N87-16403

PROJECT ANALYSIS AND INTEGRATION ECONOMIC ANALYSES SUMMARY

CONSULTANT

H. L. Macomber

Overview

- INTRODUCTION
- START-UP
- MID-TERM AND BEYOND
- OBSERVATIONS

Introduction

- LOOK AT PA & I
  - Economic Analysis Plus For Crystalline Silicon PV
  - Accomplishments, Lessons Learned, Potential and Continuing R&D Needs
- LOOK INSIDE
  - Business Investment Decision Analysis Well Developed and Practised in Industry
  - New to Government Led Programs
- LOOK FROM OUTSIDE
  - Effects on Industry, Effects on Gov't Programs

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PA&I Start-Up

- WHY
  - System Motivated
  - Achieve Proposed Objectives

- HOW
  - Planning, Modeling, Analysis, Liaison

- WHAT
  - Task Efforts; Project/Program Objectives & Goals; Industry Technology, Market & Economic Information

- WHO
  - Early Players at JPL, ERDA, Other Labs & Industry

Materials from Early Presentations: 1975-1976

LOW COST SILICON SOLAR ARRAY PROJECT

SYSTEMS ANALYSIS AND INTEGRATION

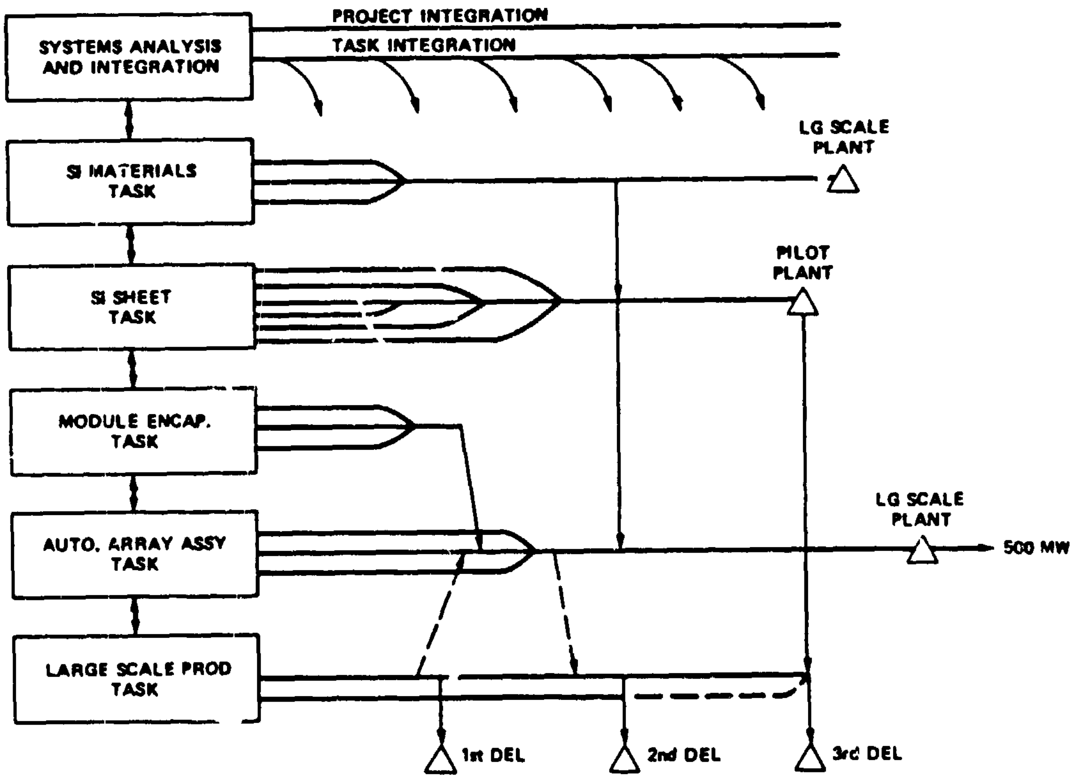
H L Macomber

1975

Systems Analysis and Integration: Objectives

- DEVELOP AND PROVIDE THE PROJECT INFORMATION REQUIRED FOR ASSESSING THE PROBABILITY OF ACHIEVING THE PROJECT GOALS
- PROVIDE PROJECT RECOMMENDATIONS FOR MAXIMIZING THE PROBABILITY OF ACHIEVING THE PROJECT GOALS
- PROVIDE THE NECESSARY SYSTEMS ANALYSIS, SYSTEM ENGINEERING AND DESIGN, AND SYSTEM TEST SUPPORT FOR ASSURING THE INTEGRATION OF PROJECT TASKS TO ACHIEVE THE PROJECT GOALS
- PROVIDE PROJECT SUPPORT FOR INTEGRATING THE PROJECT WITH ERDA PV PROGRAM

Task Process



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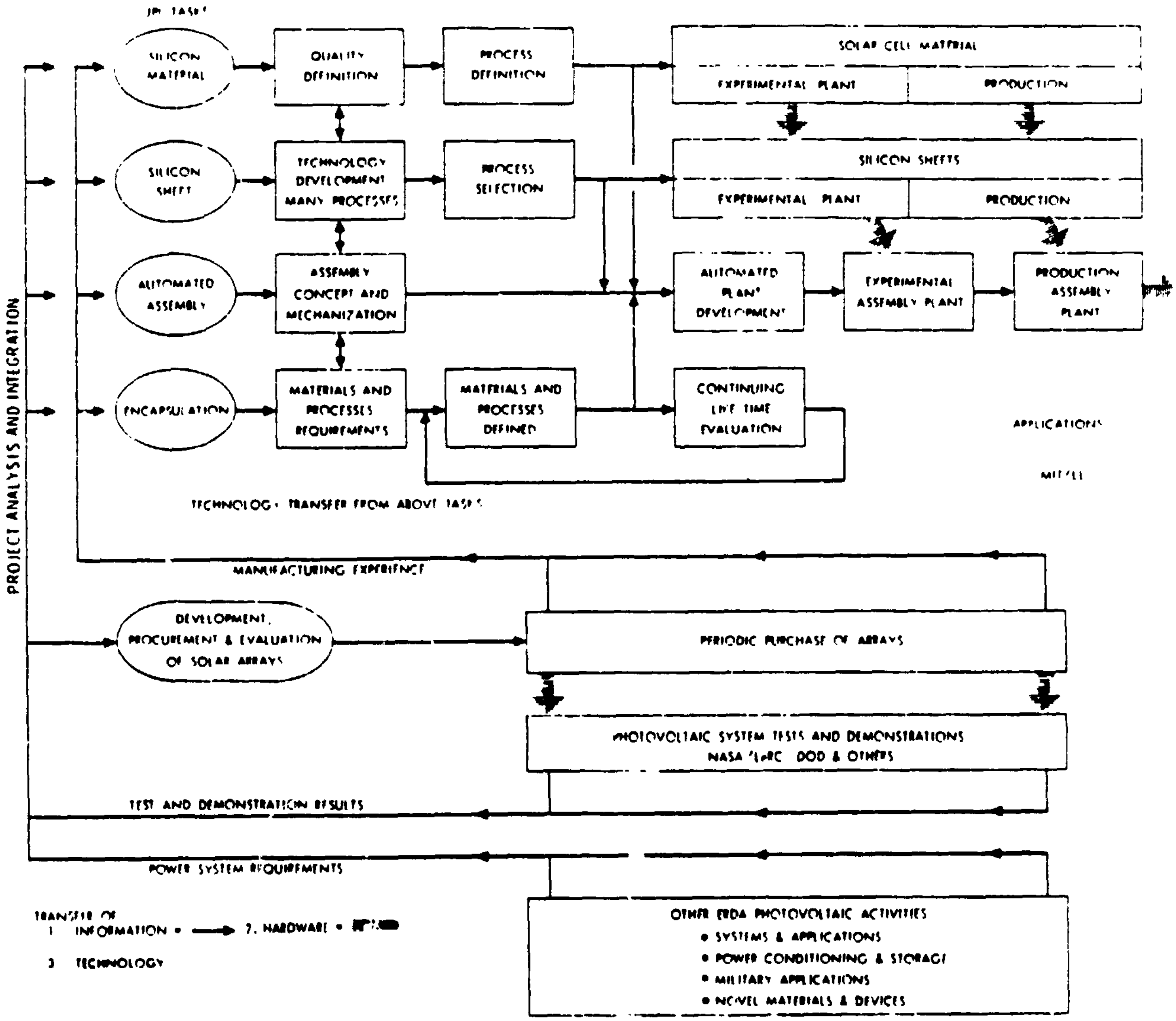
Functional Relationships Within the Project and Between the Project and ERDA



