RESEARCH POSSIBILITIES? NO!
Needs for Research to Make PV Solar Energy Utilization Broadly Competitive

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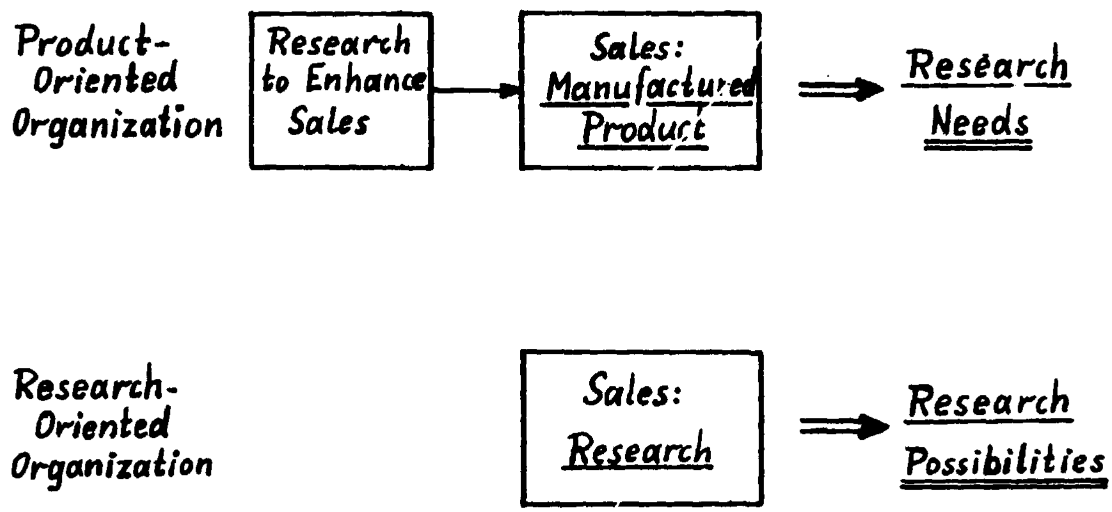
Two Types of Research Philosophies



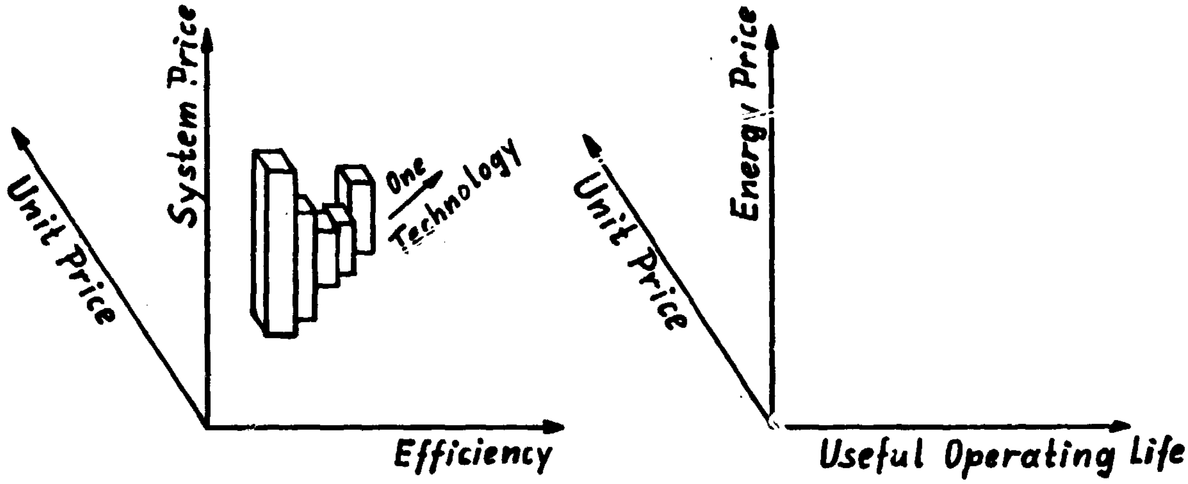
MAJOR CRITERION

FOR

COMPETITIVENESS:

PRICE OF ELECTRIC ENERGY

Multivariable Relationships



The Subsystems

LIGHT PROCESSOR (CONCENTRATOR, TRACKER)

MODULE → CONVERTER ARRAY

POWER CONDITIONING

ENERGY STORAGE

CONTROL, PROTECTION

AUXILIARY ENERGY

ORIGINAL PAGE IS
OF POOR QUALITY

System Characteristics Determine Market

SYSTEM TYPE	LIKELY USE	MARKET SIZE	MOST LIKELY CANDIDATES
HIGH CONCENTRATION, TRACKING VERY HIGH EFFICIENCY CONVERTER	ARID CLIMATES, CENTRAL STATION (ATTENDED OPERATION)	LIMITED	SINGLE CRYSTAL $Al_xGa_{1-x}As$/GaAs (SINGLE CRYSTAL SI?) MULTI-BANDGAP SYSTEMS
FLAT-PLATE, HIGH EFFICIENCY LONG LIFE	ALL USES, COMMERCIAL INSTALLATION	LARGEST	SINGLE CRYSTAL SI (MULTI-BANDGAP SYSTEMS?)
VERY LOW COST, LOW EFFICIENCY LIMITED LIFE	PRIM LY RESIDENTIAL, DO-IT-YOURSELF INSTALLATION	LIMITED	THIN-FILM A-SI OTHER THIN FILM SEMICOND. (Cu_2InSe/CD S?)

