Some Potential Material Supply Constraints in the Deployment of Photovoltaic Solar Electric Systems

(A Preliminary Screening to Identify
Critical Materials)

September 1978

**Prepared for the U.S. Department of Energy
under Contract EY-76-C-06-1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

The views, opinions and conclusions contained in this report are those of the contractor and do not necessarily represent those of the United States Government or the United States Department of Energy.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
Under Contract EY-76-C-06-1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy \$ ____*; Microfiche \$3.00

*Pages	NTIS Selling Price
001-025	\$4.00
026-050	\$4.50
051-075	\$5.25
076-100	\$6.00
101-125	\$6.50
126-150	\$7.25
151-175	\$8.00
176-200	\$9.00
201-225	\$9.25
226-250	\$9.50
251-275	\$10.75
276-300	\$11.00

SOME POTENTIAL MATERIAL SUPPLY CONSTRAINTS
IN THE DEPLOYMENT OF PHOTOVOLTAIC SOLAR
ELECTRIC SYSTEMS

(A Preliminary Screening to Identify
Critical Materials)

by
R. L. Watts
W. E. Gurwell
C. H. Bloomster
S. A. Smith
T. A. Nelson
W. W. Pawlewicz

September 1978

Pacific Northwest Laboratory
Richland, Washington 99352

ACKNOWLEDGMENTS

In the conduct of this study valuable contributions were made by a number of people and organizations.

Contributing organizations are: Massachusetts Institute of Technology's Lincoln Laboratory, Charles River Associates, General Electric Company Valley Forge Space Center and C&D Battery.

The following Battelle-Northwest Laboratories personnel contributed:
N. E. Carter, T. B. Correy, D. K. Davis, D. E. Deonigi, R. L. Egeland,
C. M. Eliason, T. P. Harrington, J. N. Hartley, K. E. Keene, J. W. Litchfield,
S. D. Rosier, and R. P. Smith.

S.I. TO ENGLISH CONVERSIONS

S.I. units are used almost exclusively in this report. Some of the pertinent conversions are:

Metric Ton	1 MT = 2204.6 lbs
Square Meter	1 m ² = 10.764 ft ²
Kilowatt	1 kW = 3414 Btu/hr
Gigawatt	1 GW = 3.414 x 10 ⁹ Btu/hr
	33.44 GW - yr = 10 ¹⁵ Btu
	= 1 Quad
Insolation	1 kW/m ² = 317.2 Btu/hr - ft ²
	1 kW - hr/m ² - yr = 317.2 Btu/ft ² - yr

CONTENTS

ACKNOWLEDGMENTS	iii
S. I. TO ENGLISH CONVERSIONS	v
FIGURES	ix
TABLES	ix
I. SUMMARY OF OVERALL RESULTS AND RECOMMENDATIONS	1
II. INTRODUCTION	3
III. PHOTOVOLTAIC DESIGN DESCRIPTIONS	5
DESIGN DESCRIPTIONS	5
REFERENCE DESIGNS METHODOLOGY	7
CHARACTERIZATION OF REFERENCE DESIGNS	10
IV. MATERIALS REQUIREMENTS	13
V. METHODS, MODELS AND ASSUMPTIONS USED TO IDENTIFY POTENTIAL MATERIALS CONSTRAINTS	19
THE EFFECT OF THE ASSUMPTIONS MADE IN THE STUDY	27
VI. RESULTS AND RECOMMENDATIONS	29
DETAILED "A" MATERIAL DISCUSSION	47
REFERENCES	75
APPENDIX A - ACTUAL COMPUTER RUNS OF BULK AND RAW MATERIAL SCREENING FACTORS	A-1
APPENDIX B - CHARACTERIZATION OF PHOTOVOLTAIC DEVICES	B-1
APPENDIX C - PHOTOVOLTAIC SYSTEMS DESIGN CHARACTERIZATION AND MATERIAL REQUIREMENTS	C-1

FIGURES

1. Photovoltaic Design	5
2. The Materials Cycle	19
3. Flow Chart of Materials Assessment Methodology	21
4. Interactive Screening System	22
5. Assessment of Potential Materials Problems	23
6. Growth Curves for Solar Systems Deployment	28
7. Price History and Future Price Estimates for Lead	49
8. Price History and Future Price Estimates for Arsenic	52
9. Price History and Future Price Estimates for Gold	55
10. Price History and Future Price Estimates for Tellurium	58
11. Price History and Future Price Estimates for Cadmium	60
12. Price History and Future Price Estimates for Indium	63
13. Price History and Future Price Estimates for Aluminum	66
14. Price History and Future Price Estimates for Gallium	69
15. Price History and Future Price Estimates for Germanium	72

TABLES

1. Materials Categories by Functional Component for Photovoltaics	9
2. Bulk Material Requirements	14
3. Raw Material Requirements	16
4. Bulk Material Threshold Criteria	24
5. Raw Material Threshold Criteria	25
6. "A" Materials in Photovoltaic Systems Studied	30
7. "A" Materials Identified for 15 Photovoltaic Systems and Variations	31
8. Photovoltaic Bulk/Raw "B" Material Table for Each Cadmium Cell Type at 50 GWe	38
9. Photovoltaic Bulk/Raw "B" Material Table for Each Gallium Cell Type at 50 GWe	39
10. Photovoltaic Bulk/Raw "B" Material Table for Each Silicon Type Cell at 50 GWe	40
11. Photovoltaic Bulk/Raw "B" Material Table for the Combined Scenarios, Deleted Energy Storage, and Collector Only Systems	41
12. Criteria Exceeded by "B" Bulk Materials in Photovoltaic Systems for the 50 GWe Combined Scenarios	43
13. Criteria Exceeded by "B" Raw Materials in the Photovoltaic Systems for the 50 GWe Combined Scenario	44

I. SUMMARY OF OVERALL RESULTS AND RECOMMENDATIONS

Thirteen photovoltaic cell designs were investigated in 15 system configurations to identify potential future material constraints to their large scale installation. The designs were studied individually and in a combination totaling 50 GWe of installed capacity by the year 2000. The 50 GWe combination required about 150 million tons of 62 bulk materials which in turn required the processing of about 1.8 billion tons of about 50 raw materials.

Seven of the systems studied individually show no serious material constraints if each were deployed at 50 GWe by the year 2000.

We did identify potentially serious constraints for the other eight systems at 50 GWe (individually). These constraints involved;

- Arsenic
- Cadmium -
- Gold
- Gallium
- Germanium
- Indium
- Tellurium

in the various systems as shown in the body of the report in Table 7.

After a detailed analysis of the above materials, we concluded that there exists definite availability constraints for:

- Indium
- Gallium
- Germanium

The appearance of a material in the list above indicates that the computer program (on the basis of stored data) "raised flags" indicating a potentially serious problem. These materials are examined further to see how serious the limitations really are and each material is discussed individually in the results section.

There were potential problems identified for structural support materials (aluminum, iron and steel) and for the energy storage materials (lead and antimony) which are common to all systems. However, the structural materials usage could be reduced through substitution or redesign. Energy storage is already being left out of many contemporary designs for economic reasons. Thus, these materials are not considered truly serious.

There are a sizeable number of materials which were used in these systems in small quantities or having low cost and were thus judged "not critical." During the screening process, these materials raised one or more "flags" indicating that their use and availability should be monitored.

These materials are:

Antimony/ore	Petroleum
Arsenic/arsenic trioxide	Selenium
Asbestos	Silver
Boron	Tantalum
Chromium/chromite/ferrochrome	Tin/ore
Copper/ore	Titanium/rutile
Ferromanganese/ore	Zinc/ore
Fluor spar	
Nickel/ore	
Palladium	

II. INTRODUCTION

The objectives of this study are to:

- Identify potential material supply constraints which could seriously impede the large scale installation of photovoltaic (PV) systems.
- Provide a functional description of materials used in the construction of selected photovoltaic systems in computerized format suitable for interactive updating in workshops or for future reviews.
- Provide a data base of statistics and production processes in machine accessible format for making this assessment and supporting future PV assessments.
- Show the sensitivity of potential shortages to the size of the PV implementation scenario.