Mid-Term and Beyond

- **MODELS — PARTIAL LIST OF EARLY EFFORTS**
  - **USES:** "Utility-owned Solar Electric System"
  - **SAMIS:**"Solar Array Manufacturing Industry Simulation"
  - **SAMICS:** "Solar Array Manufacturing Industry" Costing Standards"
  - **IPEG:** "Improved Price Estimation Guidelines"
  - **PAG:** "Price Allocation Guidelines"
  - **PADEM:** "Project Alternative Design Evaluation Model"
  - **LCP:** "Lifetime Cost and Performance"
  - **ESA:** "Energy Systems Economic Analysis'
  - ***SIMRAND:** "**SIM**ulations of Research **A**nd **D**evelopment"
  - ***SAMPEG:** (Simplified Version of SAMIS)

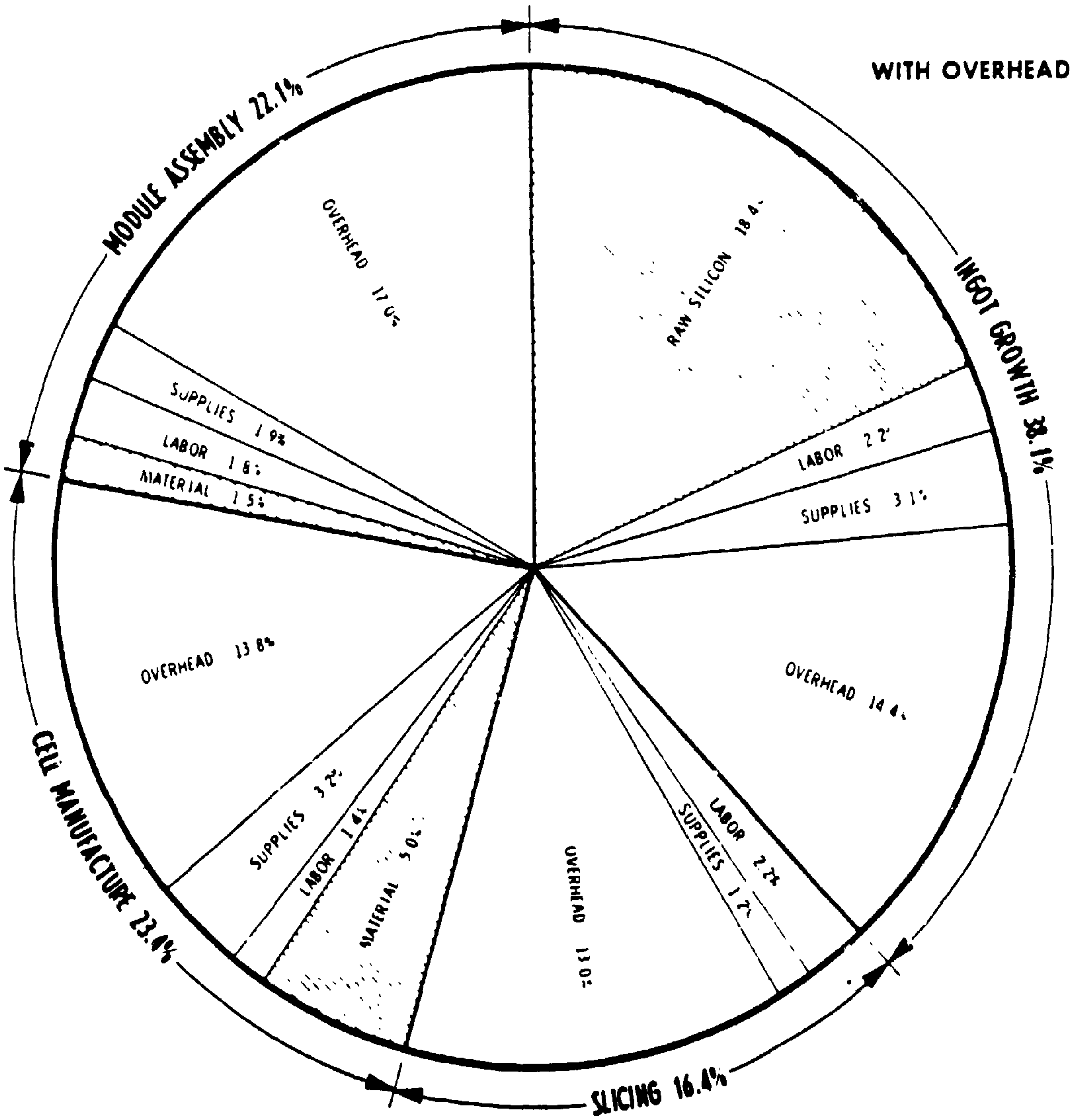
* After HLM Tenure

- PLANS — PARTIAL LIST OF EARLY EFFORTS
  - LSSA (FSA) Interface Activity Plan 11/75
  - PV Systems Planning Group - Interim Systems Development Plan 9/76
  - PV Planning Group - Draft Study Report (PV Strategy Inputs) 7/77
  - PV Program Multi-year Plan 10/78
  - Technical Readiness, 1982 Plan 9/79
  - Annual Project Plans

- ANALYSIS — SELECTED EARLY WORKS
  - industry Growth Rate Studies
  - Learning (Experience) Curve Assessments
  - Pricing Studies
  - Cost Allocation Studies
  - Efficiency vs Cost Trade-Offs — A Workshop
  - SERI Venture Analysis Inputs