Research Needs on BOS

SUBSYSTEM	NEEDED ATTRIBUTES	PAYOFF	RISK	TIME RANGE TO ATTAINMENT
POWER CONDITIONING	LOW PRICE, HIGH EFFICIENCY	I	L	S TO I
CONTROL, PROTECTION	LOW PRICE, SIMPLE	I	L	S
ENERGY STORAGE	LOW PRICE LONG LIFE HIGH EFFICIENCY HIGH DISCHARGE RATE DEEP CYCLE CAPABILITY	VH	H	L
FIELD INSTALLATION	LOW PRICE	VH	VH	?
HIGH-RATIO CONCENTRATOR	LOW PRICE LOW MAINTENANCE	I	H	I
AUXILIARY ENERGY	LOW PRICE	H TO VH	VH	L

S = SMALL OR SHORT
I = INTERMEDIATE
H = HIGH
VH = VERY HIGH
L = LONG
RISK = INVERSE PROBABILITY FOR ATTAINMENT OF EXPECTED PAYOFF

Research Needs on Modules

ITEM	NEEDED ATTRIBUTES	PAYOFF	RISK	TIME TO ATTAINMENT
CELL (MANUF'G PROCESS)	COST REDUCTION 10-20 TIMES	VH	I	S TO I
CELL	EFFICIENCY INCREASE 25 TO 66% SIMPLE CELLS TO 300% MULTI-BANDGAP SYSTEMS (WILL REQUIRE MODIFIED CELL PROCESSING)	VH	I VH	S TO I L
MODULE	≥ 20 YEAR LIFE, COST REDUCTION } COMPATIBLE?	VH	I	I TO L

Current Status of Major Module Processes

TECHNOLOGY AREA	APPROACH	EXPECTED RESULTS	STATUS
SILICON SOLAR/MODULES:			
LOW COST PURIFICATION	SiH_4 PROCESS	~\$14.-/KG SEMICONDUCTOR-GRADE SI	PRIVATE INDUSTRY (UNION CARBIDE) GOES INTO PILOT PLANT OPERATION.
	$Si\ H_2Cl_2$ PROCESS	~\$25.-/KG SEMICONDUCTOR GRADE SI	PRIVATE INDUSTRY (HEMLOCK SEMICONDUCTOR CONVERTS EXISTING $SiHCl_3$ PLANT
SHEET GENERATION	(SEMI-) CONTINUOUS AUTOMATED CZ X-TAL GROWTH	150KG/CRUCIBLE, 15 CM DIA	NEARLY PRODUCTION READY BOTTLENECK: SLICING
	SEMICRYSTAL SI	LOWER COST THAN CZ, COMPARABLE PERFORMANCE	PRODUCTION COST/PERFORMANCE EXPERIENCE NEEDED. BOTTLENECK: SLICING
	SLICING	HIGH THROUGHPUT, LOW KERF, LOW COST	LITTLE ADVANCEMENT. PROBLEM AREA.
	RIBBON GROWTH: EFG	LOW COST, CZ COMPATIBLE CELL PERFORMANCE	PILOT PRODUCTION CELL EFFICIENCY STILL TOO LOW

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Technology Area	Approach	Expected Results	Status
	Web-dendrite	Low cost, Cz compatible cell performance	Cz compatible efficiency proven. Only material with internal gettering. Pre-pilot stage. Production cost experience needed. Will private industry go ahead?
Cell Fabrication:	Process simplification, by-product reduction, automation	$\$0.5$ to $1.5/W_p$ modules of 14-17% efficiency	Considerable technology advancements made. $\sim\$10/W_p$ at 7-12% efficiency. Continued slow progress in private industry. Stagnation at a price level of 5-10$\$/W_p$ ahead?
Module Assembly	Better material selection, automation	DTO 20-year life	DTO Cost/life trade-off uncertain.
A Si	Thin film processes, low-cost encapsulation	$< \$0.5/W_p$ limited efficiency	Research stage. Production in Japan for calculator/watch market
$Al_xGa_{1-x}As/GaAs$	Single X-tal cells.	Higher efficiency than Si cells, superior high temperature performance, better radiation resistance for space cells	Pilot line quantities available. Primarily concentrator and space cells. May form component in multi-bandgap system
Cu_2S/CdS Cells	Thin film processes, low-cost encapsulation	$< \$0.5/W_p$. Limited efficiency, life	Technology being abandoned?
Cu_2InSe/CdS Cells	DTO	Higher efficiency, longer life than Cu_2S/CdS	Research stage, may form component in multi-bandgap system.
All other compound semiconductors	Mostly thin film processes	Mostly low cost	Various levels of research. Likely redundant with further advanced approaches. Some candidates for multi-bandgap systems.

Who Buys What Research?