The scope of the study includes the screening of 13 photovoltaic cells in a total of 15 system designs. Some cells are also included in concentrating systems at 500 suns and 30 suns. The systems all are based on the substitutions of various cells and concentrator devices into designs based on the Meade, Nebraska 25 kW installation. The system designs all include energy storage but the effect of deleting energy storage is also examined.

Many additional design variations could be studied, but the scope of systems covered, including variations such as the deletion of energy storage equipment, would appear to have provided a reasonable first cut at identifying future potential material constraints.

We have studied each design separately at levels of 50 GWe and 10 GWe. This range reaches up to the 50 GWe of ERDA-49⁽¹⁾ again shown in DOE/ET-0062⁽²⁾.

In addition, we studied a combination of system designs adding up to 50 GWe. In order to do a sensitivity analysis on the combination, we also analyzed a scenario of 100 GWe.

The purpose of the study is not to decide feasibility of solar designs which are as yet subject to considerable change and improvement, but rather the purpose is to provide data and information possibly helpful in guiding those changes and improvements.

III. PHOTOVOLTAIC DESIGN DESCRIPTIONS

DESIGN DESCRIPTIONS

This assessment is based upon the system built by the Massachusetts Institute of Technology-Lincoln Laboratory. This system (Figure 1) produces power to pump irrigation water to 80 acres of corn and soybeans at the University of Nebraska Field Laboratory near Mead. The unit's peak power output of 25 kW makes it the largest photovoltaic power system in existence today.

FIGURE 1. Massachusetts Institute of Technology-Lincoln Laboratory Photovoltaic System and at the University of Nebraska Field Laboratory at Mead, Nebraska
(Source: MIT-Lincoln Laboratory)

The solar cell array is comprised of a total of 28 flat panels, each 8 ft by 25 ft. The array output (6.2 amps at 150 volts per panel) is fed to two buildings. One houses the system control equipment and inverters to convert the direct current (DC) produced by the solar cells into alternating current (AC) at 220 volts to power the irrigation pump motor and other loads. The other building houses 38 large lead-acid storage batteries capable of storing 85 kWh.

The system is a prototype of future photovoltaic systems with two major exceptions. The solar panel supports were designed to be tilted and may be more massive than the fixed supports envisioned in future systems. Also the technology of photovoltaic cells is advancing towards cells which are thinner and more efficient.

The materials requirements were assessed for 13 alternative photovoltaic cell designs. The solar cells examined in this study include:

- CdS/Cu₂S Cells: Backwall and Frontwall
- CdS Heterojunctions with CdTe, InP, CuInSe₂
- Cu₂O Cells
- Si Cells: n/p, MIS, Heterojunctions with In_{2-x}Sn_xO₃ and SnO₂, and amorphous devices
- GaAs Cells: Ga_{1-x}Al_xAs/GaAs, MIS

Material requirements for each cell are based upon current research and the technology projected for 1985 and later. That is, layer thickness and efficiencies assumed were those thought to be practically achievable in the 1985 to 2000 time frame. Details of the cell characterizations and material requirements along with current research references are contained in Appendix B.

Each of the 13 different cells were incorporated into the MIT-LL design. An assumed geometric packing factor of 0.8 and the projected practical cell efficiency were used to determine the required solar cell panel area for 25 kW peak output. Thus, each solar cell panel array, when married to the remaining MIT-LL system, becomes a distinct photovoltaic system of its own.

In addition, two concentrating arrays and their resulting systems were characterized:

- $\text{Ga}_{1-x}\text{Al}_x\text{As}/\text{GaAs}$ -500X - Fresnel Lens
- Si n/p Single Crystal - 30X - Parabolic Trough

In all, a total of 15 distinct systems were built up from the basic MIT-LL system and the 13 cell types and the two concentrators. The material requirements for these systems were determined in detail and entered on the computer data base used in this study. The 15 system identifications and their short titles used in this report are listed in Table A.2. For each system, the complete characterizations, material requirements, and assumptions are given in Appendix C.

REFERENCE DESIGNS METHODOLOGY

It is important to draw a distinction between the reference system designs studied in this work and generic system designs. Generic systems are usually not representative of a real system, and may represent an "average" of several selected systems. Generic systems are often used in estimating material requirements for mature technologies, where the implementation scenario is well established and stable. If the technology changes, then the implementation scenarios changes, and the generic system

no longer represents the "average" system. The complete material count must be done on a redefined generic system. A more convenient method of updating material requirements is needed under changing technology and scenarios, as is the case with solar energy. The reference system methodology facilitates updating.

For photovoltaics, the MIT-LL designed system at Mead, Nebraska, was selected with the aid of DOE staff as a reference system. It is a real system with references to engineering drawings and specifications and with known performance. System components are compatible in size, performance, cost, corrosion resistance, etc. A detailed list of material requirements was established for the system, as well as the 13 photovoltaic cell types selected to cover the range of plausible future cells, and the two concentrators.

Total material requirements for a photovoltaic scenario can then be obtained simply by selecting the total installed capacity of photovoltaics and the mix of cell types.

Not all photovoltaic cell or system variations were included. Additional cells, residential systems, utility systems, etc., can be added in the future without disturbing the material requirements for the existing designs in the data base. They will merely supplement previous data already in place.

Most solar system designs will never wholly be replaced; but they will be modified, evolving as improvements are made in performance and cost. These improvements are likely to come at the component level. Updating of material requirements will be facilitated by having materials systematically accounted for, component by component, as is illustrated in Table 1.

TABLE 1. Materials Categories by Functional
Component for Photovoltaics

12. (a) <u>Energy Collector</u>	15. <u>Energy Storage</u>
12.02 Encapsulant	15.01 Miscellaneous
12.03 Absorber - Solar Cell	15.02 Primary Storage
12.04 Energy Transport	15.03 Secondary Storage
12.06 Concentrator	15.04 Supports
12.07 Frame, Backing Panel	16. <u>Energy Conditioning</u>
12.09 Support Structure	16.02 Inverter
12.10 Tracking & Controls	17. <u>Energy System Controller</u>
13. <u>Energy Transport</u>	17.01 Miscellaneous
13.02 Electrical Wire	17.02 Meters, Switches, Terminal Boards
13.05 Supports, Conduit	17.03 Supports, Cabinets

(a) The numbering system here is taken from a larger list of functional components for solar technology. Numbers not appearing in this table represent functions that apply to solar technologies other than photovoltaics.

Each component is identified separately, according to general function. As components are significantly altered or eliminated by design, the data bank can be updated by simply removing the data for the old component and entering data for the new component. Hence, the effects of gradual changes of design on materials requirements can be monitored continuously with little effort.

In a similar manner, variations in a system design can be studied by substituting individual components (e.g., aluminum for copper wiring) or by substituting complete subsystems (e.g., one cell type for another as was done in this study).

CHARACTERIZATION OF REFERENCE DESIGNS

Detailed characterizations and material requirements of the reference photovoltaic system designs are in Appendix C. Drawings and data for the basic MIT-LL system were courteously supplied by Lincoln Laboratory.

A "component takeoff" was done first. Then, each component was broken down into its materials of construction using drawings and bills of material from the component designer or manufacturer. In cases where drawings and bills of material were not available, schematics, component descriptions, sales literature, and verbal contact with the manufacturer substituted adequately for detailed design drawings. Accuracy of material quantities is generally within 10%. Exact engineering materials or alloys of construction are listed where available.

The engineering alloys are converted within the computer program into their bulk material components using a transformation matrix which contains the actual alloy composition. For example, 60-40 solder is composed of 63% tin and 37% lead.