Some Early Analyses: 1975-1976

Present State-of-the-Art Major Manufacturing Cost Estimates



BASED ON SAMIS* COMPUTER PROGRAM (103)

* SOLAR ARRAY MANUFACTURING INDUSTRY SIMULATION

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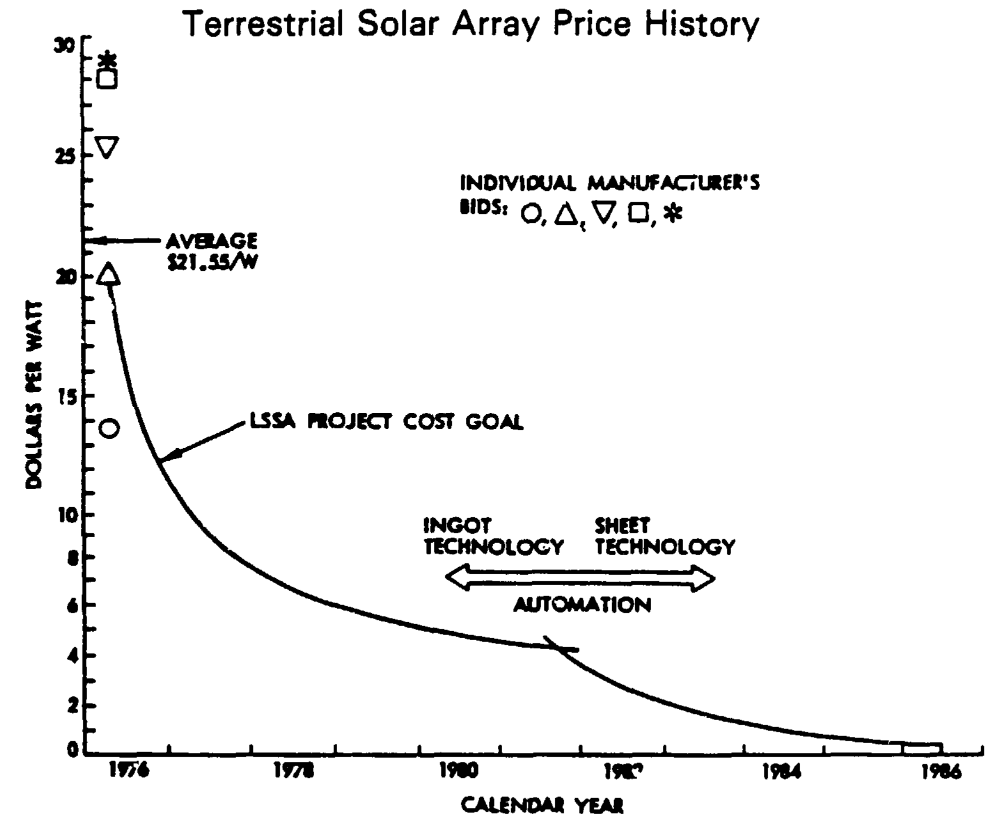
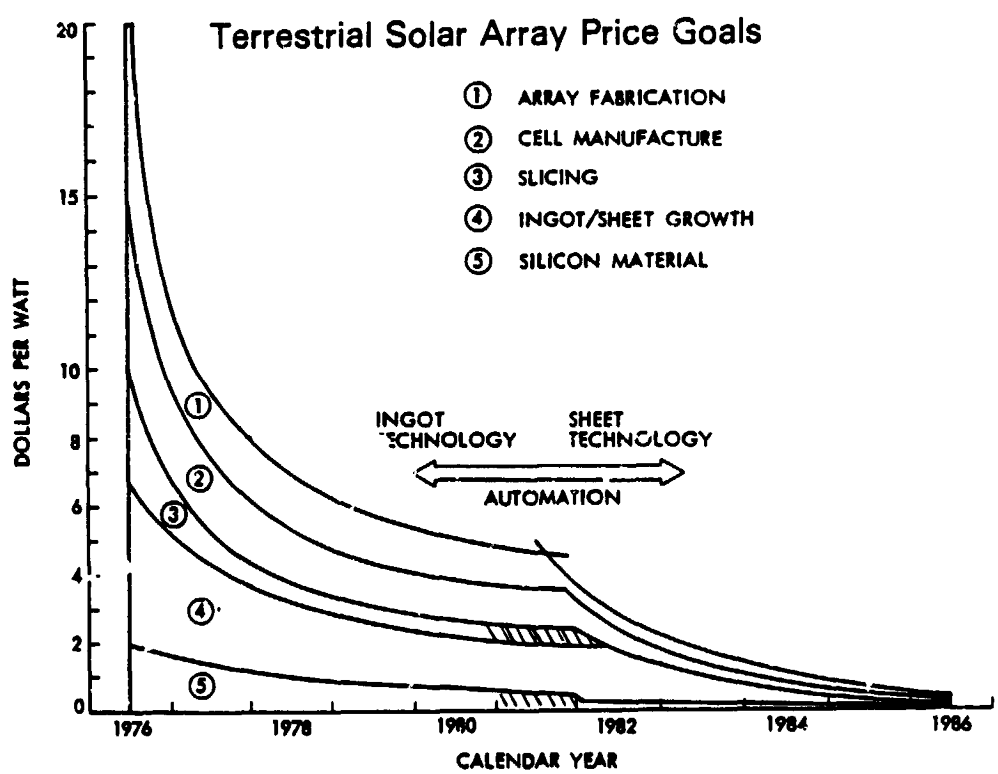

Terrestrial Solar Array Price History
DOLLARS PER WATT
CALENDAR YEAR
INDIVIDUAL MANUFACTURER'S BIDS: ○, △, ▽, □, *
AVERAGE $21.55/W
LSSA PROJECT COST GOAL
INGOT TECHNOLOGY
SHEET TECHNOLOGY
AUTOMATION
1976
1978
1980
1984
1986


Terrestrial Solar Array Price Goals
① ARRAY FABRICATION
② CELL MANUFACTURE
③ SLICING
④ INGOT/SHEET GROWTH
⑤ SILICON MATERIAL
DOLLARS PER WATT
CALENDAR YEAR
INGOT TECHNOLOGY
SHEET TECHNOLOGY
AUTOMATION
1976
1978
1980
1982
1984
1986

Project Cost Goal Allocations (all costs in 1975 dollars)

