHYLENE VINYL ACETATE- MYLAR

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jpl

LOW-COST SOLAR ARRAY PROJECT

0.50 \$/Wpk TECHNOLOGY

	30 MEGAWATT CAPACITY	50 MEGAWATT CAPACITY	250 MEGAWATT CAPACITY
PRICE	0.487 $\$/W_{pk}$	0.479 $\$/W_{pk}$	0.465 $\$/W_{pk}$
INITIAL INVESTMENT	5.8×10^6 \$	9.5×10^6 \$	42×10^6 \$

SENSITIVITY TO SCALE (1975 DOLLARS)

BASED ON:

- 12% ENCAPSULATED CELL EFFICIENCY
- \$10/kg SILICON

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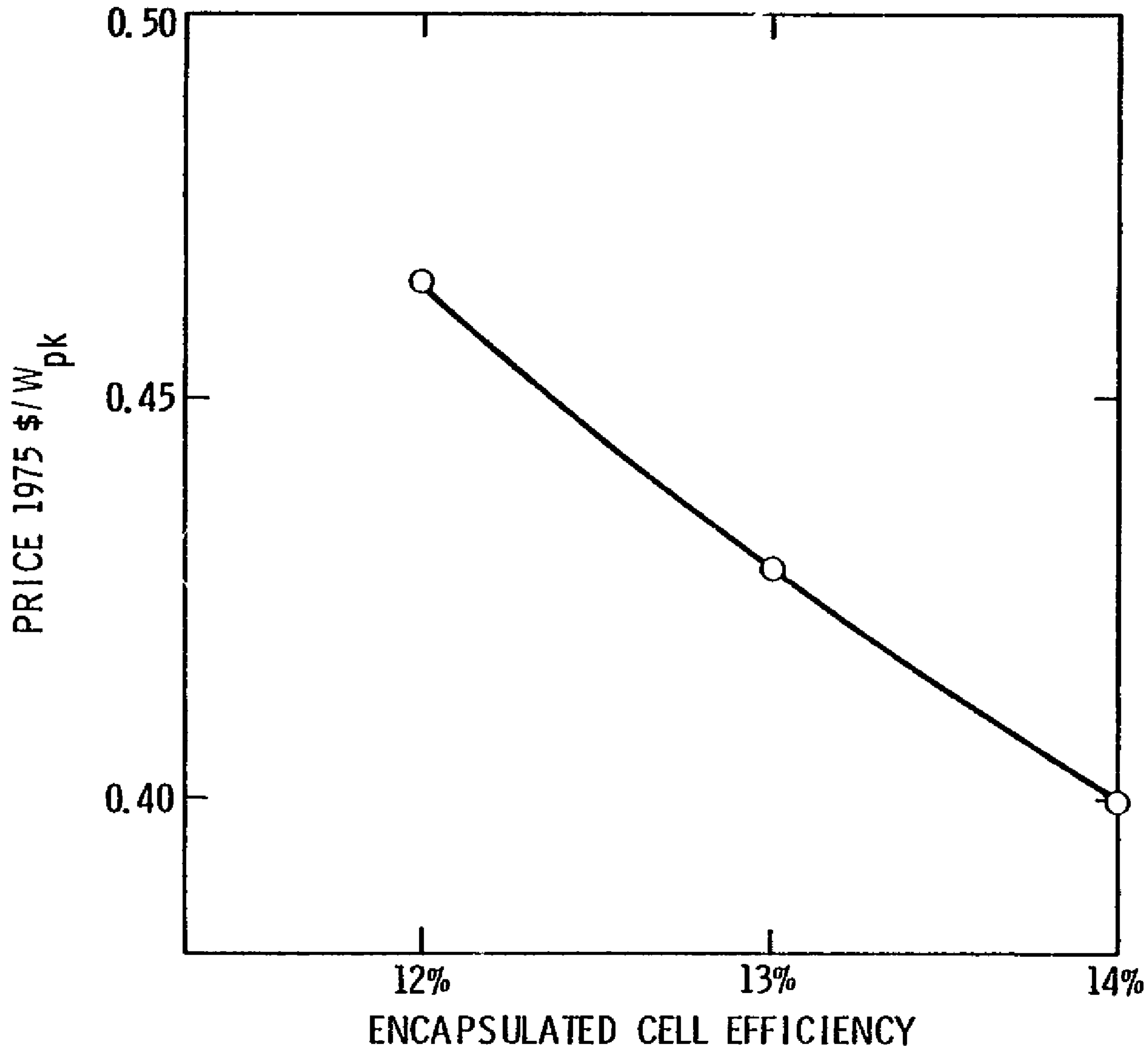
LOW-COST SOLAR ARRAY PROJECT

