N87-16395

# THE JET PROPULSION LABORATORY LOW-COST SOLAR ARRAY PROJECT 1974-1986

PHOTOVOLTAIC ENERGY SYSTEMS, INC.

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## Historical Overview

The Lowcost Solar Array Project (LSA) had its origin in the JPL-organized Cherry Hill Conference on October 23-25, 1973. /1 Cherry Hill was dedicated to find paths for implementing all forms of solar energy. The Cherry Hill Conference heard a large number of invited papers on silicon and polysilicon from many persons still very active in PV. Gene Ralph presented a detailed development plan which actually had "milestones." Gene's road map (Fig 1) was a precursor to the JPL-LSA plan. We heard other papers at Cherry Hill. Dr. Joe Lindmayer, having just formed Solarex, gave a paper entitled "Silicon Cells." He said, "I believe that terrestrial cells could be produced now (1973) for $10 per Watt peak and a panel completed for $20 per Watt. It seems certain that the efficiency could be over 20 percent." We heard from C.G. Currin of Dow Corning and R.K. Riel of Westinghouse on dendritic web; Tom Surek, Bruce Chalmers, A.I. "Eddy" Mlavsky and G.H. Schwuttke on EFG ribbon. On polysilicon we heard from P.H. Fang, Ting L. Chu, P.A. Iles and Bernie Seraphin.

At this key conference, several National Science Foundation professionals were leaders in the PV discussions. When the Energy Research and Development Administration was formed in 1973, some of these NSF professionals were assigned to ERDA to set up the U.S. Photovoltaics Program. The NSF crew was Dr. Dick Blieden, Dr. Len Magid, Dr. Lloyd Herwig, Dr. Don Schueller and Doug Warschauer. Dick Blieden had charge of all the electric options and Len Magid was running PV. Len had negotiated and helped plan and fund the JPL program.

Another key national effort in establishing energy priorities was the Dixy Lee Ray Report - "The Nation's Energy Future" /2 which also scoped out the potential for PV.

Our good friend, Bob Forney, was the first manager of the LSA program and John Goldsmith was his technical director. John found greener pastures at Solarex and represents one of our most important results of the project - people. We trained - John and dozens others very well so they could join industry and become leaders in the private sector.

In this timeframe we had the origins of the precise milestones which guided the program. Mort Prince joined ERDA in July 1975 and took over the PV branch. I joined ERDA in August '75 and took over the PV division in 1977. Hank Marvin had joined us in August '75 to lead the solar division and despite some pressure from management, we issued the so-called "Marvin Plan." /3 The objectives of this plan were our "bible" for the entire program until the Reagan budget hit the street and we started high risk research. Table 1 shows the key objectives for the LSA Technology Development area of the Marvin Plan. Table 2 shows the planned funding for the entire PV program. The LSA project was primarily concerned with the technology development goals.

A key factor in the planning of the LSA program was the FEA Task Force Report Project Independence Blue Print issued November 1974. /4 Our PV team was instrumental in writing Section VII. Some names pop out that are worth mentioning. The PV participants included Mickey Alpers, Dick Blieden, Gene Ralph, Ralph Luttwack, Sam Taylor, Lloyd Herwig, Dan Bernatowicz, Pete Bos, Bill Cherry, John Goldsmith (NASA Lewis), Pat Rahilly, Fred Bartels. Project Independence proposed an accelerated national effort which would by 1985 cause:

Peak Power Production - 1000MW
Average PV Array Cost - $500/kW peak (the famous $.50/W goal in 1975$)
Total Installed Cost - $900/kW peak
Number of PV Workers - 38,700

Obviously these were a bit optimistic, but the goals were the results of our best thinking at the time. The JPL, ERDA, DOE Photovoltaic goals were the result of a complicated concensus process by the best minds in government and industry.