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	CALENDAR YEAR					
	1976	1978	1980	1982	1984	1986
SILICON MATERIAL						
	Semiconductor Grade →					Solar Grade
Silicon Material $/kg	60	50	40	15	10	7
$/w	1.9	1.1	0.65	0.09	0.05	0.03
INGOT/SHEET GROWTH						
	Czochralski Ingots →					Large Area Sheet
Processing Value Added - $/w	4.8	2.1	1.6	1.9	0.52	0.14
Wafer Material - $/w	6.7	3.2	2.2	2.0	0.57	0.17
INGOT SLICING						
Processing Value Added - $/w	3.7	0.6	0.5	0.01	0	0
Wafers - $/w	10.4	3.8	2.7	2.0	0.57	0.17
CELL MANUFACTURE						
	Silver →					Commercial Conductor
Materials Added (Contacts, etc.) - $/w	0.8	0.4	0.35	0.20	0.08	0.07
	Mostly Manual →					Automated
Processing Value Added - $/w	4.3	1.2	0.85	0.25	0.09	0.06
Cells - $/w	15.5	5.4	3.9	[illegible].45	0.72	0.30
ARRAY FABRICATION						
Materials Added (Encapsulation, Framing, etc.) - $/w	0.5	0.5	0.3	0.10	0.08	0.08
	Mostly Manual →					Automated
Processing Value Added - $/w	4.0	1.1	0.8	0.45	0.18	0.12
ARRAY PRICE GOALS - $/w	20	7	5	3	1	0.50
Silicon material in final product	27%	30%	38%	78%	87%	91%
Total processing value added	84%	71%	75%	87%	73%	64%
Watts/kg of silicon material	32	47	62	162	187	[illegible]03
Cell efficiency (AM1)	11%	11.5%	12%	12.5%	13%	[illegible]3.5%
Cell thickness - mils	15	12	12	10	10	10

Mid-Term and Beyond (Cont'd)

- LIAISON — SELECTED ACTIVITIES
  - — PIMS
  - — Industry Reviews: Models, Inputs, Allocations, and Assessments
  - — Technology Transfer of SAMIS/SAMICS/IPEG
  - — Intertask/Interproject Coordination Support
  - — Conference Presentations

Observations

- RESULTS
  - — Many Products Developed — Models, Plans, and Assessments
  - — Provided Project/Program Strategy Inputs

- VALUE
  - — To Project/Program — Useful Quantitative Inputs to Complex Decision Making
  - — To Industry — Provided Yardsticks, But Value Mixed Since NOT Company Specific
  - — To JPL and Other Government Programs — Demonstrated Application of a Key Element to Any Program: How To Evaluate and Understand the Worth of an R&D Activity

More Observations

- THE FUTURE
  - For Program — Models/Techniques Available, Culture Remains — But Who is the Practitioner and How Does the Analytical Technology Continue to be Improved to Better Reflect Real World

- For Industry — Models/Techniques Available*, But, Small Firms Usually Lack Resources to Implement and Big Companies Usually Have Own Ways to Conduct Investment Decision Analyses

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*Software and Documentation Available from COSMIC: The Computer Software Management Information Center, Suite 112 Barrow Hall, University of Georgia, Athens, Georgia 30602.

PANEL: RECOMMENDATIONS FOR CRYSTALLINE-SILICON IN DOE'S 5-YEAR PHOTOVOLTAIC RESEARCH PLAN

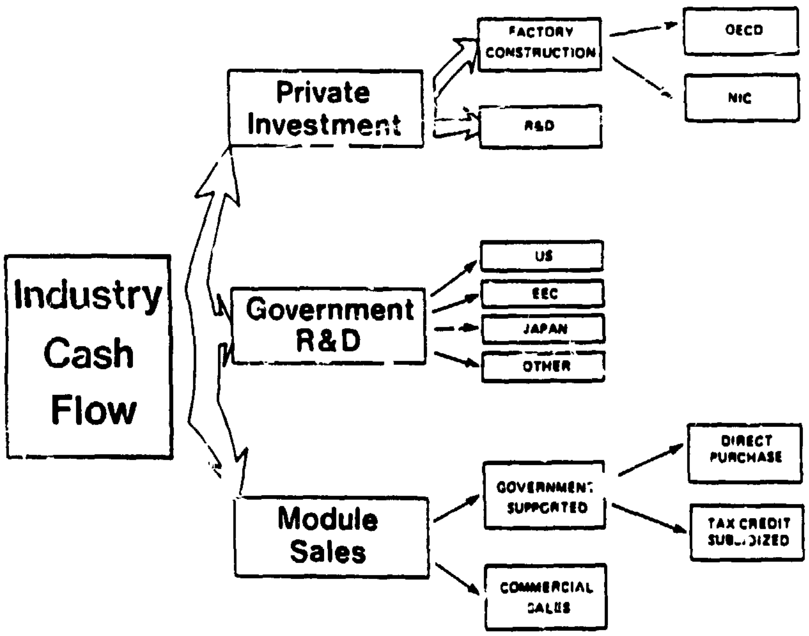
STRATEGIES UNLIMITED

J. Day

Industry Perspective on Change

- o INDUSTRY CASH FLOW
- o CHANGE IN
  - Government Influence
  - the Market
  - the nature of the business
  - the people
  - the companies
- o Where is the future?
- o Changing Government Policy

Industry Cash Flow



Change

	1976	1985
Government Influence	95% of Cash Flow	25% of Cash Flow
Market	Sell to the Government	Sell to the Commercial Market
Nature Of Business	Entrepreneurial	Controlled, deliberatly Planned Organizations
The People	Individualists	Team Players
The Companies	Small Ventures Under financed	Industrial Companies well financed

Where is the Future?

- o Next 5-10 years --- Remote Power
- o Beyond 10 years --- Grid Connected

Government Policy Recommendations

Next 5 years	---	Export Assistance
	---	Utility Education
	---	Long Term Research

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PANEL: RECOMMENDATIONS FOR CRYSTALLINE-SILICON IN DOE'S 5-YEAR PHOTOVOLTAIC RESEARCH PLAN

U.S. NAVY

G. Smith

Activities by the Department of Defense Photovoltaic Review Committee

The Department of Defense (DoD) is the largest single consumer of energy in the U.S., using approximately 250 million barrels of oil equivalent (MBOE) annually. Currently, upwards of 70 percent of the DoD energy requirement is met by petroleum-based products. While DoD expenditures for fuel have dropped $1 billion per fiscal year since 1983, assured supplies of petroleum to meet future energy needs remains a predominant issue. Recent world events relating to the avilability of petroleum fuels, stability of supplies, and volatility of fuel costs have made the issue of effective energy management a high priority within DoD. In particular, DoD has initiated programs to ensure that petroleum supplies are available to sustain peacetime and combat operations (e.g., through the Defense Fuel Supply Center), improve the energy effieiency of the operating forces and the shore establishment, and substitute more plentiful energy sources for petroleum.

Conservation and renewable energy technologies (e.g., photovoltaics, wind, geothermal, biomass, active/passive solar, etc.) can play a major role in contributing to DoD energy management objectives, particularly in programs aimed at petroleum substitution in shore facilities. These facilities account for approximately 25 percent of the total energy budget for DoD. In 1985 in particular, facilities accounted for $3 billion of the $11 billion dollar energy budget.

One of the most promising alternative technologies for use by the military is photovoltaics (PV) -- a technology that directly converts sunlight to electricity. The advantages to PV are that it is fuel free, simple to operate and maintain, modular in nature, and environmentally benign. Futhermore, in remote areas without access to grid-connected power, this technology has been shown to be cost-competitive with conventional energy alternatives, such as diesel - and kerosene-engine generators.