0.50 $/Wpk TECHNOLOGY PRICE vs CELL EFFICIENCY



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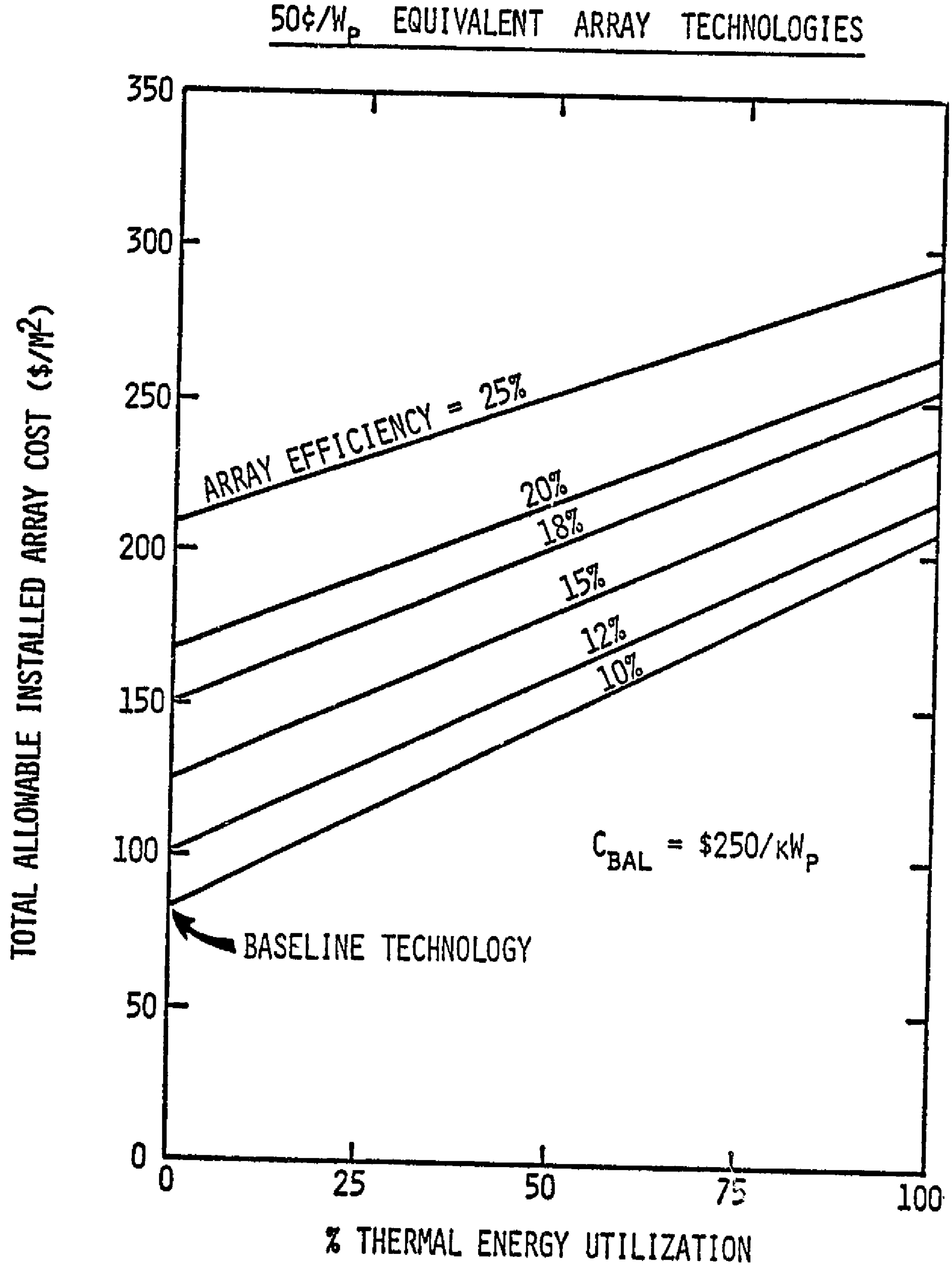
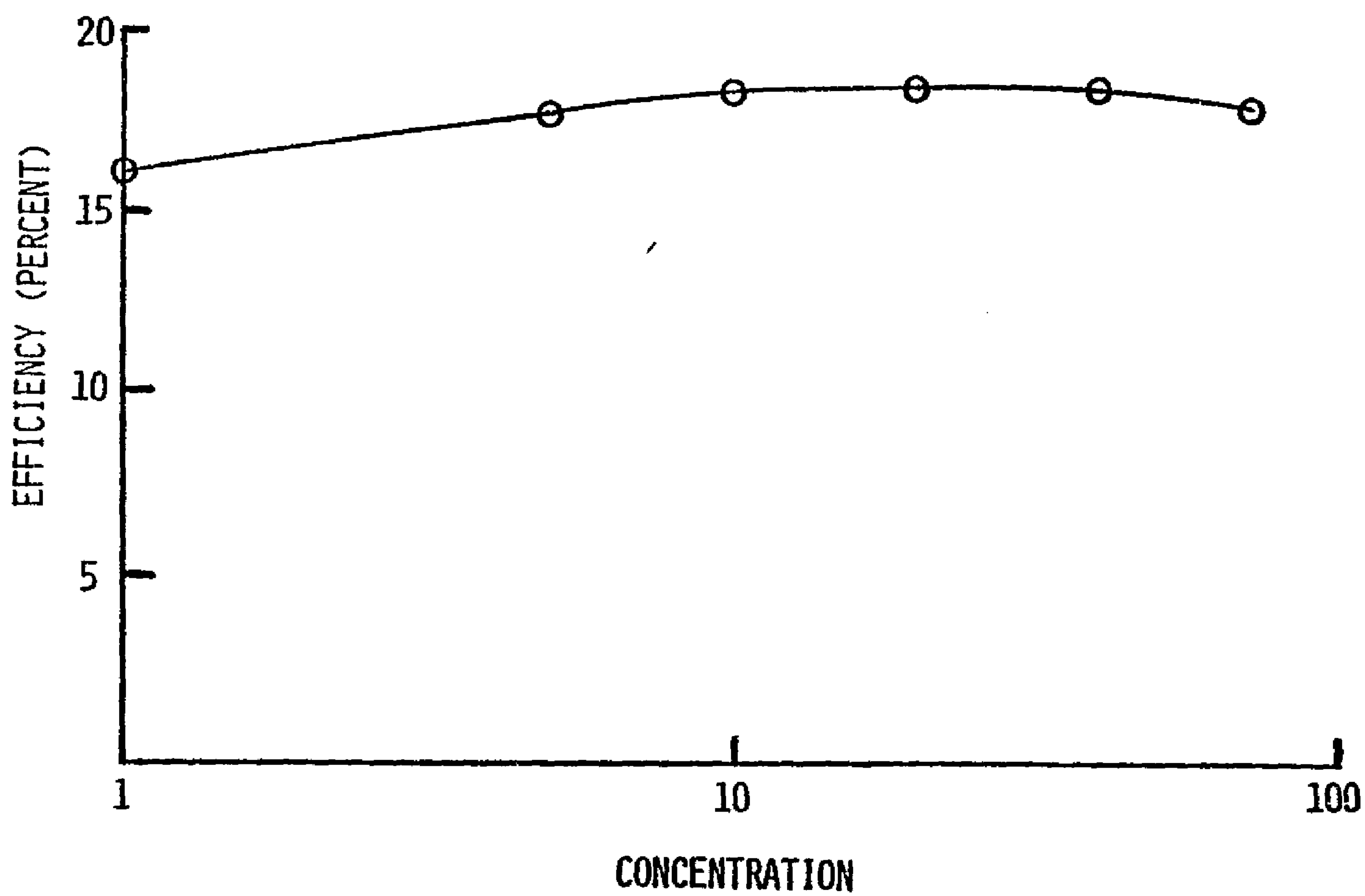
INSTALLED CONCENTRATOR ARRAY COST
AS IT RELATES TO THE 50¢/WATT GOAL