Material requirements for the two concentrating arrays were estimated from data developed for costing purposes by the General Electric Company Valley Forge Space Center. The resulting material requirements data closely approach those obtained from a full "component takeoff" and material breakdown.

Photovoltaic cell material requirements were established for reference designs which were based on a survey of current technology trends and the anticipated technology in the 1985 to 2000 time frame.

The information necessary for computation of the material required for use of a given photovoltaic device includes:

- a reference design for the construction and operation of the device
- an estimated efficiency for the device fabrication process, assumed to be 100% in this study.

A reference design consists of a drawing of a cell construction, the thickness and percent area coverage of each layer of the cell, the concentration of sunlight with which the cell is expected to be operated, and the conversion efficiency of the cells under the expected operating conditions. Fabrication process efficiency includes the utilization of material during either crystal growth or thin film deposition, the estimated efficiency of material recovery, and also the production yield of devices meeting electrical output specifications.

Given the above reference design and fabrication process efficiency, the quantity of each element used in each layer of a cell can be calculated per unit power output from the following single expression.

$$\text{Element Quantity} = \frac{C (\text{Layer Thickness})(\text{Area Coverage})(\text{Power Output})}{(\text{Solar Insolation})(\text{Conversion Efficiency})(\text{Concentration Factor})(\text{Process Efficiency})} \quad (1)$$

where C is a constant which depends on the atomic number of the element, the density and molecular number of the compound containing the element, and the units chosen for the computation. The solar insolation value used for all calculations in this study is the Air Mass 1 (AM1) or peak insolation value of 1 kWm^{-2} . The material requirements calculated on the basis of a

yearly average insolation are generally 4 to 7 times higher than the peak values, depending on geographic location and the prevailing atmospheric conditions. More specific information concerning the reference design parameters is given in Appendix B.

IV. MATERIALS REQUIREMENTS

The utilization of solar energy will require large quantities of materials. Tables 2 and 3 list the bulk materials and raw materials required to construct photovoltaic systems totaling 50 GW peak electrical output. Material requirements are listed for each photovoltaic system at 50 GWe as well as the material requirements for the 50 GWe combined scenario, (each photovoltaic system at 3.33 GWe totaling 50 GWe for 15 systems).

The raw material requirements listed are those required to produce the bulk material requirements listed.

In terms of sheer quantities, the largest bulk material requirements are for iron and steel, aluminum, copper, the most universally used materials in solar systems, and lead. Conversely, other materials such as the photovoltaic cell materials are used in only one or two systems and in small quantities.

The magnitude of use of a material is not important in itself. However, the relationship of material use to availability is important along with a host of other factors such as: cost, import pattern, production growth rate required to meet solar demand, and the extent of known reserves and resources. The object of this report is to address these factors and to assess their influence on the orderly and timely construction of solar energy systems to meet our national energy goals.

The following sections discuss the specific approach used in addressing those questions and the results of the study.

TABLE 2. Bulk Material Requirements in Metric Tons for Photovoltaic Systems at 50 GWe. Individual Systems at 50 GWe and Mixed Systems Scenario - All 15 Systems at 3.37 GWe Each Totaling 50 GWe.

Materials	Amorphous Silicon	Cad Sulfide/ Cd Tellur.	Cadmium Sulfide/ CU-IN-Se	Cad/Cu Sulfide/ Backwall	Cad/Cu Sulfide/ Frontwall	Cad Sulfide/ Indium Phos.	Copper Oxide MIS
Aluminum	17,821,626	17,821,626	17,821,626	17,821,884	17,821,626	17,821,626	17,821,626
Antimony	119,700	119,700	119,700	119,700	119,700	119,700	119,700
Arsenic							
Boron							
Cadmium		4,360	3,760	2,900	37,460	3,180	
Cement	17,058,720	17,058,720	17,058,720	17,058,720	17,058,720	17,058,720	17,058,720
Chromium	7,500	40		40		40	
Copper	1,379,190	1,387,910	1,387,570	1,384,870	1,424,690	1,387,910	1,423,810
Gallium							
Germanium							
Glass, Fiber	1,796,000	1,796,000	1,796,000	1,796,000	1,796,000	1,796,000	1,796,000
Glass, Soda Lime	1,360	4,881,360	4,881,360	4,881,360	1,360	4,881,360	1,360
Gold			4,840			3,660	
Indium		560	990			2,160	
Iron, Steel	12,747,030	11,231,966	11,231,945	11,231,966	11,231,945	11,231,966	12,718,970
Lead	5,074,514	5,074,514	5,074,514	5,084,114	5,074,514	5,074,514	5,074,514
Magnesium	167,479	167,479	167,479	167,479	167,479	167,479	167,479
Ferromanganese	71,891	62,915	62,915	62,915	62,915	62,915	71,891
Molybdenum							
Nickel	3,960	2,020		120		120	
Palladium							
Phosphorous	0					440	
Platinum	60						
Porcelain	680	680	680	680	680	680	680
Sand, Gravel	35,335,920	35,335,920	35,335,920	35,355,920	35,335,920	35,335,920	35,335,920
Stone	69,453,360	69,453,360	69,453,360	69,453,360	69,453,360	49,453,360	49,453,360
Selenium							
Silicon	126,988			125,728	125,728	125,728	125,728
Silver							
Sulfur				1,300	10,920	920	
Sulfuric Acid	1,452,000			1,452,000	1,452,000	1,452,000	1,452,000
Tantalum							
Tellurium		1,320					
Tin	17,867	17,867		18,687	17,867	17,897	17,867
Titanium							
Zinc	1,360	1,360	1,360	1,360	3,120	1,500	1,360
Stainless Steel	1,790,740	1,790,740	1,790,740	1,790,740	1,790,740	1,790,740	1,790,740
Ferrochrome	58,618	58,618	58,618	32,550	58,618	58,618	58,618
Lindseed oil	6,800	6,800	6,800	6,800	6,800	6,800	6,800
Acrylic	143,800	143,800	143,800	143,800	143,800	143,800	143,800
Alkyd Resin	13,600		13,600	13,600	13,600	13,600	13,600
Epoxy Resin	1,814	1,814	1,814	1,814	1,814		1,814
Epoxy-Fiber	480	480	480	480	480	2,294	480
Calcium	86,280	86,280	86,280	86,280	86,280	86,280	86,280
Glue	20,120	20,120	20,120	20,120	20,120	20,120	20,120
Lumber Softwood	985,880	985,880	985,880	985,880	985,880	985,880	985,880
Phenolic Resin	31,766	31,766	31,766	31,766	31,766	31,766	31,766
Plastic, Resin	18,800	18,800	18,800	18,800	18,800	18,800	18,800
Polyester Resin	8,160	8,160	8,160	8,160	8,160	8,160	8,160
Pvc Plastic	18,780	18,780	18,780	18,780	18,780	18,780	18,780
Rubber, SBR	29,980	29,980	29,980	29,980	29,980	29,980	29,980
Silicones							
Teflon	3,900	3,900	3,900	3,900	3,900	3,900	3,900
Nylon	600	600	600	600	600	600	600
Polypropylene	414,000	414,000	414,000	414,000	414,000	414,000	414,000
Cotton Fibers	641	641	641	641	641	641	641
Kraft Fibers	275	275	275	275	275	275	275
Tung Oil	20,400	20,400	20,400	20,400	20,400	20,400	20,400
Neoprene							
EVA	299,200	299,200	299,200	299,200	299,200	299,200	299,200
ABS							
Aluminum Oxide							
Total	166,591,839	214,060,741	168,357,363	169,955,737	165,150,638	169,952,615	166,595,619