DoD has had substantial experiance with PV, primarily through joint activities with the U.S. Department of Energy's (DOE) Federal Photovoltaics Utilization Program (FPUP). FPUP was designed to increase PV awareness and experience in federal agencies through the design, procurement, installation, and operation of PV systems at their facilities. Through FPUP, more than 3,000 systems were installed at 26 federal agencies. DoD was one of the principal agency participants in this program, accounting for approximately 25 percent of FPUP funds, or $5.8 million. This funding contributed to the installation of 218 PV systems that spanned a wide variety of applications and ranged in size from a few watts to 56 kW. PV proved to be particularly viable power source in remote areas that required reliable energy supplies, and were difficult to reach for system refueling, operation and maintenance.

Currently, the Navy serves as the lead service within DoD for photovoltaic system activities, and is the principal agent responsible for the transfer of technology from PV research and development efforts to the user community. Based on a recent survey completed by the Navy, more than 21,000 cost-effective applications for PV were identified throughout this service branch.

In an effort to more aggressively expand PV use throughout DoD, a tri-service group was formed in December 1985. Formally titled the Photovoltaics Review Committee, this group was given a five-year charter to achieve the following objectives: study different methods of identifying potential applications within DoD; reduce overall costs of DoD PV-related products; transfer technical information about PV throughout the military; and promote widespread application of these systems in the three service branches. The Photovoltaics Review Committee comprises energy officials from each of the three services.

A number of factors combine to demonstrate the timeliness and need for the PV Review Committee to support the development and use of PV throughout DoD.

The price of oil has decreased resulting in diminished interest in conservation and renewable technologies, despite indicators by many individuals in the public and private sectors that this price decline is only a short-term fluctuation.

The pressure from the Gramm-Rudman-Hollings budget bill has made new project initiation extremely difficult.

There is a reluctance on the part of military decision-makers to propose projects that have high up-front capital costs, such as photovoltaics.

The expiration of federal tax credits has dealt an economic blow to the photovoltaics industry at a time when it has matured and provides quality products and services.

There has been a turnover in the decision-making echelons throughout each of the services, which has resulted in a cadre of professionals who are uninformed about photovoltaics.

Thus, there is a strong need to encourage the continued use of PV technology which promises to provide a proven, reliable, and cost-effective electricity source for a variety of DoD applications.

The Photovoltaics review Committee is considering a number of activities which it will be pursuing over the next year. These include:

Developing a Five-Year Plan to identify PV-related initiatives to be undertaken by the Committee over the period 1987 to 1991.

Developing an educational videotape to encourage the use of PV systems at the field level.

Producing a brochure on PV for DoD applications which would serve as a companion document to the videotape.

Preparing a PV design and applications handbook for base commanders.

Sponsoring a joint industry/DoD meeting in which there would be a free exchange of information on the PV needs of the various services.

Securing engineering analysis and technical support and assistance to conduct activities required by the Committee.

A number of potential benefits are to be realized by the success of the DoD PV Review Committee. Specifially, DoD would obtain cost-effective, reliable energy alternatives for meeting facility energy needs and reduce requirements for petroleum-based fuels, particularly imports. The PV industry would increase sales to the military, a potential high-volume buyer of PV over the next few years, and thus move closer to its goal of mass production and lower prices. DOE, by assisting in the development of these activities, would increase the awareness among the military of the merits of PV, and thus help industry to increase sales of this technology. These activities contribute to DOE initiatives as lead agency for the Committee on Renewable Energy Commerce and Trade (CORECT), a federal interagency working group formed to enhance commerce in U.S. renewable energy products and related services. The DoD serves as an active participant in the CORECT.

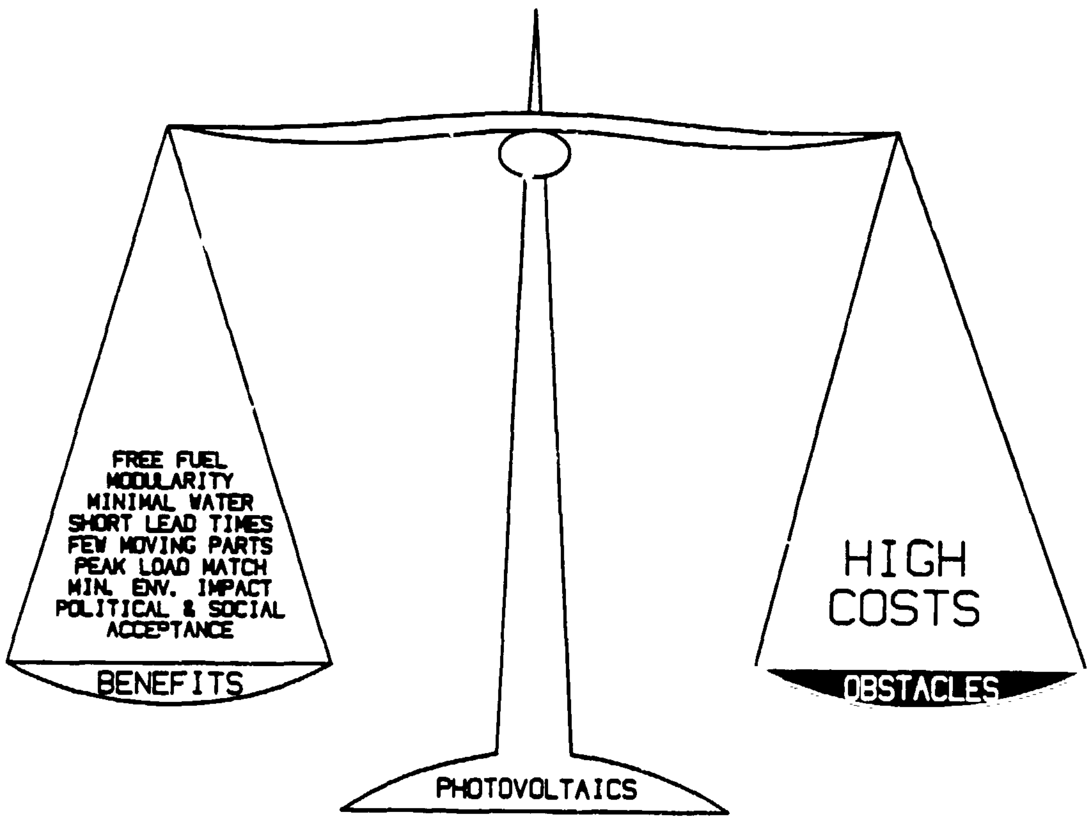
PANEL: RECOMMENDATIONS FOR CRYSTALLINE-SILICON IN DOE'S 5-YEAR PHOTOVOLTAIC RESEARCH PLAN