B. D. SHAFER
SANDIA LABORATORIES



50¢/W_P EQUIVALENT ARRAY TECHNOLOGIES
350
300
250
200
150
100
50
0
TOTAL ALLOWABLE INSTALLED ARRAY COST ($/M²)
ARRAY EFFICIENCY = 25%
20%
18%
15%
12%
10%
C_BAL = $250/KW_P
BASELINE TECHNOLOGY
0
25
50
75
100
% THERMAL ENERGY UTILIZATION

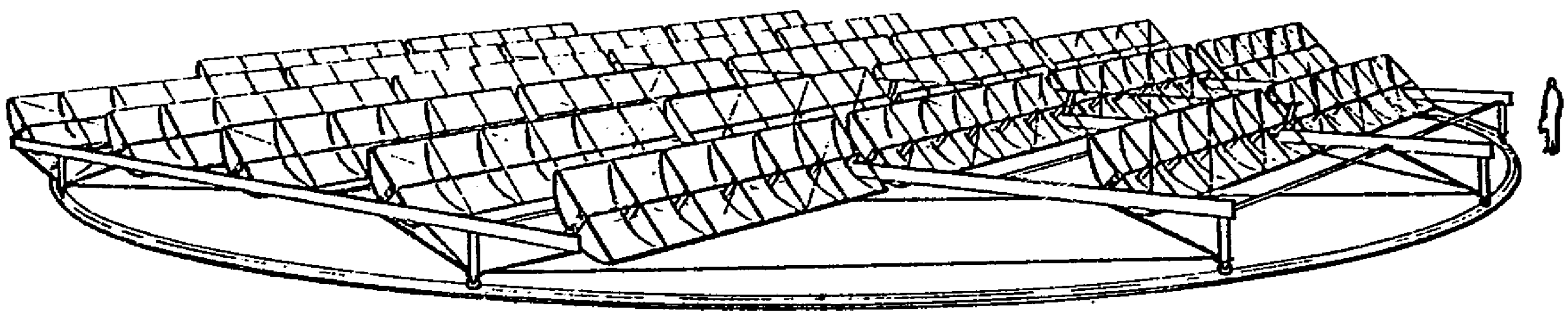
CELL EFFICIENCY
VERSUS CONCENTRATION



GENERAL
ELECTRIC

CONCENTRATING
PHOTOVOLTAICS

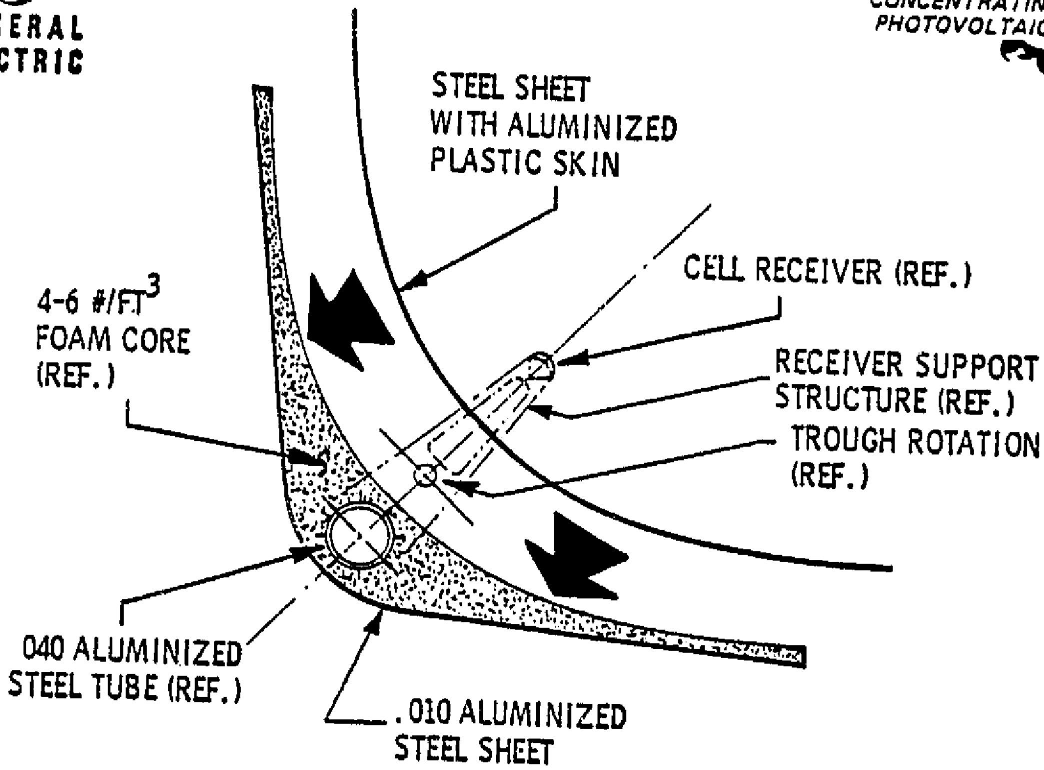
PRIME ARRAY



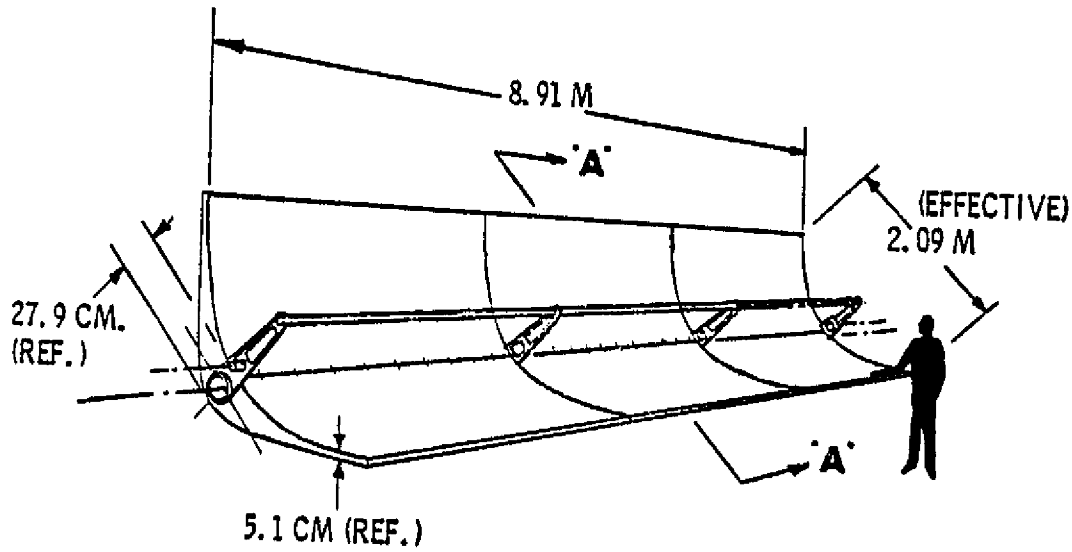
GENERAL ELECTRIC

FOAM SANDWICH TROUGH

CONCENTRATING PHOTOVOLTAICS



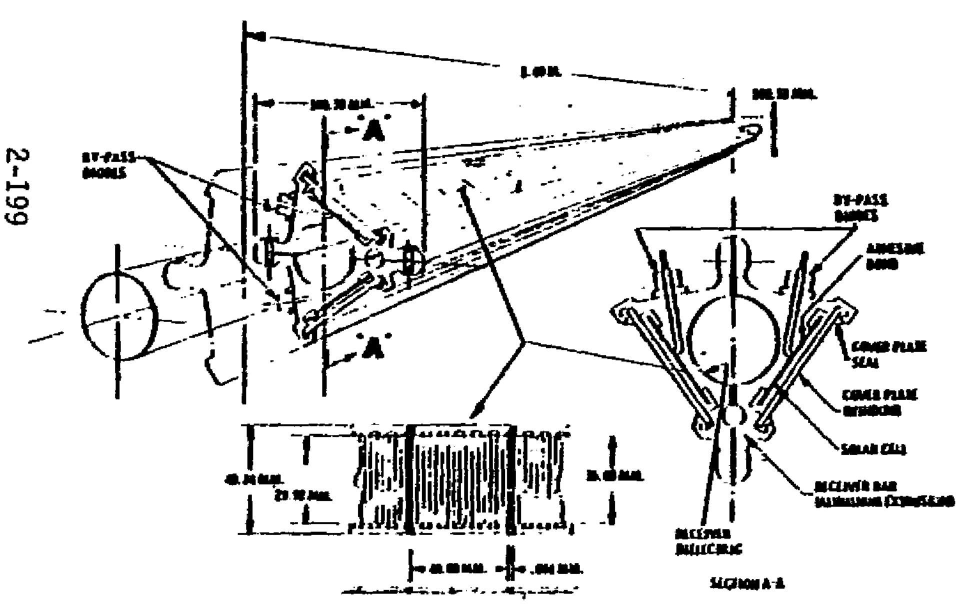
SECTION A-A

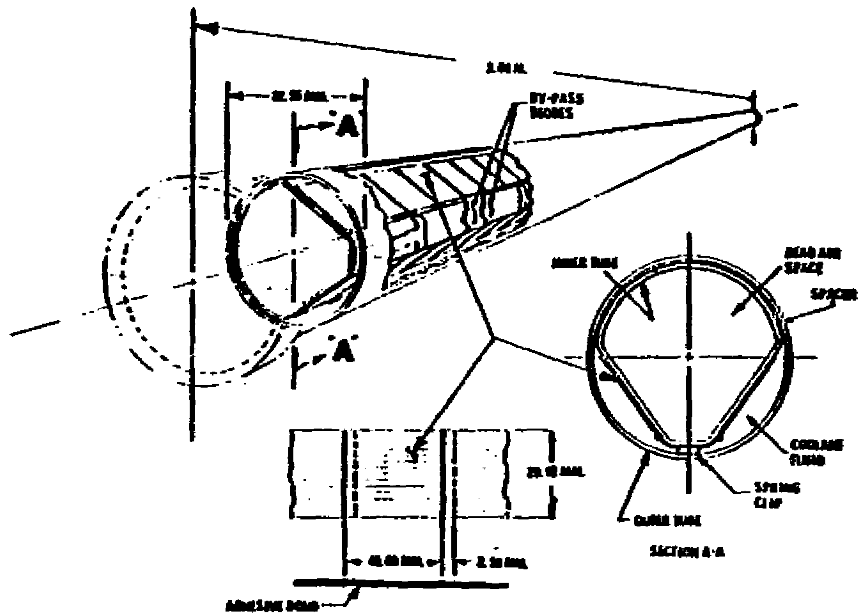