SHORT RANGE, LOW RISK	IN BETWEEN	LONG RANGE, HIGH RISK GOVERNMENT
MANUFACTURING INDUSTRY	MANUFACTURING INDUSTRY	GOVERNMENT
GRADUAL PROCESS ADVANCEMENT, AUTOMATION FOR COST REDUCTION.	SOME THIN FILM APPROACHES (HOW LONG, IF MARKET DOES NOT DEVELOP SOON?)	SI-CELLS: EFFICIENCY >20% (AM1) MULTI-BANDGAP SYSTEMS GRAIN BOUNDARY RESEARCH THIN FILM DEVICES (?) BATTERIES/FUEL CELLS
SMALL STEPS TO EFFICIENCY IMPROVEMENT, EXTENSION OF OPERATING LIFE	?WHO?	
GRADUAL POWER CONDITIONING PROGRESS	RADICAL PROCESS ADVANCEMENT RELIABILITY DEVELOPMENT STANDARDIZATION CONCENTRATORS FIELD INSTALLATION	MANUFACTURING INDUSTRY A-SI APPROACHES

Identifiable Research Needs for Efficiency Improvement

SINGLE CRYSTAL SI CELLS

GOAL	NEEDED UNDERSTANDING	FURTHER ACTIONS
LONGER MINORITY CARRIER LIFETIME SI	CRYSTAL STRUCTURE, ROLE OF IMPURITIES (HEAVY METALS?) ROLE OF COMPLEXES (O_2, C, STRUCTURE DEFECTS?) ORIGIN OF DEFECTS, IMPURITIES INTRODUCTION MECHANISM OF DEFECTS, IMPURITIES POTENTIAL AND LIMITS OF GETTERING	PROCESS CONTROL IN CRYSTAL (RIBBON) GROWTH
	INFLUENCE OF POST-GROWTH HEATING, LIGHT	PROPER POST-GROWTH PROCESS SELECTION

GOAL	NEEDED UNDERSTANDING	FURTHER ACTIONS
	SINGLE CRYSTAL SI CELLS, CONTINUED	
SURFACE PASSIVATION	EXACT MECHANISM REQUIREMENTS ON PASSIVATION LAYERS WAYS TO MEET REQUIREMENTS OPTICAL PROPERTIES OF PASSIVATION LAYERS INTERACTIONS WITH AR COATINGS	PROCESS DEVELOPMENT
ATTAINMENT OF PREDESIGNED DEVICE STRUCTURE	EFFECTS RESULTING FROM INDIVIDUAL PROCESSES (DIFFUSION, CVD OR LPE EPI, ETC) "LOW TEMPERATURE" PROCESSING FEASIBLE? LIFETIME MAINTENANCE THROUGHOUT PROCESSES? OR RECOVERY? SIMPLER PROCESS METHODS?	
"CLOSED LOOP DESIGN"	ANALYSIS: ALL PARAMETERS WHICH INFLUENCE PERFORMANCE OR ENTER MODELLING LACKING: RELIABLE MEASUREMENTS OF FRONT LAYER DIFFUSION LENGTH; MEASUREMENT OF: DIFFUSION LENGTH OF MORE HEAVILY DOPED LAYERS; EFFECTIVENESS OF HIGH/LOW JUNCTIONS; FRONT SURFACE RECOMBINATION VELOCITY. TWO METHODS BASED ON COMPLETELY DIFFERENT EFFECTS SHOULD BE AVAILABLE FOR CORROBORATION OF RESULTS. UNDERSTANDING OF HEAVY-DOPING EFFECTS TO ALLOW MORE PRECISE MODELLING, ASCERTAIN ULTIMATELY ACHIEVABLE EFFICIENCY.	
	POLYCRYSTAL DEVICES	
	ALL THE ABOVE, PLUS: EFFECTS OF GRAIN BOUNDARIES ON DEVICE PERFORMANCE; CONTROL OF ELECTRICAL EFFECTS OF GRAIN BOUNDARIES DEVICE DESIGN TO MINIMIZE EFFECTS OF GRAIN BOURNDARIES	

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GOAL	NEEDED UNDERSTANDING	FURTHER ACTIONS
	COMPOUND SEMICONDUCTORS (INCL. AMORPHOUS SI:H, ETC) ALL OF ABOVE, EXCEPT FOR GRAIN BOUNDARIES, WHERE NOT APPLICABLE. PLUS: LEVEL OF EXISTING KNOWLEDGE GENERALLY MUCH LOWER THAN FOR SI EFFECTS OF STOCHIOMETRY DEVIATIONS. CONTROL OF FABRICATION PROCESSES.	
	MULTI-BANDGAP SYSTEMS ALL OF ABOVE; EXCEPT FOR GRAIN BOUNDARY EFFECTS, WHERE NOT APPLICABLE. PLUS: INTERFACES BETWEEN CELLS OF DIFFERENT BANDGAP (TUNNEL-JUNCTIONS?) PROBLEMS OF MISMATCH BETWEEN CELLS UNDER DIFFERING INTENSITY, SPECTRAL DISTRIBUTION (AM), TEMPERATURE.	

The Technology Race