PACIFIC GAS AND ELECTRIC

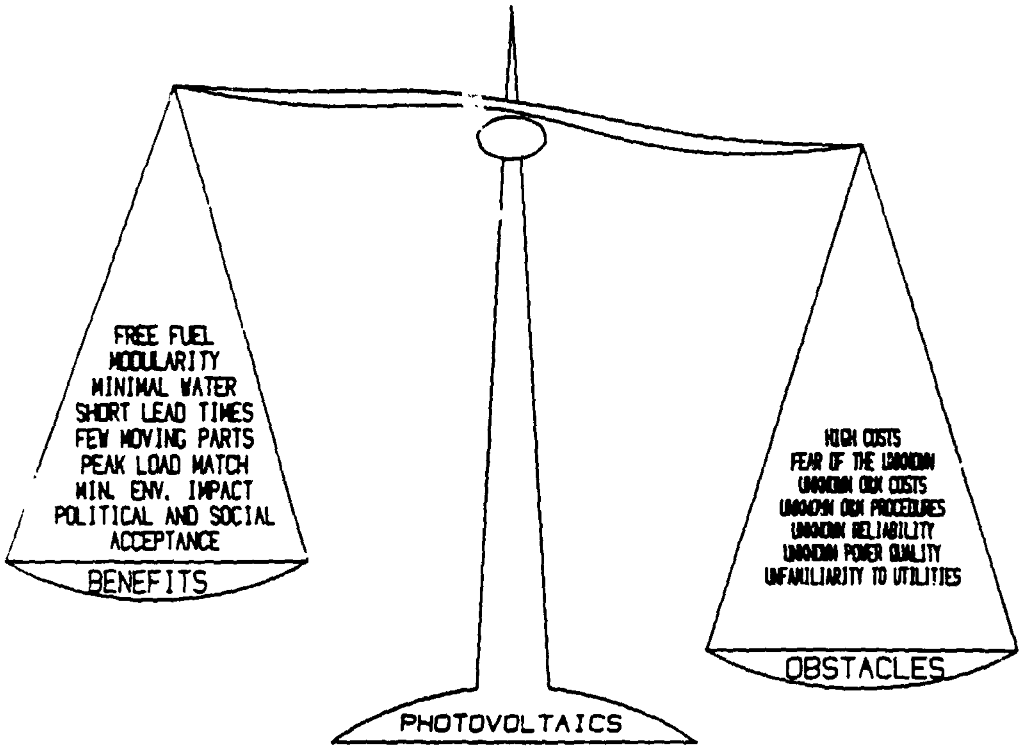
K. Firor

Utility Industry Familiarization with Photovoltaics

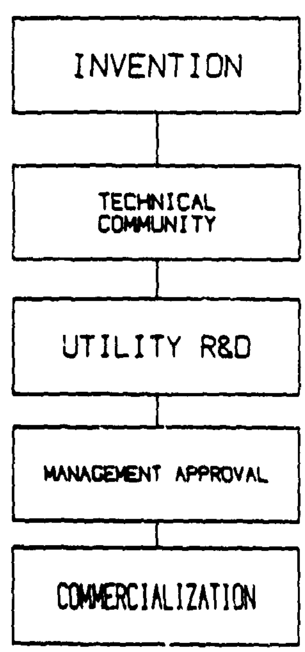
In the view of the technical community, high costs are the major obstacle to commercialization of photovoltaics.



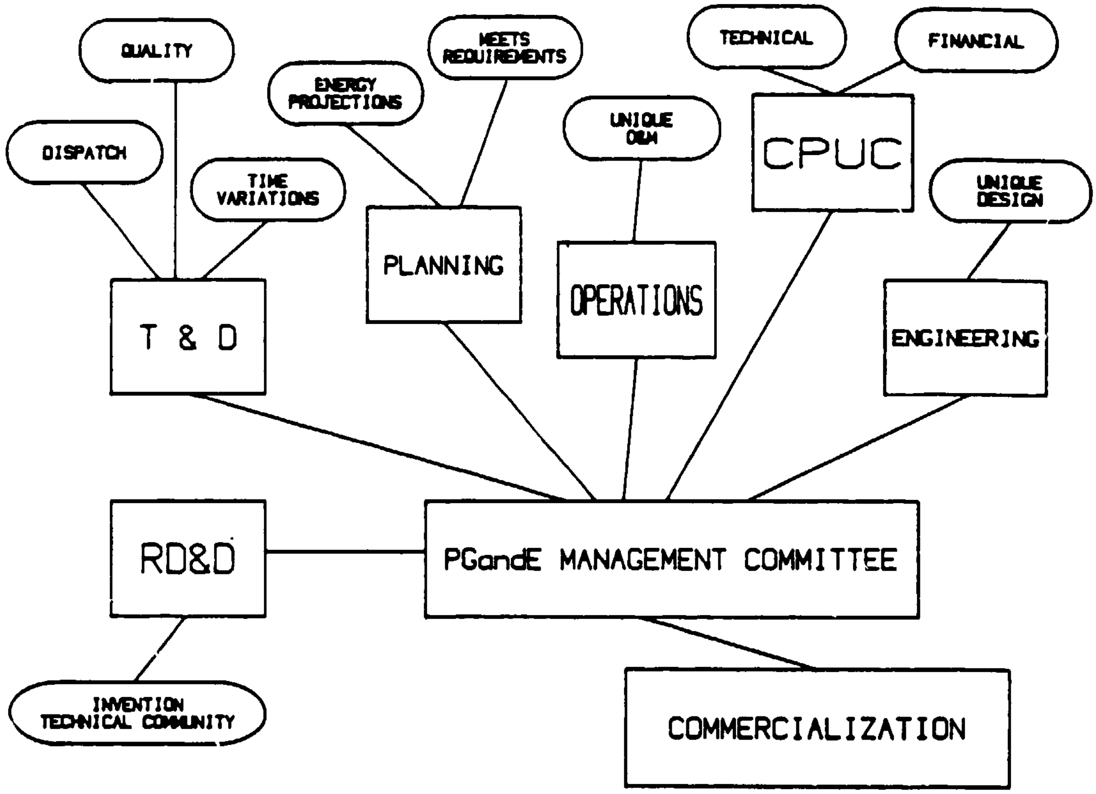
From the perspective of a utility company, many unknowns accompany high costs in the list of obstacles.



Many people believe that utility companies will make the decision to build PV power plants based on input from EPRI or their own research group.



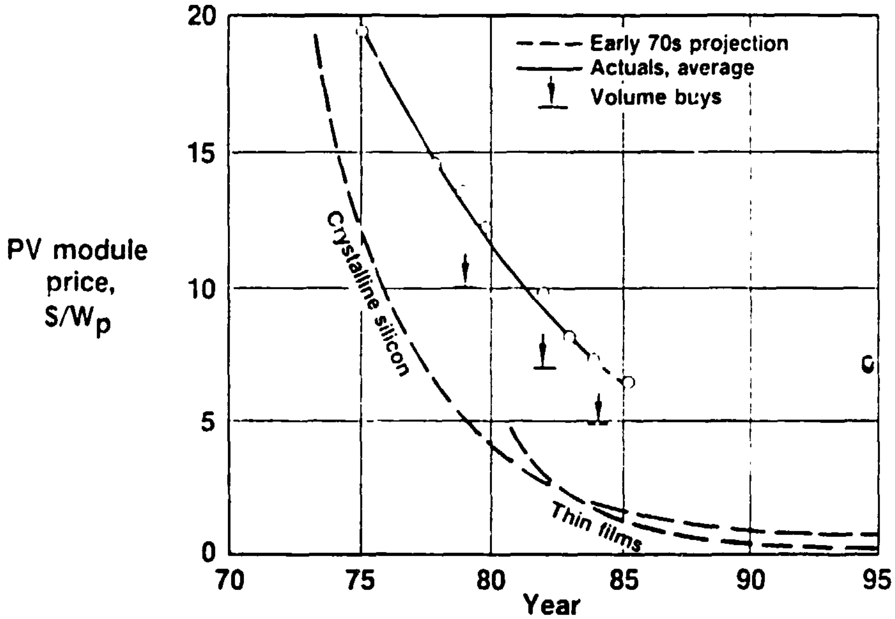
A more realistic view shows the many inputs required by a utility company's management before the decision to build PV power plants can be made.