GENERAL ELECTRIC

CELL RECEIVER OPTIONS

CONCENTRATING PHOTOVOLTAICS





GENERAL ELECTRIC

CONCENTRATING PHOTOVOLTAICS

BASIC COST ASSUMPTIONS

RAW MATERIAL

EXTRUDED ALUMINUM	\$ .85 TO \$.90/LB.
STEEL SHEET	\$ .25/LB
STRUCTURAL STEEL	\$ .38/LB
STRUCTURAL ALUM.	\$1.05/LB
COVER GLASS	\$1.00/FT^2
REFLECTIVE FILM	\$ .11/FT^2
GEL COAT	\$1.90/LB
URETHANE FOAM	\$ .90/LB
RTV 670	\$13.80/LB

KEY COMPONENTS

1/4 HP AC MOTORS	\$ 75 EA
1/2 HP AC MOTORS	\$ 100 EA
ELEV. GEAR BOX	\$ 100 EA
AZ. GEARBOX	\$ 300 EA
JACKSCREW	\$ 350 EA
SOLID STATE SWITCHES	\$ .25 EA
POSITION INDICATORS	\$ 70 EA
BEARINGS	\$ 10 EA
SILICON CELLS	\$ .25/CM^2
SUN TRACKER	\$ 500
WHEELS	\$ 35 EA