	GAAS	Gallium	Indium	Silicon	SI N/P	SI 1 X TL	Tin	50
GAAS 1 XTL Heterojunct.	1 XTL-500X Fresnel	Arsenide Mis	Tin Oxide/ P-Si	Mis	1 XTL 14 Percent	-30X Para Trough	Oxidelln -Silicon	Million M ² Mixed Scenarios
10,010,001	7,718,001	17,821,626	17,828,726	17,828,384	12,812,513	8,312,901	17,828,726	15,645,196
119,700	119,700	119,700	119,700	119,700	119,700	119,700	119,700	119,580
95,720	479	1,380						6,499
			0	0	0	0	0	0
								3,441
9,565,920	2,260,720	17,058,720	17,058,720	17,058,720	12,242,720	15,042,720	17,058,720	15,102,084
				20				509
942,330	1,653,960	1,379,190	1,378,070	1,379,190	1,009,336	1,819,560	1,378,070	1,385,657
89,040	446	1,280						6,045
2	0	66,500						4,429
1,796,000	1,796,000	1,796,000	1,796,000	1,796,000	1,796,000	1,796,000	1,796,000	1,794,204
1,569,940	1,360	4,881,360	1,360	1,360	1,360	145,360	1,360	1,740,457
2,140	9	60						713
	140		1,140					332
11,203,040	20,622,916	11,231,945	12,718,970	12,718,970	11,745,923	15,965,223	10,645,485	12,552,651
5,069,844	5,076,600	5,074,514	5,074,514	5,074,514	5,071,494	5,072,174	5,074,514	5,069,549
93,000		167,479	167,479	167,479	119,585		167,479	136,853
62,741	119,766	62,915	71,891	71,891	66,018	91,707	59,375	70,907
	120							8
	20							416
					4	0		0
					0	0	0	29
								4
680	680	680	680	680	680	680	680	679
19,815,118	4,682,920	35,335,920	35,335,920	35,335,920	25,359,920	31,159,918	35,335,920	31,282,882
38,946,956	9,204,360	69,453,360	69,453,360	69,453,360	49,845,360	61,245,364	69,453,360	61,487,060
								91
81,040	27,140	125,728	183,728	183,728	263,491	40,830	183,728	131,253
					940	74		68
								1,008
1,452,000	1,452,000	1,452,000	1,452,000	1,452,000	1,452,000	1,452,000	1,452,000	1,450,548
		180			240	19		29
								88
17,916	21,420	32,227	17,927	17,867	12,726	14,766	18,687	18,614
44	0				3	0		3
1,560	1,360	1,360	1,360	1,360	1,360	3,060	1,360	1,612
1,332,880	1,061,800	1,790,740	1,790,740	1,790,740	1,496,120	942,800	1,790,740	1,633,814
32,550		58,618	58,618	58,618	41,855		58,618	47,899
6,800	6,800	6,800		6,800	6,800	6,800	6,800	6,793
106,000	1,472,000	143,800		143,800	133,000	106,000	143,800	226,360
13,600	13,600	13,600	13,600	13,600	13,600	13,600	13,600	13,586
1,814	1,841	1,841	1,841	1,841	1,841	1,841	1,841	1,691
480	480	480	480	480	480	480	480	600
86,280	86,280	86,280	86,280	86,280	86,280	86,280	86,280	86,194
20,120	20,120	20,120	20,120	20,120	20,120	20,120	20,120	20,100
985,880	985,880	985,880	985,880	985,880	985,800	985,880	985,880	984,894
31,766	37,766	31,766	31,766	31,766	31,766	37,766	31,766	32,533
17,700	19,020	18,800	18,800	18,800	18,800	18,480	18,800	18,701
8,160	8,160	8,160	8,160	8,160	8,160	8,160	8,160	8,152
12,280	21,200	18,780	18,780	18,780	13,440	651,600	18,780	60,280
16,580	416,000	29,980	29,980	29,980	21,380	41,380	29,980	54,953
						28,400		1,891
2,180	4,700	3,900	3,900	3,900	2,800	5,400	3,900	3,891
340	720	600	600	600	420	420	600	566
414,000	414,000	414,000	414,000	414,000	414,000	425,000	414,000	414,319
641	641	641	641	641	641	641	641	641
275	275	275	275	275	275	275	275	275
20,400	20,400	20,400	20,400	20,400	20,400	20,400	20,400	20,380
		299,200	299,200	299,200	214,000	100,000		6,660
							299,200	233,446
	2,224,000							148,118
	8,740							582
104,045,458	61,584,513	170,018,758	166,465,579	166,615,777	125,543,404	145,782,752	164,529,798	152,040,787

TABLE 3. Raw Material Requirements in Thousands of Metric Tons for Photovoltaic Systems. Individual Systems at 50 GWe and Mixed System Scenario - All 15 Systems at 3.37 GWe Each, Totaling 50 GWe.

Materials	Amorphous Silicon	Cad Sulfide/ Cad Tellur.	Cadmium Sulfide/ CU-IN-SE	Cad/Cu Sulfide Backwall	Cad/Cu Sulfide Frontwall	Cad Sulfide/ Indium Phos.	Copper Oxide MIS	GAAS 1 XTL Heterojunct.
Antimony Ore	12,596	12,596	12,569	12,569	12,569	12,569	12,569	12,569
Arsenic Trioxide								153
Asbestos	5	5	5	5	5	5	5	5
Bauxite	90,991	90,988	90,991	90,988	90,987	90,990	90,991	51,538
Borate	449	449	449	449	449	449	449	449
Butane	34	34	34	34	34	34	34	19
Chromite	1,310	1,288	1,288	1,288	1,288	1,288	1,288	931
Clays	2,727	2,711	2,714	2,711	2,711	2,713	2,727	1,594
Coal	60,011	60,354	61,478	60,353	58,321	61,202	59,990	53,658
Coal Bit/lig		2	2	1	12	2		
Copper Ore	303422	305,340	305,265	304,671	313,432	305,340	313,238	207,313
Feldspar	0	454	454	454	0	454	0	146
Fluorspar	1,363	1,350	1,353	1,350	1,351	1,352	1,362	803
Gold Ore			484,000			366,000		214,000
Gypsum	819	819	819	819	819	819	819	459
Iron Ore	82,274	73,732	75,234	73,725	73,816	74,868	82,209	71,633
Lead Ore	168,981	168,981	168,981	169,301	168,981	168,981	168,981	168,826
Lime								
Manganese Ore	415	365	373	365	365	371	414	367
Molybdenum Ore								
Natural Gas	2,379	2,365	2,819	2,362	2,402	2,709	2,401	1,530
Nickel Ore	14,722	14,528	14,326	14,338	14,326	14,338	14,326	10,663
Nitrogen Fixed	1	1	1	1	1	1	1	1
Petroleum	2,307	2,253	2,405	2,253	2,254	2,368	2,307	1,521
Phosphate Rock	0					5		
Propane	879	879	879	879	879	878	879	547
Rutile								0
Salt	62,652	66,339	68,771	66,320	62,637	68,154	62,614	49,944
Sand/Gravel	40,015	43,222	43,222	43,222	40,011	43,222	40,012	24,499
Silver Ore								
Stone	69,453	69,453	60,453	69,453	69,453	69,453	69,453	38,947
Sulfur	5,055	5,072	5,095	5,065	5,171	5,096	5,056	3,136
Tantalum Ore								
Tin Ore	178,668	178,968	178,668	186,868	178,668	1,788,968	178,668	179,162
Zinc Ore	532	1,404	2,232	1,113	8,055	1,888	532	954
Cotton	1	1	1	1	1	1	1	1
Flax Seed	20	20	20	20	20	20	20	20
Milk By-products	2	2	2	2	2	2	2	2
Lumber	1,043	1,042	1,042	1,042	1,042	1,042	1,043	1,027
Sea Water	125,964	125,964	125,964	125,974	125,974	125,964	125,964	72,268
Soybean	39	39	39	39	39	39	39	39
Tung Nuts	41	41	41	41	41	41	41	41
Water	37,751	37,977	82,155	37,957	37,862	71,382	37,942	54,324
Wheat	6	6	6	6	6	6	6	6
Misc.	643	631	872	629	641	813	654	583
Steam	463,192	462,534	465,288	462,537	461,545	464,583	463,178	301,980
Limestone	83,171	86,139	94,171	86,137	82,391	92,203	83,159	155,831
Cu Anode Slimes								
Bauxite byprod.								4,452,001
Zinc byprod.		3,136	5,488			12,096		17
Coal byprod.	189,514	189,514	189,514	189,514	189,514	188,624	189,514	186,373
Electricity		2,232,330	1,925,136	1,484,800	19,179,520	1,628,196		
Cu byprod. 1		10,560	2,720					
Cu byprod. 2	59,399,996							
Zinc byprod. 3								17
Zinc byprod. 2								17
TOTAL (a)	1,813,933	1,818,348	2,363,481	1,825,342	1,818,515	3,840,613	1,823,374	1,681,489

a. Not including byproducts and electricity.