JPL analyzed every step in the creation of a crystal silicon module in terms of material used, material cost, material properties; process used, cost and results. The major programs included: polysilicon production cost and properties; crystal silicon; slicing or area creation; cell formation; metallization; interconnection; packaging and testing. For every program element, a matrix of technical options was defined and funded. For example, in the polysilicon area, twelve chemical approaches to purifying silicon were funded. For every program element, detailed technical feasibility milestones were established. As technical feasibility was shown, technical readiness goals, and finally commercial readiness objectives were established. Table 3 shows the history of funding of the LSA project versus the planned budget. This funding plan and goals become the basis for the PVRD&D Act of 1978 which called for nearly $2 billion of RDT&E and essentially institutionalized the goals of the Marvin Plan.

It is clear that the budgets imposed by President Reagan did not allow the plan to be implemented. I left DOE because adequate resources were not being offered in order to meet our commercial readiness goals. I felt by forming the Renewable Energy Institute, getting on the Boards of SEIA and ASEC and "working" the Hill to mark up Reagan's proposed $20 million levels to $50 million plus, that I could do more for PV than staying with a bankrupt policy.

Major Conclusions and Results of JPL/LSA

- The DOE/JPL program caused over 2000 professionals to devote their careers to solving cost and performance problems in PV.
- Virtually all of the technical feasibility and technical readiness goals were fully met by the JPL/DOE effort.
- The shift in emphasis in 1981 from a balanced, well funded RDT&E PV program to an underfunded, high risk research effort delayed the carefully planned transition from technology readiness to commercial readiness. JPL was forced to cancel five key commercial readiness contracts involving silicon production, sheet production, ingot casting and crystal film deposition.
- Crystal silicon PV is a truly remarkable energy product. It is uniquely reliable (30 year plus), high efficient, environmentally benign, that can be manufactured with costs permitting fully economic PV for the U.S. peaking and intermediate power and for stand alone power in remote sites.
- The DOE/JPL LSA project is one of the most successful, cost effective, government/university/industry technology development efforts in the history of U.S. federal support of technology.

I am proud to have had a small role in managing the JPL/LSA project and join the industry in saying well done!

References:

/1 Workshop proceedings "Photovoltaic Conversion of Solar Energy for Terrestrial Applications, Vol I, Vol II, October 23-25, 1973, Cherry Hill, NJ, Organized by JPL; Sponsored by NSF RANN-NSF-RA-N-74-03.

/2 The Nation's Energy Future", Report to Richard M. Nixon, Submitted by Dixy Lee Ray, December 1, 1973, Washington 1281.

/3 "Marvin Plan" - February 3, 1978, "National PV Program Plan" DOE/ET-0035(78).

/4 Federal Energy Administration Project Independence Blue Print Final Task Force Report Solar Energy, Directed by NSF, November 1974.

Figure 1. Gen : Ralph's Cherry Hill Road Map for PV-1973

| MILESTONE SCHEDULE | | | |
|---|---|---|---|
| PARAMETER | TECHNOLOGY STATUS | | |
| | PRESENT 1973 | 5 YEARS 1978 | 10 YEARS 1983 |
| Cell Size ($cm^2$) | 20 | 45 or Cont. Ribbon | Continuous Multi-Ribbon or sheet |
| Cell Efficiency (% AMO) | 14 | 16 | 18 |
| (% AMI) | 16.5 | 19 | 21 |
| Cell Cost ($/watt AMI) | 5 | 2.50 | 0.30 |
| Power System Cost ($/watt AMI) | 20 | 5 | <1 |
| Production Rate (MW/yr) | .09 | 6 | 200 |

## Table 1. Objectives and Goals

### Objectives and Goals

The overall objective of the photovoltaic program is to ensure that photovoltaic conversion systems play a significant role in the nation's energy supply by stimulating an industry capable of providing approximately 50 GWe of installed electricity generating capacity by the year 2000.

In order to achieve this overall objective, several time-phased program goals have been defined.