INSTALLATION

REINFORCED CONCRETE \$150/YD^3 (INCLUDES CONCRETE)
STRUCTURAL STEEL \$1.00/LB (INCLUDES STEEL)
PAINTING \$ .25/FT^2
TURNTABLE WIRING \$1.25/LF
TURNTABLE PIPING \$1.50/LF

ARRAY MATERIAL COST SUMMARY

1978 COSTS-$/M^2 (EFFECTIVE APERTURE)

ARRAY HARDWARE	ANNUAL PRODUCTION LEVEL-M^2/YR 10^4	10^5	10^6	10^7
SOLAR CELLS	73.77	59.02	44.26	29.51
RECEIVER BAR	6.80	5.23	.25	.25
INTERCONNECT RIBBONS	3.91	2.78	-	-
BOND ADHESIVE, ENCAPSULANT, GLASS	.80	.74	1.14	1.14
DIODES	1.70	1.70	1.50	1.50
MISC. WIRING, BUSS BAR	.25	.16	.16	.13
	87.00	69.70	47.30	32.50
TROUGH SUBSTRATE & INTERFACE HDW.	13.13	22.16	19.36	18.39
REFLECTIVE SURFACE & PROTECTIVE COAT	9.80	2.95	2.95	2.95
	23.00	25.00	22.00	21.00
ELEVATION DRIVE				
MOTORS, GEAR BOX, JACKSCREW	2.27	2.27	2.00	2.00
LINKAGES, ATTACHMENT HARDWARE	2.30	2.30	2.30	2.20
BEARINGS, SWITCHES	1.14	1.14	1.14	1.14
	5.70	5.70	5.40	5.30
AZIMUTH DRIVE				
WHEEL ASSEMBLIES	2.50	2.40	2.30	2.30
MOTORS, GEAR BOXES	2.50	2.50	2.40	2.30
PINTLE ASSEMBLY	1.70	1.70	1.70	1.70
	6.70	6.60	6.40	6.30
SUNTRACKER AND ELECTRONICS	1.82	1.02	.90	.87
INSTRUMENTATION, INDICATORS	.82	.82	.75	.75
	2.60	1.80	1.70	1.60
COOLING PUMP & MOTOR	1.60	1.37	1.25	1.25
PIPING, FITTINGS, ETC.	7.50	6.83	6.83	6.00
	9.10	8.20	8.10	7.30
TOTAL	134.00	116.25	90.49	73.74

TOTAL COST SUMMARY IN 1975 $/M^2

COST AREA	ANNUAL PRODUCTION LEVEL-M^2/YR 10^4	10^5	10^6	10^7
DIRECT MATERIAL (DM) (CELL COST $M^2)	110 (2500)	95 (2000)	75 (1500)	61 (1000)
APPLIED LABOR (AL)	13	7.50	3	2
SELL PRICE(1)	200	167	127	103
SHIPPING	3.00	3.00	3.00	3.00
INSTALLATION(2)	72.00	65.00	56.00	48.00
TOTAL COST TO UTILITY	275.00	235.00	186.00	154.00

(1) SELL PRICE = 1.632 X (DM + AL)

(2) 95% LEARNING CURVE

CONCLUSIONS

- IT IS IMPORTANT TO RELAT THE .50¢/WATT GOAL TO COMPLETE ARRAY COST
- OVERALL ARRAY EFFICIENCY IS IMPORTANT IN DETERMINING THE ALLOWABLE COST/M^2 OF APERTURE AREA
- UTILIZATION OF EVEN 20-40% OF THERMAL ENERGY PRODUCED BY CONCENTRATOR ARRAY HAS A SIGNIFICANT IMPACT IN ALLOWABLE ARRAY COST
- .50¢/WATT GOALS ARE ACHIEVABLE

Summary

I Installed array cost is the most valid way of comparing flat plate and concentrator arrays

II Implications of 50¢/watt goal

A.) Installed array costs should be in the 750 to 1000$/kwp range
B.) Installed array costs of 100$/$M^2$ is required for both flat plate and concentrator arrays with no thermal utilization
C.) 200$/$M^2$ is acceptable for concentrator arrays with 100% utilization of thermal energy

III Module efficiencies required to meet 50¢/watt goal

A.) Flat plate module efficiencies below 7-8% drive structure costs to very high percentages of array costs

B.) Concentrator array efficiencies would have to be 15% with the baseline design chosen for for analysis to meet the 50¢/watt goal if 33% of the thermal energy is utilized

IV Material cost requirements to meet 50¢/watt goal

A.) A number of silicon ribbon growth techniques appear very promising methods of meeting the flat plate price allocations for single crystal silicon

B.) The probability appears somewhat reduced that ingot procuced silicon will meet the price levels required

C.) Cell costs of 1000$/$M^2$ for concentrator cells is compatible with meeting the cost goals, yet it will allow use of high efficiency semiconductor grade silicon cells

V Conclusions

A.) Both flat plate and concentrator arrays appear likely to meet the 50¢/watt goal

B.) The main obstacles are:

1) Verification of cost effectiveness of ribbon technologies

2) Delelopment of efficienct modules, 12% for flat plate, 15% for concentrators

3) Obtain economies of high level production for both technologies

SESSION IV

BALANCE OF SYSTEM TECHNOLOGY

Gary Jones

Sandia Laboratories

TOPICAL SESSION IV

FUTURE BALANCE OF SYSTEM CONCERNS

I. Introduction

The purpose of this session was to review the current and projected status of the balance of system components, and to identify those areas of future concern. In order to avoid overlap, this group met in combined sessions with Group V (Current Design and Operating Experience) on Wednesday afternoon. The group subsequently met by itself on Thursday morning for about two hours. From 25 to 30 individuals were present throughout the meeting with individuals from government, industry and universities.

The meeting consisted of presentations by invited individuals in the areas of array subsystems, (structures, foundations, etc.), power conditioning and control, and battery storage. In addition to these presentation, Dr. Gerald Hein of NASA Lewis Research Center, gave a short review of their program to obtain current balance of system price data. The group questioned each of the speakers during these presentations with no formal discussion period following the talks.

II. Presentations

A. Balance of Systems for Small Systems - G. Hein, NASA Lewis Research Center

Lewis is currently compiling data on the balance of system price for small systems. These data are based on their own experience as well as that which they have been able to obtain from industry. They had divided the costs into the major elements of storage, installation and checkout, and other electrical equipment. Based on their experience for small systems, the balance of system had been about $13/W_p$. This figure includes design and installation but no shipping. It was emphasized that these are one of a kind systems to date, with no replication of systems to lower costs. As would be expected the observed costs have varied with system purpose.