GAAS 1 XTL-500X Fresnel	Gallium Arsenide MIS	Indium Tin Oxide/P-Si	Silicon MIS	SI N/P 1 XTL 14 Percent	SI 1 XTL-30X Para Trough	Tin Oxide In-Silicon	50 Million M ² Mixed Scenarios
12,569	12,569	12,569	12,569	12,569	12,569	12,569	12,556
1	2						10
5	6	5	5	4	4	5	5
40,011	90,987	91,028	91,025	65,692	42,980	91,021	80,001
449	449	449	449	449	449	449	449
462	34	34	34	24	46	34	61
677	1,326	1,288	1,288	1,058	602	1,288	1,165
616	2,714	2,727	2,727	1,997	2,413	2,705	2,432
46,627	66,629	60,056	60,056	47,940	44,149	57,729	57,180
6		1			15,000		1,001
363,871	303,422	303,175	303,422	241,854	400,491	303,175	304,857
0	454	0	0	0	14	0	162
742	1,352	1,363	1,363	1,004	730	1,346	1,210
880	6,000						71,321
109	819	819	819	588	722	819	725
124,766	74,128	82,109	82,112	74,965	98,470	70,394	80,881
169,051	168,981	168,981	168,981	168,881	168,903	168,981	168,816
0							0
674	477	414	414	382	521	346	417
90							6
1,618	2,468	2,378	2,378	1,809	2,225	2,347	2,277
8,496	14,326	14,326	14,326	11,969	7,542	14,326	13,112
1	1	1	1	1	1	1	1
33,147	2,257	2,307	2,307	1,762	1,470	2,233	4,206
				0	0	0	0
1,722	881	879	879	787	560	879	885
0				0	0		0
37,154	70,693	62,638	62,634	47,654	35,240	62,632	59,013
7,502	44,126	40,136	40,136	29,734	34,722	40,134	36,891
				6,699	526		481
9,204	69,453	69,453	69,453	49,845	61,245	69,453	61,487
3,095	11,706	5,065	5,057	3,840	2,681	5,057	5,011
	67			89	7		11
214,200	322,268	179,268	178,668	127,260	147,660	186,868	1,364
534	543	532	532	535	562	532	1,364
1	1	1	1	1	1	1	1
20	20	20	20	20	20	20	20
2	2	2	2	2	2	2	2
1,018	1,042	1,043	1,043	1,033	1,014	1,042	1,036
5,214	125,964	125,964	125,964	91,430	5,209	125,964	103,878
39	39	39	39	39	39	39	39
41	41	41	41	41	41	41	41
74,030	46,281	37,727	37,732	34,640	36,989	37,559	46,771
6	6	6	6	6	6	6	6
752	1,136	641	641	535	759	622	703
232,096	467,940	463,351	463,343	341,420	237,965	461,012	413,717
42,017	88,138	83,167	83,166	63,401	60,009	82,072	84,260
				1,990	156		143
22,311	64,000						302,252
784	576,356	6,384					40,244
1,482,876	189,514	189,514	189,514	187,903	194,769	189,514	275,437
166,627		19					1,772,667
							884
							3,956,040
0	567,356						38,386
0	576,289						38,382
1,433,497	1,999,748	1,814,003	1,813,633	1,431,959	1,424,558	1,803,703	1,804,604

V. METHODS, MODELS, AND ASSUMPTIONS USED TO IDENTIFY POTENTIAL MATERIALS CONSTRAINTS

One usually thinks of the flow of materials proceeding from raw materials to the engineering materials (Figure 2). Take, for example, copper. Copper ore is mined and sent to a mill and smelter. The bulk material copper that leaves this process may be formed into an engineering material like brass. This brass may then be incorporated into a solar device. The tracking process used by the critical materials assessment model follows the opposition direction. First, the amount of brass in the solar device is characterized. Then this engineering material is translated into its bulk materials one of which is copper. At this point, the bulk material copper would be reviewed for possible capacity constraints. Next, the copper would be translated into its raw materials, copper ore, asbestos, clays, coal, fluorspar, etc. The copper ore and all of the other raw materials are then checked for potential capacity constraints and for availability of reserves and resources.

THE MATERIALS CYCLE

FIGURE 2. The Materials Cycle

This process of tracking the materials and examining their use for potential constraints involves large quantities of data and consequent arithmetic. Thus, much of the methodology was organized and placed on an interactive computer system.

That part of the methodology which was placed on the computer includes all of the steps down to and including those steps labeled screening in Figure 3. Figure 4 shows the flexibility which resulted from making the program interactive. The top blocks of user supplied input is all available to change at the terminal, while the cases are being examined. The bottom left block lists material which is entered by card deck. Of course, this material can also be updated periodically, but cannot be changed at the terminal.

The specific questions raised by the computer and answered from the stored data base are shown on Figure 5 which highlights the logic of the methodology. The questions raised by the computer are reviewed subsequently in a manual process where materials are classified as "A", "B", or "C" materials.

"A" materials are those materials regarded as causing possible constraints in the large scale implementation of particular solar designs and thus requiring further review. "B" materials are those that exceed some threshold levels, but also show by the printed data that they are not likely to present a serious constraint to future deployment. An example is antimony. It is largely imported and is derived as a byproduct, but it is used in such small quantities that it is unlikely to be a serious problem. Thus, it is classified as a "B" material. "A" materials on the other hand, require further study using data not supplied in the computer printout and may in fact require a mitigating strategy to avoid serious constraints in future solar systems construction schedules. "C" materials are those materials that do not exceed any of the threshold levels and are not expected to present future material constraints.

These threshold levels may be changed at any time from the computer terminal. The threshold values used for this study are shown in Table 4 for bulk materials and Table 5 for raw materials. Following the tables, the sensitivity of the study to the major assumptions is discussed.

FIGURE 3. Flow Chart of Materials Assessment Methodology

FIGURE 4. Interactive Screening System

FIGURE 5. Assessment of Potential Materials Problems

TABLE 4. Bulk Material Threshold Criteria

<u>Factor</u>	<u>Value Selected</u>	<u>Reason Selected</u>
Percent supplied as a byproduct	50%	If a large percentage of normal supply is derived as a by-product, it may be extremely difficult to expand production. In our judgment, when 50% of normal supplies are dependent on the production of a primary material, ones ability to expand production significantly is uncertain.
Percent of current consumption that is imported	50%	When a large percentage of a material originates outside of the U.S., the uncertainty surrounding future materials prices and availability is increased. Fifty percent of current materials consumption resulting from imports may not represent a problem if all imports do not originate in a few countries. However, the 50% level was selected as a general level of concern.
Percent of world consumption supplied by the largest supplier country outside of the U.S.	35%	Price leadership and the possibilities of cartels and geopolitical problems are important when approximately 35% of current supply originates in a single non-U.S. supplier.
Production growth rate necessary to meet forecasted world consumption and solar requirements	10%	A sustained compound growth rate of 10% per year is unusual for most bulk material production processes and frequently puts severe pressures on capital, labor, and the environment.
The largest single year market share consumed by solar over the period of the development plan (solar's % of world's consumption)	10%	When a single consumer of a material represents 10% of world consumption, the possibility exists to significantly influence market prices.
The contributions to capital costs per unit of peak power	\$50/GWe	\$50/GWe would represent about 5% of the selling price of a typical system.