- **Near Term:**
  - To achieve photovoltaic flat-plate module or concentrator array prices of $2 per peak watt (1975 dollars) at an annual production rate of 20 peak megawatts in 1982. At this price level, energy costs should range from 100 to 200 mills/kWh.
- **Mid Term:**
  - To achieve photovoltaic flat-plate module or concentrator array prices of $0.50 per peak watt (in 1975 dollars), and an annual production rate of 500 peak megawatts in 1986. At this price level, energy costs should be in the range of 50 to 80 mills/kWh. Studies project that photovoltaic systems will begin to compete for both distributed and larger load-center utility-type applications and thereby open up significant markets for large-scale photovoltaic systems. This production level would permit the use of industrial-scale array production processes and would ensure the market availability of photovoltaic arrays as they become economic.
- **Far Term:**
  - To achieve photovoltaic flat-plate module or concentrator array price goal of $0.10 to $0.30 per peak watt in 1990 (in 1975 dollars), and an annual production rate of 10-20 peak gigawatts in 2000. At this price range, energy costs should be in the range of 40 to 60 mills/kWh and be cost effective for utility applications. Such a level of annual photovoltaic capacity installation can ensure that photovoltaic conversion systems become a significant source in the Nation's energy supply.

Achievement of these goals can make photovoltaic systems economically competitive with other energy sources for dispersed on-site applications as well as for central power generation.

Since these goals are time specific it is assumed that program funding will follow that identified in Table 3. Significant departures in funding will affect the time of performance.

Table 2. Photovoltaic Funding
Performance Funding (B/A) Needed for Photovoltaic Activities ($ in Millions)

| PROGRAM ACTIVITY | FY 77 | FY 78 | FY 79 | FY 80 | FY 81 | FY 82 | FY 83 | FY 84 | FY 85 | FY 86 | TOTAL 77-86 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TECHNOLOGY DEVELOPMENT | 33.7 | 36.0* | 27.0 | 40.0 | 50.0 | 60.0 | 60.0 | 50.0 | 40.0 | 30.0 | 426.7 |
| RESEARCH & ADVANCED DEVELOPMENT | 6.2 | 8.7 | 13.5 | 20.0 | 25.0 | 30.0 | 30.0 | 35.0 | 35.0 | 25.0 | 228.4 |
| SYSTEMS SUPPORT | 7.0 | 9.0 | 9.7 | 10.0 | 10.0 | 8.0 | 5.0 | 6.0 | 6.0 | 4.0 | 77.7 |
| QUALITY ASSURANCE | 0.0 | 1.0 | 2.0 | 3.0 | 4.0 | 4.0 | 4.0 | 3.0 | 2.0 | 2.0 | 25.0 |
| PROGRAM MANAGEMENT & ANALYSIS | 2.0 | 2.3* | 1.8 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 19.8 |
| ST&A – FLAT PLATE | 6.5 | 2.0 | 11.0 | 20.0 | 50.0 | 60.0 | 60.0 | 60.0 | 50.0 | 40.0 | 396.5 |
| ST&A – CONCENTRATORS | 0.0 | 5.0 | 11.0 | 20.0 | | | | | | | |
| ST&A – FEDERAL PURCHASES | 0.0 | 12.2* | 20.0** | 20.0** | 40.0** | 20.0** | 0.0 | 0.0 | 0.0 | 0.0 | 112.2 |
| TOTAL PROGRAM | 65.4 | 78.2* | 96.8 | 136.0 | 161.0 | 184.0 | 164.0 | 158.0 | 135.0 | 103.0 | 1286.4 |

*INCLUDES SUPPLEMENTAL FUNDS - $19 million
**DEPENDS ON NEA PASSAGE

Table 3. Low-Cost Silicon Solar Array Project
Current 10-Year Summary

| | 75 $ | | | 77 $ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $ MILLIONS FY | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | TOTAL |
| ORIG. PLAN | 3.0 | 16.1 / 6.4* | 30.2 | 46.2 | 62.3 | 91.2 | 124.0 | 124. | 84.2 | 47.0 | 22.0 | 656.6 |
| REVISED PLAN | 3.0 | 12.4 / 3.5* | 18 | 24 | 32 | 42 | 54 | 68 | 100 | 130 | 100 | 586.9 |
| ACTUAL | 3.0 | 19 | 32 | 36 | 38 | 42 | 29 | 17 | 13.6 | 14 | 15 | 258.5 |