B. Array Subsystems - Paul Masser, Motorola, Inc. and Andy Franklin, Bechtel National, Inc.

(Both speakers had just completed studies of low-cost structures for non-tracking arrays under Sandia Laboratories contracts. The results of these efforts formed the basis for their presentations.)

It was found that structure, foundation, and attachment costs on the order of $1.00 - $2.50/sq. ft. are possible with large production rates at large sites. (This does not include array panel costs if any are present.) The major question in all this work appears to be the loads. Current code guidance may not be realistic for arrays. Blind use of these codes could impede structure cost reductions. Bechtel advocated the use of a two level environmental factor definition, with the array designed to a "normal" level based on a 25-year reoccurrence interval for a property (wind, hail) and an "extreme" level based on a 100 year interval. Both contractors agreed that wind loads remain the major unknown question. For larger systems it was recommended that site-specific data be sought as is currently done for airports.

C. Power Conditioning Projections - Paul Pittman, Westinghouse Electric Corporation

One of the major confusions in listing the projected cost for power conditioning equipment appears to be the misuse of the term inverter. The equipment needed in the larger grid connected applications consists of much more than just the inverter. For instance, based on data from the Westinghouse Conceptual Design Study, the inverter for a 500 kW power conditioning unit may cost $25/kW but the entire power conditioning unit will cost $128/kW. Similarly for a 17 MW unit the inverter represents only about $30/kW out of a total of $108/kW. It was also emphasized that the key to lower cost power conditioning is an increase in production levels. Westinghouse estimated a learning curve with $a = 0.85$ governing price reductions up to levels of 10^5-10^6 units per year for residential (10 kW) sizes. In this size range, it was also noted that the fixed costs of the power conditioning will effect the attainable $/kW.

D. Current Power Conditioning Status - Walt Stolte, Bechtel National, Inc.

The power conditioning industry is rather well established, supplying units for applications ranging from uninterruptible power supplies to high voltage DC transmission costs. The low $/kWH prices often quoted assume an industry dedicated to a specific battery type producing greater than 100 MWH annually. For current lead-acid batteries, the cost of lead is a major concern. At the time of the conference, lead had gone from $0.33/lb. to $0.40/lb. in a 4-week interval. Lower battery costs ($40-60/kWH) for lead acid batteries will require a sizable increase in lead utilization efficiency.

F. Battery Storage Properties and System Design - Walter Stolte, Bechtel National, Inc.

There is a danger in system design if the capacity rating of the battery storage system is not correlated with the charge/discharge rate. A battery rated at a given capacity when operated at C/5 drops to about 50% of that capacity at C/1. In general a battery has reached its end of life when capacity drops to 80% of the original value. This lifetime is also very dependent on temperature, with lifetime about halved in going from 77°F to 130°F. The battery designer can help some on special low temperature problems but modifications are expensive. The charge/discharge rate also influences the battery roundtrip efficiency. Very low rates, (C/50), result in efficiency percentages in the high 80's. All of these factors need to be taken into account in sizing the storage system. While some work has been done, no model, such as a computer code, exists which describes all these factors. As to cost, it was noted that a change of 1¢/lb for lead results in a $0.50-$1.00 change in the kWH cost of batteries.

III. Conclusions

It was recognized by all those attending the session that the balance of system costs must be reduced if photovoltaic systems are to be viable in the future. There are several aspects and concerns about that reduction which the attendees felt needed to be emphasized.

1. The group felt that (with the possible exception of battery storage) no major technical breakthroughs are needed or should be expected in lowering the balance of system costs. However, engineering development and its accompanying advances are a major factor in the achievement of lower costs.

2. The major element common to the cost goals of all of the balance of system subsystems was high production levels of a specific design from a dedicated plant. This is a basic requirement if BOS costs are to be reduced.

3. Without significant and appropriate early markets, there are concerns regarding the ability of industry to reach the necessary production levels by 1985, in order to adequately support initial grid-connected applications. This is of primary concern in the areas of power conditioning and energy storage.

4. The concerns regarding structure, foundations and installation are generally related to environmental survivability. Experience is needed from large scale field tests and special loading data from areas such as wind tunnel testing.

5. Currently,more field test experience is needed with all subsystems. All speculation about the readiness of the industry still needs verification in a large scale application related testing program.

SESSION V

EXPERIENCE GAINED FROM THE DESIGN AND OPERATION OF PHOTOVOLTAIC SYSTEMS

M. D. Pope

MIT/Lincoln Laboratories

Topical Session V

Experience Gained from the Design and Operation of Photovoltaic Systems

1. INTRODUCTION

This topical session provided a forum for open discussion on experiences gained to date on PV power systems, and was concerned with both experience gained from designing systems which have not yet been constructed as well as with operating experience gained from deployed systems. Both flat plate and concentrator systems were discussed. The total attendence was 72 persons, which included 45 representatives from industry, 14 from government organizations and 13 from universities.

Since this session was closely associated with many of the same concerns as Session IV - Balance of Systems, the two topical sessions met jointly for the first meeting on 8 November. On the following morning separate sessions were convened.

In order to maximize the information content of the sessions, a series of 20 prepared but informal presentations were given by people who had pertinent experience to relate in varying technical areas. These included: large and small PV flat plate systems, concentrator systems (e.g., the Mississippi County Community College Project), PV systems control, battery storage and inverters. The results of the discussion in each of these areas are summarized below.