TABLE 5. Raw Material Threshold Criteria

Factor	Value Selected	Reason Selected
Percent of current consumption that is imported	50%	When a large percentage of a material originates outside of the U.S., the uncertainty surrounding future materials prices and availability is increased. Fifty percent of current materials consumption resulting from imports may not represent a problem if all imports do not originate in a few countries. However, the 50% level was selected as a general level of concern.
Percent of world consumption supplied by the largest supplier country outside of the U.S.	60%	Raw materials suppliers tend to be larger and, therefore, control a larger percentage of the market than bulk material suppliers. When a single supplier controls 60% of world consumption, raw materials availability is a potential problem.
Production growth rate necessary to meet forecasted world consumption and solar requirements	7%	The time required to develop raw material supplies is from 5-20 years and a 7% compound growth rate appears to be an appropriate level of concern.
Largest single year market share consumed by solar over the period of the solar development plan	10%	When a single consumer of a material represents 10% of world consumption, the possibility exists to significantly influence market prices.
Percent of the world reserves that will be consumed by the year 2000	300%	A frequently used rule of thumb for appropriate reserve margins is 10 years at current consumption. With respect to using world reserves, we anticipate possible problems if we wish to consume 3 times known reserves over the next 20 years. This represents planned consumption of 300% of known world reserves.
Percent of the U.S. reserves that will be consumed by the year 2000	400%	Because U.S. reserves are much more certain, extensive use of reserves, up to 4 times the currently known reserves, may not be a problem.

TABLE 5. (Continued)

Factor	Value Selected	Reason Selected
Percent of world resources that will be consumed by the year 2000	200%	The definition of resources includes presently uneconomic deposits and, therefore, consumption of a larger percentage may be a problem. A reasonable estimate appears to be in the range of 200%. Thus, if we plan on consumption of 2 times currently known resources we anticipate raw material availability problems.
Percent of U.S. resources that will be consumed by the year 2000	300%	U.S. resources have less uncertainty than do world resources. We estimate that up to 3 times currently known deposits can be consumed by 2000.
The contribution to capital costs of raw materials per unit of peak power	\$50/GWe	\$50/GWe would represent about 5% of the selling price of a typical system.

THE EFFECTS OF THE ASSUMPTIONS MADE IN THE STUDY

A major part of the study centers around the assumption that 50 GWe will be installed for a given design by the year 2000. Both the total quantity and the rate at which installation occurs are important for specific criteria.

The rates at which various technologies will be installed in the future is, of course, unknown; however, a number of studies have examined past technology diffusion rates and some things are foreseeable. Technologies are unlikely to be installed in a uniform manner (constant rate) for a sustained period. They are more likely to be described by an "S" shaped curve. This study assumes the year 2000 as the end point of the study and we felt that most solar technologies could better be described by an exponential growth curve which approximates the first part of an "S" curve (Figure 6).

For the exponential curve chosen, the maximum installation rate in a single year is about 15% of the total, assuming a starting date of 1985. This is, of course, about 2.5 times the rate which would be encountered if a uniform rate of installation were assumed. We feel that the analysis resulting is properly more conservative than a uniform rate would entail and yet doesn't unduly penalize the technology. In practical terms you can't start a business at full speed instantly and on the other hand, we shouldn't assume a scenario which is so severe on a single year that this alone causes a shock to materials supply chains which could actually limit the solar installations.

FIGURE 6. Growth Curves for Solar Systems Deployment.
Exponential growth assumed in this study.

The selection of the threshold levels for the screening criteria used in the computer model are very important in determining which materials are selected for further review. The threshold levels may be changed at any time by the user at the computer terminal.

VI. RESULTS AND RECOMMENDATIONS

A total of 15 photovoltaic systems which includes 13 cell designs and 2 concentrating arrays were screened by the computer, and many systems were found to be astonishingly free of serious probable future material constraints. Seven systems have no serious potential constraints at the level of 50 GWe installed by the year 2000.

The screening was carried out individually at 10 GWe and 50 GWe of each system design. The results of the screening are shown in Table 7 and are discussed in detail in the following pages for both 10 GWe and 50 GWe installed by the year 2000 for each system and for 50 GWe and 100 GWe of mixed systems.

An "A" material as used in this report is a material that is considered to need further investigation (beyond the computer analysis) to determine possible availability and/or cost constraints. "A" materials are not necessarily serious problems. Flags raised by the computer program under the headings of: solars percent of world consumption, or \$/kW for a material usually indicates a problem worthy of further review. The "A" materials are listed according to function in Table 6; and they are individually discussed in the section review of "A" materials.

A "B" material, as used in this report, is a material that usually exceeds at least one threshold level in the computer program, but it is used in small quantities and/or at a low cost. However, "B" materials should be monitored closely since some "B" materials could conceivably become (due to design changes etc.) problems in the future. A detailed discussion of "B" materials follows the "A" material discussion.

TABLE 6. "A" Materials in Photovoltaic Systems Studied

<u>Cell Materials</u>	<u>Structural Support</u>
Arsenic	Aluminum
Cadmium	Iron and Steel
Gallium	
Germanium	<u>Storage Batteries</u>
Gold	Lead
Indium	Antimony (at
Tellurium	100 GWe mixed scenario Only)

"A" Materials Which are a Potential Problem for All Systems

Aluminum, iron and steel, and lead were potential problems in all 15 of the systems studied, because of excessive cost. Typical values were: Aluminum \$350/kW, iron and steel \$77/kW, and Lead \$56/kW. Aluminum and iron and steel strictly structural or support materials and it is likely that they can be reduced in usage in the design or substitutes will be found. Since the reference system (the actual Mead, Nebraska design) we examined was designed as a technical demonstration, it seems likely that the structural materials can be reduced through design improvements to eliminate these constraints.

Lead and antimony are used as an energy storage material in the batteries. Many contemporary systems are being designed without energy storage and thus, lead and antimony are not judged to be a serious material constraint for these systems. Any system which uses energy storage should be reviewed carefully for possible future material constraints. Table 7 lists the "A" materials across the top of the page and the designs and variations in the designs down the left hand side of the page. An entry of "8" under indium for the Cd S/Cd Te design indicates two things: 1) that indium is an "A" material in the Cd S/Cd Te design,

TABLE 7. "A" Materials Identified for 15 Photovoltaic Systems and Variations(a)

System Number	Materials										Iron and Steel	Lead	Total No. of "A" Materials Included
	Antimony	Arsenic	Cadmium	Gallium	Germanium	Gold	Indium	Tellurium	Aluminum				
1. Amorphous Silicon									7	1.75	1.1	3	
2. Cd S/Cd Te							8	5	7	1.5	1.1	5	
3. Cd S/Cu In Se						10	14		7	1.5	1.1	5	
4. Cd/Cu S Backwall									7	1.5	1.1	3	
5. Cd/Cu S Front Wall			1.43 ^(a)						7	1.5	1.1	4	
6. Cd S In Phos						7	30		7	1.5	1.1	5	
7. Cu Oxide MIS									7	1.75	1.1	3	
8. Ga As 1-XTL Heterojunction		3 ^(a)		2600		4			2	1.5	1.1	6	
9. Ga As 1-XTL 500X Fresnel				13			3 ^(a)		3	2.8	1.1	5	
10. Ga As MIS				30	1900				7	1.5	1.1	5	
11. In Tin Oxide/P-Si							16		7	1.5	1.1	4	
12. Silicon MIS									7	1.5	1.1	3	
13. Si N/P 1 XTL 14%									7	1.5	1.1	3	
14. Si 1 XTL - 30X Para Trough									3.3	2.1	1.1	3	
15. Tin Oxide/N Silicon									7	1.5	1.1	3	
NA 50 GWe Mixed Scen. (b)				180	50	3	5		7	1.5	1.1	7	
NA 100 GWe Mixed Scen. (c)	1.7			360	100	3	9		6	1.75	1.1	8	

(a) Numbers indicate the number of times that the "A" materials exceed the most stringent threshold levels in the 50 GWe scenario. * indicates that at 10 GWe by 2000 this would not be an "A" material.