PANEL: RECOMMENDATIONS FOR CRYSTALLINE-SILICON IN DOE'S 5-YEAR PHOTOVOLTAIC RESEARCH PLAN

HUGHES AIRCRAFT

E. L. Ralph



Market Factors

- Markets needed at various price levels
- Cost reduction comes in steps
- Profits needed to finance research and development
- New technology plus new capital reduce costs
- New markets penetrated with lower costs
- Sound pricing and management needed
- Specialty markets exist
- Utilities need and like PV systems

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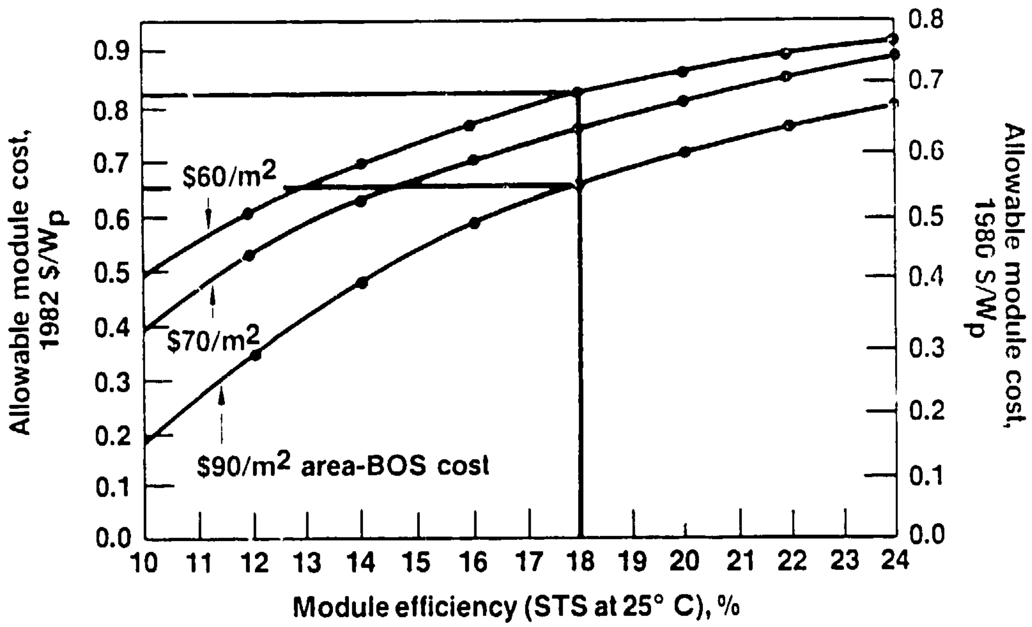
Future Expectations (Terresterial)

- Silicon cell efficiency of 20%
- Silicon cell array efficiency of 18%
- Sheet grown silicon arrays of 17%, and $1/Wp
- Amorphous silicon modules of 9% and < $1/Wp
- Tandem α-silicon cells of > 12% η
- Competitive $CuInSe_2$ and CdTe cells

Module Costs Versus Efficiency
(15¢/kWh 30-Year Levelized Energy Costs)



PV Program Assessment

- NO CLEAR SUPERIORITY BETWEEN:
  THIN FILMS, MULTIBAND GAP CELLS, CRYSTALLINE Si
  (WHEN BOS COSTS, RELIABILITY, AND η CONSIDERED)
- CRYSTALLINE SILICON CELL TECHNOLOGY HAS IN ITS FAVOR:
  A PROVEN DATA BASE
  PROVEN ADVANCES NOT YET INCORPORATED INTO PRODUCTION
  CONSIDERABLE FUTURE ADVANCES AVAILABLE
- LAST YEAR JAPAN (NEDO) ESTABLISHED A POWERFUL XTAL Si PROGRAM
  GOALS: 18% CELL & 15% MODULES BY 1988
  BY 1990 PV ENERGY COST AT $.50/KWHR - DIESEL COMPETITIVE
- DOE CRYSTALLINE SILICON PROGRAM DANGEROUSLY LOW

Program Recommendations: Crystalline Silicon

GOALS: PRODUCTION TECHNOLOGY LEADING TO 15% MODULES
RESEARCH LEADING TO 18% FLAT MODULES
RESEARCH LEADING TO 25% FLAT MODULES, MULTIBAND GAP (Si BASE)

RESEARCH NEEDS:

- SHEET GROWTH :
  CRYSTAL QUALITY, HI THROUGHPUT SHEET, AUTOMATIC GROWTH
- MINIMIZE CELL SURFACE LOSSES :
  PHYSICAL/CHEMICAL STRUCTURES, SURFACE PROPERTIES, METHODS
- MEASUREMENTS :
  RECOMBINATION AT SURFACES AND INTERFACES, LIFETIMES, MOBILITIES
- PROCESS DEVELOPMENT :
  LOW COST, COMPATIBLE WITH HIGH EFFICIENCY GOALS

PANEL: RECOMMENDATIONS FOR CRYSTALLINE-SILICON IN DOE'S 5-YEAR PHOTOVOLTAIC RESEARCH PLAN

JET PROPULSION LABORATORY

K. M. Koliwad

Future Crystalline Silicon Research

- CRYSTALLINE SILICON TECHNOLOGY CAN MEET THE LONG-RANGE OBJECTIVES OF DOE PV PROGRAM
- FUTURE RESEARCH SHOULD FOCUS ON
  - SOLVING FUNDAMENTAL PROBLEMS TO ENABLE THE PRODUCTION OF HIGH QUALITY SILICON SHEET
  - **ADVANCING THE KNOWLEDGE OF BASIC MECHANISMS OF CHARGE CARRIER LOSSES LEADING TO LARGE AREA HIGH EFFICIENCY SOLAR CELLS ON LOW-COST SILICON SHEET**