2. LARGE AND SMALL FLAT PLATE SYSTEMS

Presentations were given in this area by Bill Yerkes (ARCO Solar), Zim Putney (Solarex), Tony Ratajczak (NASA Lewis), and Ray Hopkinson, Louis Bucciarelli and Ed Murphy (all from MIT/Lincoln Laboratory). A common theme which ran through all of the talks was the extremely high reliability experienced with all of the systems installed to date, which covers a very large range in power from less than 100 watts to over 25 kilowatts. For the small remote systems, most problems relating to PV arrays have been traced to vandalism. The next most important cause of performance degradation appears to be hail damage, which has resulted in a small number of cracked and broken PV cells. Some data was presented on damage which resulted to the Nebraska array as a result of a hailstorm which occurred in May 1978. This is the only occurrence of hail at that site in nearly two years of operation. The problem of detecting and measuring hail stones was discussed, which derives mainly from the transitory nature of the phenomenon. A careful inspection of 44,000 PV cells (approximately half of total number installed at Mead) has revealed 136 cracked cells which are believed to be caused by the hail storm. In turn, only 6 PV modules out of the 1100 modules inspected were found to have failed to generate electricity as a result of the cracked cells. Jim Arnett (JPL), mentioned that they have developed soft plastic foam "tell-tale" sensors which provide evidence on the spatial density and size of hail stones based on quantity and size of indentations in the plastic. All participants were urged to install such devices at their PV sites in order to help obtain badly needed data in this area.

Lightning damage to arrays has been minimal, with only one array failure attributed to a strike. However, there have been instances of other components and subsystems being affected by lightning such as, power handling equipment damage and blowing of fuses due to lightning-induced surges in the power lines connecting the arrays to the rest of the system. The lone case of lightning damage to an array was reported by Tony Ratajczak, who noted that an array was struck and PV cells were vaporized. This occurred even though the array was situated near the communication tower which it powered, which by conventional wisdom should have provided adequate lightning protection. He theorized that this was inadequate in this instance because the system was situated atop a 14,000 foot mountain, and it was impossible to find a good electrical grounding point.

Nevertheless, the reliability of PV systems continues to be high. For example, the Nebraska 25 kW PV system experienced 18 power outages during its first 2200 hours of operation, and during that same period the local electric utility experienced 47 outages. Some information was also given on array washing for the Nebraska system. Since the performance of this system is carefully monitored on a continuous basis, it was possible to estimate the rate at which the array power output decreases with time after washing the PV panels (Fig. 1). Assuming a value of $.10/kWhr for the lost energy, the array washing interval can be estimated by noting when the value of the lost electric energy equals the cost of array washing (Fig. 2). As noted in Figure 2, the appropriate washing interval for the Nebraska system is about 500 days. This is probably an upper limit for most PV systems, however, for the following reasons: 1) the cost for washing these arrays is high - the rate of $\$.10/ft^2$ paid at Nebraska is the same price charged for window washing - and automated equipment at a PV installation should reduce this expense; and 2) PV power loss due to array soiling occurs at a lower rate in rural sites (such as Nebraska) in comparison with dirtier, urban sites.

A need for high density PV arrays was expressed. This was based mainly on the need for reducing structural costs, which currently range from $.50 to $3-$4 per peak watt, as well as for reducing erection, land and shipping costs.

Also, the builders of small PV power systems would like to see peak power trackers become available for these systems (<1 kW) as well as for large units, since they would permit the use of smaller arrays. However, extremely high efficiency in dc-to-dc conversion must be present in order for their use to be worthwhile.

3. THE MISSISSIPPI COUNTY COMMUNITY COLLEGE (MC^3) PROJECT

Experience gained to date in the design of this large, complex system and in the development of the concentrating collectors and the battery subsystems were discussed by Mike Henry, Cliff Parten and Mike Tucker, all from TEAM, Inc. This project involves the construction of a 250 kWe (peak) system which will provide the electric energy for the subject college. This system will also collect thermal energy for water heating and space heating and cooling. The original program plan called for development of iron redox batteries and for a subsequent review of their suitability for inclusion in the system. This review was held recently and the decision was made to utilize conventional lead-acid batteries. This was based on need for further development of the iron redox process, which continues to hold promise for providing economic electric storage, they said.

Based on MC^3 experience to date, the following observations were made:

1) System considerations are important and non-negligible for large, complex PV systems of the type involved here. For example, systems integration comprises approximately 15% of the current effort at TEAM.

2) There is a need for a test facility whereby concentrating collector assemblies can be brought in for test and evaluation under controlled test conditions. Preferrably, this should be an indoor facility to eliminate vagaries in the evaluations resulting from variations in insolation. Furthermore, there is a need for measuring the variation in energy on a string of cells in a concentrator. This applies to variations along the length as well as across the width of the string.

3) If local meteorological data are not available, appropriate measurements should be made early in the project. To accomplish this, standardized, reliable equipment, including reference PV cells, is needed.

4) In order to protect against financial losses resulting from delays and rising costs resulting therefrom, it is essential that escalation clauses be written into the contract.

4. CONTROL OF PV POWER SYSTEMS

This topic was discussed by Jack Helfrich (MIT/LL), who pointed out that this is an important area, particularly with systems containing storage and especially for those which utilize both storage and back-up power sources (i.e., diesels or utility connection). He discussed potential instability problems associated with interactions between diesel generators and battery chargers. He also pointed out that system voltage oscillations can occur around the desired full charge voltage in a system containing batteries, and presented a design solution. Needs were highlighted in the following areas:

1) Better understanding of the electrical behavior of batteries, particularly near the full-charge state; and

2) Meters for measuring battery state-of-charge.

5. STORAGE

Information on battery storage systems was presented by Mr. F. Malaspina (ESB Corp.) and Dr. D. Boden (C&D Battery Co.). They reviewed the currently available battery designs which can be used to alleviate (if not eliminate) problems relating to deep discharge and to hydrogen gas evolution. The current prices of battery storage was also discussed. It was noted that the batteries which are available today at the lower prices (~$100/kWhr) quoted in the GSA price lists do not contain the features which are normally desired in a PV power system (e.g., 5 or more years lifetime, use of wrapped plate designs to provide ruggedness for deep discharge usage, use of recombiner caps to eliminate hydrogen evolution, etc.). When these features are added, the price rises to ~$120-$130/kWhr. It was also noted that there is not universal agreement on how the kilowatt-hour capacity of a battery should be described. (In some cases the full discharge value is used and in other cases the 75 or 80 percent discharge level is used.) In addition, one must be very careful in quoting prices since low rate cells (such as used on buoys) make significantly better use of the active materials and thus appear cheaper per kWh.