(b) This scenario is made of equal parts of the 15 systems (3.33 GWe per system).

(c) This scenario is made of equal parts of the 15 systems (6.66 GWe per system).

and 2) that the amount of indium used in this design at 50 GWe is eight times the minimum amount required to trigger indium as an "A" material.

In Table 7, the results are shown for system 8 with the energy storage deleted. This was done by making use of the interactive program capability where designs can be altered at the terminal. No other material was eliminated from the "A" materials list for this case by this change except for lead.

A further modification was made to this system (see lower part of Table 7) deleting all material except for that directly associated with the photovoltaic array and its support material. This change eliminated enough iron and steel from the system to let it drop from the "A" material list. Aluminum remained as a potential constraint in this modified design (collector only) because it is used to support the photovoltaic cells. The only alternative here is to reduce the amount of aluminum needed per kilowatt for support purposes.

"A" Material Results at 50 GWe for Individual Systems

The following is a listing of the "A" materials for each system. This list does not include aluminum, iron and steel, or lead discussed above.

- 1) Amorphous silicon
 - None
- 2) Cad sulfide/Cad telluride
 - Indium
 - Tellurium
- 3) Cadmium sulfide/Cu-In-Se
 - Gold
 - Indium
- 4) Cad/Cu sulfide backwall
 - None

- 5) Cad/Cu sulfide Frontwall
 - Cadmium
- 6) Cad sulfide/Indium phosphide
 - Gold
 - Indium
- 7) Copper oxide MIS
 - None
- 8) Ga As 1-XTL heterojunction
 - Arsenic
 - Gallium
 - Gold
- 9) Ga As 1-XTL 500 Fresnel
 - Gallium
 - Indium
- 10) Gallium Arsenide MIS
 - Gallium
 - Germanium
- 11) Indium Tin oxide/p-Si
 - Indium
- 12) Silicon MIS
 - None
- 13) Si N/P 1-XTL 14 percent
 - None
- 14) Si 1-XTL 30 x Para Trough
 - None
- 15) Tin Oxide/N-silicon
 - None

Table 7 also shows the effect of reducing the scenario size from 50 to 10 GWe. In design number 5 (Cd/Cu Sulfide Frontwall), cadmium drops from the "A" material list at 10 GWe. This is reasonable because the amount of cadmium used is only 1.43 times the amount of cadmium required to exceed the threshold at 50 GWe. In design number 8 (Ga as 1-XTL heterojunction), arsenic materials usage is 3 times that needed to exceed the threshold. This number is relatively low, and arsenic is not an "A" material at 10 GWe. The same reasoning applies to indium in design number 9. At 10 GWe indium is not an "A" material. The numbers in Table 7 are included to give the reader a "feeling" for which materials are sensitive to changes in on line capacity. A material such as cadmium in design number 5 will be sensitive to different on line capacities because the materials usage for cadmium in this design at 50 GWe is roughly the same as the minimum materials usage that will trigger cadmium as an "A" material. A material such as gallium in design number 8 will not be sensitive to on line capacity changes. It will be an "A" material regardless of on line capacity because at 50 GWe the materials usage for gallium in this design exceeds the threshold level by 2,600 times.

"A" Material Results at 10 GWe for the Individual Systems

The list of "A" materials for the 10 GWe cases is exactly the same as the list at 50 GWe except that 3 materials (cadmium, arsenic and indium) drop from the list for the reasons given above. Consumption of the "A" materials at 10 GWe is, of course, 1/5 of that shown in Tables 2 and 3 for the 50 GWe case.

The Effects of a Mixed Scenario at 50 GWe and 100 GWe Implementation Levels by the Year 2000

Table 7 also shows the results for the mixed scenario taking 3.333 GWe for each of the 15 designs at the year 2000 for a total of 50 GWe and a similar scenario of 6.666 GWe per design for a total of 100 GWe.

We hypothesized that the mixed case would eliminate many of the materials unique to specific systems from the "A" material list and that it would more nearly represent the "real world" situation where different systems have their own unique market niche. For the mixed scenario at 50 GWe, the usage of each material was low enough to eliminate all of the "A" materials except the structural metals (aluminum, iron and steel), lead, gallium, germanium, gold and indium. In the 100 GWe mixed scenario, antimony is the only addition to the above list. Photovoltaic systems would use 14% of the world antimony consumption for the year 2000. Antimony usage came from the lead acid storage batteries and would not be a problem if the energy storage were deleted.

Summary by System at 50 GWe Each

The following is a list of systems grouped according to the number of "A" materials contained in each. The first group have no serious limitations (i.e., "A" materials) except aluminum, iron and steel, and lead.

- Cad/Cu Sulfide Backwall
- Copper Oxide MIS
- Silicon MIS
- Si n/p 1-XTL 14 percent
- Si 1-XTL 30 x Para Trough
- Tin Oxide/n-Silicon
- Amorphous Silicon

Two systems have one potentially serious material constraint. The material and constraint are listed for both systems.

- Cad/Cu Sulfide Frontwall

1) Cadmium demand reaches 13% of world consumption in the year 2000.

- Indium Tin Oxide/p-Si

- 1) Indium demand reaches 63% of world consumption.

Five systems have a potentially serious constraint for two materials.

- Cad Sulfide/Cad Telluride

- 1) Indium demand reaches 46% of world consumption.
- 2) Tellurium demand reaches 37% of world consumption.

- Cad Sulfide/Cu-In-Se

- 1) The cost of gold is \$460/kW and gold demand reaches 27% of world consumption.
- 2) Indium demand reaches 60% of world consumption.

- Cadmium Sulfide/in Phosphide

- 1) The cost of gold is \$348/kW and gold demand reaches 22% of world consumption.
- 2) Indium demand reaches 76% of world consumption.

- GaAs 1-XTL 500 X Fresnel

- 1) Gallium demand reaches 59% of world consumption.
- 2) Indium demand reaches 17% of world consumption.

- Gallium Arsenide MIS

- 1) Gallium demand reaches 81% of world consumption and has a compounded growth rate of 12%/year.
- 2) Germanium demand reaches 99% of world consumption at a cost of \$415/kW.

One system has potentially serious constraints for three materials.

- GaAs 1-XTL heterojunction

- 1) Arsenic demand reaches 22% of world consumption.
- 2) Gallium demand reaches 100% of world consumption at a cost of \$1227/kW.
- 3) Gold demand reaches 14% of world consumption at a cost of \$203/kW.

"B" Materials in Photovoltaic Systems

The "B" materials, both bulk and raw, in the photovoltaic systems are listed in Tables 8, 9 and 10 for each cell type. Referring to Table 8, both antimony (bulk material) and antimony ore (raw material) were classified as "B" materials (i.e., B/B) in the cad sulfide/cad telluride cell when examined at 50 GWe; thus, an entry of B/B is placed under design number 2 and across from antimony/ore. At the bottom of these tables are the total number of "B" materials for each system. The number of "B" materials ranges from 18 in copper oxide MIS to 28 in Ga As 1-XTL 500X fresnel. Table 11 lists the bulk and raw "B" materials for the 50 GWe combined scenario (each individual photovoltaic system is put on line at 3.33 GWe, for a 15 system total of 50 GWe), 100 GWe combined scenario, design number 8 (gallium arsenide single crystal system) run at 10 GWe, design number 8 run with the energy storage segment deleted, design number 8 run with everything deleted except the collector (photovoltaic array) itself, and for comparison, the design number 8 run at 50 GWe.