Recommendations

- EMPHASIZE FUNDAMENTAL AND GENERIC RESEARCH THAT CAN BENEFIT A LARGE SEGMENT OF THE INDUSTRY
- KEEP A BALANCE BETWEEN THE VARIOUS TECHNOLOGY OPTIONS
- KEEP A BALANCE BETWEEN INDUSTRY, UNIVERSITY AND FEDERAL LABORATORIES
- DEVELOP A MECHANISM FOR LONGER TERM SUPPORT TO UNIVERSITIES
- AS YOU EMPHASIZE RESEARCH, THE <u>TECHNOLOGY TRANSFER</u> PROCESS BECOMES A CRITICAL ACTIVITY. THE PROGRAM SHOULD ESTABLISH A FORMAL PROCESS FOR DOING THAT.
- LEVERAGE DOD AND OTHER SUPPORT IN RELATED AREAS

PANEL: RECOMMENDATIONS FOR CRYSTALLINE-SILICON IN DOE'S 5-YEAR PHOTOVOLTAIC RESEARCH PLAN

WESTINGHOUSE ELECTRIC CORPORATION

C. Rose

Dendritic Web Technology Progress and Long-Range Requirements

Date	Web Growth (cm^2/Week/Furnace)	Module Efficiency (%)
December 1984	9,000	13%
December 1985	47,000	14%
December 1986	100,000	14.5%
December 1987	150,000	15%

Advanced Silicon Sheet Requirements General Research in High-Speed Ribbon Growth

- Detailed Analysis of Plastic Flow and Deformation to Optimize Growth Speed
- Control of Thermal Stress Induced Ribbon Buckling to Produce > 10 cm Wide Ribbons
- On-Line Crystal Quality Assessment
- Improved Replenishment/Growth Region Isolation in Molten Silicon
- Refinements in Closed Loop Growth Controls in Ribbon Furnaces
- Removal of Web Strips During Continuous Growth

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Silicon Materials Requirements

- Material Capable of Continuous Feed
- Small Particles, Semiconductor Grade
- Cost < $30/kg

Flat-Plate Collector Requirements

"15% Modules from a $90/m^2 Process"

- Cell Efficiency/Material Characteristics Correlation
- High Throughput Simultaneous Junction Formation
- Multilayered AR Coating
- Back Surface Grid
- Lower Cost Metallization System
- Low Cost Ribbon Cassette Designs
- Automated Material Handling Devices

PANEL: RECOMMENDATIONS FOR CRYSTALLINE-SILICON IN DOE'S 5-YEAR PHOTOVOLTAIC RESEARCH PLAN

SOLAREX CORPORATION

E. E. Daniels

Crystalline Technology Development Focus

- **Silicon**
- **Wafer Fabrication**
- **Cell Processing**
- **Product Assembly**
- **Arraying**
- **Systems Integration**

The Crystalline Photovoltaic Industry Today

- **Established Reliability**
- **Dramatic Improvement in Performance**
- **Significant Price Reductions**
- **Growing Commercial Acceptance**

Vertical Integration

- o SILICON PRODUCTION
- o CRYSTALLIZATION
- o WAFERING
- o CELL PRODUCTION
- o MODULE ASSEMBLY

SYSTEM DESIGN, ASSEMBLY, INSTALLATION

Photovoltaic Advantages

- ENVIRONMENTAL BENIGN
- MAINTENANCE FREE
- ECONOMIC UNIT SIZE
- EASILY INSTALLED
- SHORT LEAD TIMES
- VERY LOW OPERATING COSTS
- PROVEN RELIABILITY

Accomplishments of the Photovoltaic Community

- **Research & Development**
  - **Established Sound Technology Base**
- **Industry**
  - **Utilization of Sound Technology Base**
  - **Establish Sound Business Base**

Crystalline Industry Focus

- **User Awareness**
- **User Acceptance**

Technology

OPTIONS

- SINGLE CRYSTAL
- SEMICRYSTALLINE
- RIBBON
- AMORPHOUS

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The Future: Technology

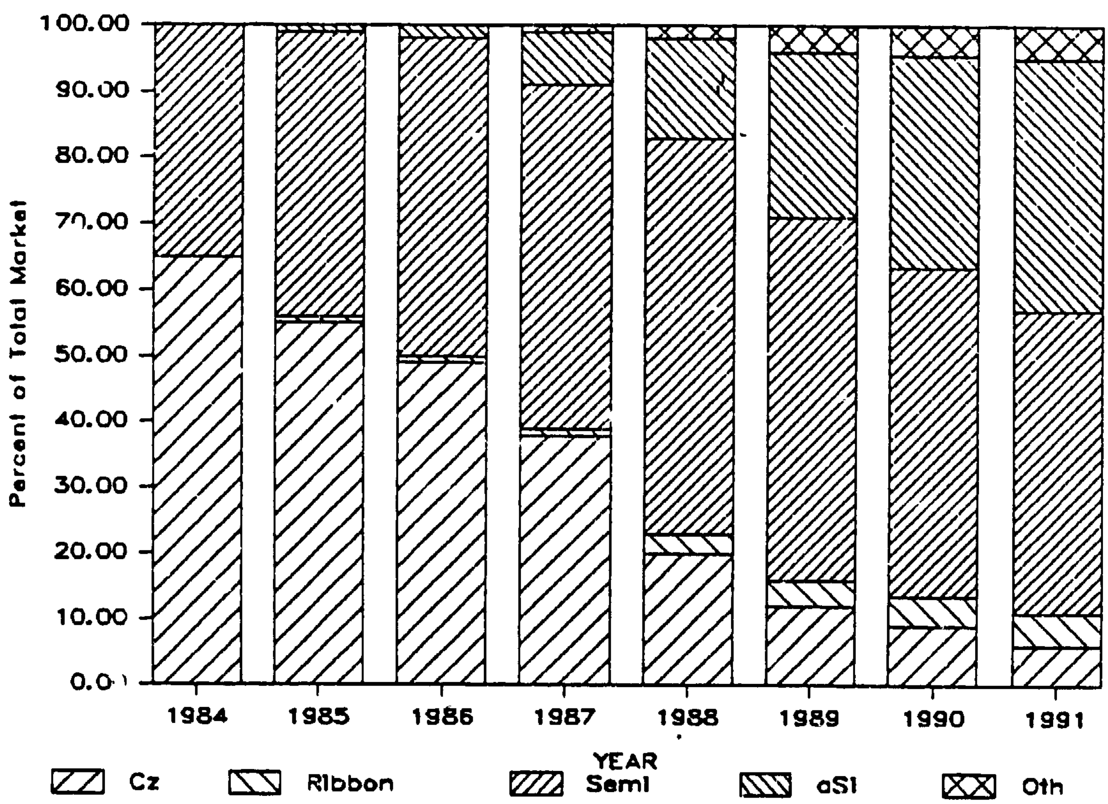
Crystalline Technology

- **Semicrystalline (Poly) Product for Next 5-10 Years**
- **8 - Major Manufacturers Have Introduced this Technology Since 1981**

Sheet Technology

- **May Actually Be Polycrystalline**
- **Needs to Prove Reliability**

World Photovoltaics Market
(Technology as a Percent of Market)



The Future: Industry Needs

Viable Business Base Development

- **Education**
  - **Appropriate Demonstration Projects**
- **Internationally Recognized Test Sequence**
- **Internationally Accepted Product Rating System**
- **Financing Support**