Some of the Session participants expressed concern over the lack of battery design data available for PV system designers to use in performing systems trade-off design studies as well as in detailed design of specific items such as arrays and battery chargers. They felt that the battery manufacturing industry was remiss in not supplying this information. Mr. Malaspina noted that this problem is being rectified by a DOE-sponsored effort through Sandia and ESB, which will develop battery design and sizing procedures for use by PV system designers.

The current high cost for batteries does not appear to be a short-lived problem. For example, the price of lead alone comprises over $30/kWhr in today's deep cycle lead-acid batteries. From this, it appears doubtful that DOE will be able to achieve the sought-for price of $50/kWhr for advanced lead-acid batteries in mid to late '80's.

6. INVERTERS

Presentations were given in this area by Roy Pickrell (NASA Lewis), Don Faehn (MERADCOM), Manny Landsman (MIT/Lincoln Laboratory), Hans Meyer (Windworks) and D. Stechschulte (Westinghouse). Both stand-alone and utility interactive inverters, as well as units which are capable of either mode of operation are either available or under development. Large inverters (bigger than, say a 10 kW residential unit) utilize silicon controlled rectifiers (SCR's), whereas smaller units utilize either SCR's or power transistors. As examples of both technology areas, DOE is supporting the development of a 50 kVA dual-mode (stand-alone/utility interactive) inverter at Westinghouse, which utilizes SCR's; and another DOE-funded effort at Abacus Controls is directed towards development of a 10 kW, dual-mode inverter for residential use, using transistors.

According to industrial representatives, a very large inverter size range is available, ranging from 250 W units up to 1.5 Megawatt systems.

Considerable discussion took place concerning the relative merits of utility interactive versus stand-alone versus dual-mode inverters. From the standpoint of complexity, a line-commutated inverter contains only one-fifth as many components as in a self-commutated unit. However, power quality requirements may make it economically attractive to utilize self commutation in a utility interactive inverter in order to reduce harmonic current injection and control power factor. If one utilizes a self commutated inverter, a stand-alone capability would facilitate off-line checkout and repair. If this were done, then the added complexity (and cost) for providing dual-mode operation is almost negligible (an increase of only a few percent), according to manufacturers.

The only cost projections provided in these discussions related to residential utility interactive (line-commutated) inverters, for which quantity production unit prices were estimated to be about $100/kW. However, it was pointed out that the cost of utility interactive inverters will be extremely sensitive to requirements placed on power quality (e.g., harmonics), and that heavy filtering requirements could raise the price by at least 50% closing the

Although this has proved satisfactory for high power operation, there have been instances where the inverter subsequently did not perform as expected at lower power levels corresponding to early morning, late afternoon or cloudy weather operation. From this it was concluded that the inverter should be coupled to and operated with an array as part of the inverter development effort.

7. ACKNOWLEDGEMENT

The efforts put forth by the session speakers in preparing presentations for this meeting is sincerely appreciated.

Special thanks are due to Dr. E. E. Landsman (MIT/Lincoln Laboratory), who did much of the prepatory work for this Topical Session. Among other things, he contacted and arranged for the participation of the session speakers.

M. D. P e
Session V Chairperson

APPENDIX A

ATTENDEE LIST

APPENDIX A

Attendee List

U.S. DOE PHOTOVOLTAICS TECHNOLOGY
DEVELOPMENT AND APPLICATION PROGRAM REVIEW

LIST OF ATTENDEES

U.S. DOE PHOTOVOLTAICS TECHNOLOGY
DEVELOPMENT AND APPLICATION PROGRAM REVIEW
ARLINGTON, VIRGINIA
NOVEMBER 7 through 9, 1978

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APPENDIX B

AGENDA

APPENDIX B

U.S. DOE PHOTOVOLTAICS TECHNOLOGY DEVELOPMENT AND APPLICATIONS PROGRAM REVIEW

November 7-9, 1978

AGENDA

Tuesday, November 7, 1978	Time
Registration.	7:45
Program Overview.	8:30
Technology Overview	
PROJECT STATUS REPORTS	
Aerospace Corporation.	9:15
Coffee Break.	9:45
MIT/Energy Laboratory.	10:00
Sandia - Systems	10:30
Lunch Break	12:00
PROJECT STATUS REPORT (cont.)	
Jet Propulsion Laboratory.	1:15
Sandia - Concentrators	2 45
Coffee Break	
NASA/Lewis Research Center	3:45
MIT/Lincoln Laboratory	4:15
DOD/MERADCOM	5:00
Meeting Adjourned	5:30

Wednesday, November 8, 1978

STATUS REPORTS	
Research & Development (Feuch/SERI	8:30
Photovoltaics & Environmental . . . . Impact Considerations (Weber/APS)	9:00
Standards Status Report (Nuss/SERI).	9:30

U.S. DOE PHOTOVOLTAICS TECHNOLOGY DEVELOPMENT AND APPLICATIONS PROGRAM REVIEW

November 7-9, 1978

AGENDA (cont.)

Wednesday, November 8, 1978 (cont.)	Time
TOPICAL SESSIONS - Introductions.	10:00
SECTION I Standards Performance Criteria (Nuss/SERI)	10:00
Coffee Break.	10:10
SESSION II Cost/Economics (Tabors/MIT-EL)	10:25
SESSION III Concentrator & Flat Panel Technology Alternative for 50¢/ Watt (Shafer/Sandia, Ross/JPL)	10:45
SESSION IV Balance of System Technology (Jones/Sandia)	11:05
SESSION V Experience Gained from the Design. & Operation of Photovoltaic Systems (Pope/MIT-LL)	11:25
Lunch Break	11:45
After lunch, meeting participates will separate into topical discussion groups	
TOPICAL SESSIONS (all afternoon).	1:30
Coffee Break.	3:00
Meeting Adjourned	5:00

U.S. DOE PHOTOVOLTAICS TECHNOLOGY DEVELOPMENT AND APPLICATIONS
PROGRAM REVIEW

November 7-9, 1978

AGENDA (cont.)

Thursday, November 9, 1978	Time
TOPICAL SESSIONS II, III, and V continued.	8:30
Coffee Break	10:30
TOPICAL SESSIONS - Summaries: I,IV,II,III,V	11:00
Meeting Wrap-Up.	12:30
Meeting Adjourned.	1:00

NOTE: Social hour is scheduled for attendees directly after meetings adjourn on November 7th and 8th.

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