Notice in Table 11 that the list of "B" materials for the 50 and 100 GWe cases are very similar. The only difference is antimony which is absent in the 100 GWe case. This is because it has moved from "B" to "A" materials in going from 50 to 100 GWe. Also, the effect of going from 10 GWe to 50 GWe in design number 8 changes only arsenic. It goes from a "B" material at 10 GWe to an "A" material at 50 GWe.

A brief comparison of the collector only design number 8 with the standard case of 50 GWe shows that antimony and copper have disappeared as "B" materials. This is because antimony is not used and copper is used only in small quantities in the collector only design. Deleting the energy storage segment of number 8 drops nothing from the "B" material list except antimony which is used only in the storage batteries.

TABLE 8. Photovoltaic Bulk/Raw "B" Material Table
for Each Cadmium Cell Type at 50 GWe

Material (Bulk/Raw)	Cad Sulfide/Cad Tellurid	Cadmium Sulfide/ Cu-In-Se	Cad/Cu Sulfide Backwall	Cad/Cu Sulfide Frontwall	Cad Sulfide Indium Phos
Design Number	2	3	4	5	6
Antimony/Ore	B/B	B/B	B/B	B/B	B/B
Cadmium/Zinc Byproduct	B/B	B/B	B/		B/
Chromium/Chromite	B/B	B/B	B/B	/B	B/B
Germanium/Zinc Byproduct	/B	/B			/B
Ferromanganese/Ore	B/B	B/B	B/B	B/B	B/B
Nickel/Ore	B/B	B/B	B/B	B/B	B/B
Selenium/Copper Byproduct		B/B			
Tin/Ore	B/B	B/B	B/B	B/B	B/B
Zinc/Ore	B/B	B/B	B/B	B/B	B/B
Ferrochrome/Chromite	B/B	B/B	B/B	B/B	B/B
Tung Oil/Nuts	B/B	B/B	B/B	B/B	B/B
/Asbestos	/B	/B	/B	/B	/B
Copper/Ore	B/B	B/B	B/B	B/B	B/B
/Fluorspar	/B	/B	/B	/B	/B
/Petroleum	<u>/B</u>	<u>/B</u>	<u>/B</u>	<u>/B</u>	<u>/B</u>
Total B Materials for Each System	24	26	22	20	23

B - Signifies a "B" material for that system

A Blank - Signifies either an A material as shown on Table 7 or a C material

TABLE 9. Photovoltaic Bulk/Raw "B" Material Table for
Each Gallium Cell Type at 50 GWe

Material (Bulk/Raw)	Copper Oxide Mis	Ga As 1 XTL Heterojunct	Ga As 1 XTL-500X Fresnel	Gallium Arsenide Mis
Design Number	7	8	9	10
Aluminum/Bauxite		/B	/B	
Antimony/Ore	B/B	B/B	B/B	B/B
Arsenic/Trioxide			B/B	B/B
Chromium/Chromite	/B	/B	/B	/B
Gallium/Bauxite Byproduct			/B	/B
Germanium/Zinc Byproduct		B/B	B/	
Gold/Ore			B/B	B/B
Ferromanganese/Ore	B/B	B/B	B/B	B/B
Nickel/Ore	/B	/B	B/B	/B
Tantolum/Ore				B/B
Tin/Ore	B/B	B/B	B/B	B/B
Titanium/Rutile		B/B	B/B	
Zinc/Ore	B/B	B/B	B/B	B/B
Ferrochrome/Chromite	B/	B/	B/	B/
Tung Oil/Nuts	B/B	B/B	B/B	B/B
/Asbestos	/B	/B	/B	/B
Copper/Ore	B/B	B/B	B/B	B/B
/Fluorspar	/B	/B	/B	/B
/Petroleum	/B	/B	/B	/B
Total B Materials for Each System	18	23	28	25

B - Signifies a "B" material for that system

A Blank - Signifies either an A materials as shown on Table 7 or a C material

TABLE 10. Photovoltaic Bulk/Raw "B" Material Table for
Each Silicon Type Cells at 50 GWe

Material (Bulk/Raw)	Indium Tin Oxide/ P-Si	Silicon MIS	SI N/P 1 XTL 14 Percent	Si N/P XTL-20X Para Trough	Tin Oxide/ N-Silicon	Amorphous Silicon
Design Number	11	12	13	14	15	1
Aluminum/Bauxite				/B		
Antimony/Ore	B/B	B/B	B/B	B/B	B/B	B/B
Boron/Borate	B/	B/	B/	B/		
Chromium/Chromite	/B	B/B	/B	/B	/B	B/B
Germanium/Zinc Byproduct	/B					
Ferromanganese/Ore	B/B	B/B	B/B	B/B	B/B	B/B
Nickel/Ore	/B	/B	/B	/B	/B	B/B
Palladium/Copper Anode Slime			B/B	B/B		
Platinum/Copper Byproducts						B/B
Silver/Ore			B/	B/		
Tantalum/Ore			B/B	B/B		
Tin/Ore	B/B	B/B	B/B	B/B	B/B	B/B
Titanium/Rutile			B/B	B/B		
Zinc/Ore	B/B	B/B	B/B	B/B	B/B	B/B
Ferrochrome/Chromite	B/B	B/B	B/B	B/B	B/B	B/B
/Asbestos	/B	/B	/B	/B	/B	/B
Copper/Ore	B/B	B/B	B/B	B/B	B/B	B/B
/Fluorspar	/B	/B	/B	/B	/B	/B
/Petroleum	/B	/B	/B	/B	/B	/B
Total B Materials for Each System	19	19	25	26	17	21

B - Signifies a "B" material for that system

A Blank - Signifies either an A material as shown in Table 7 or a C material

TABLE 11. Photovoltaic Bulk/Raw "B" Material Table for the Combined Scenarios, Deleted Energy Storage, and Collector Only Systems

Materials (Bulk/Raw)	50 GWe Combined Scenario	100 GWe Combined Scenario	10 GWe Ga As 1-XTL Hetero	Energy Storage Deleted Ga As Hetero	Collector Only Ga As 1-XTL Hetero	Ga As 1-XTL Hetero 50 GWe
Design Number	--	--	8	8	8	8
Aluminum/Bauxite			/B	/B	/B	/B
Antimony/Ore	B/B		B/B			B/B
Arsenic/Trioxide	B/B	B/B	B/B			
Boron/Borate	B/	B/				
Cadmium/Zinc Byproduct	B/	B/				
Chromium/Chromite	B/B	B/B	/B	/B	/B	/B
Germanium/Zinc Byproduct	/B	/B	B/B	B/B	B/B	B/B
Ferromanganese/Ore	B/B	B/B	B/B	B/B	B/B	B/B
Nickel/Ore	B/B	B/B	/B	/B	/B	/B
Palladium/Copper Anode Slime	B/B	B/B				
Platinum/Copper Byproducts	B/B					
Selenium/Copper Byproduct	B/B	B/B				
Silver/Ore	B/	B/				
Tantalum/Ore	B/B	B/B				
Tellurium/	B/	B/				
Tin/Ore	B/B	B/B	B/B	B/B	B/B	B/B
Titanium/Rutile	B/B	B/B	B/B	B/B	B/B	B/B
Zinc/Ore	B/B	B/B	B/B	B/B	B/B	B/B
Ferrochrome/Chromite	B/B	B/B	B/B	B/B	B/B	B/B
/Asbestos	/B	/B	/B	/B	/B	/B
Copper/Ore	B/B	B/B	B/B	B/B	/B	B/B
/Fluorspar	/B	/B	/B	/B	/B	/B
/Petroleum	/B	/B	/B	/B	/B	/B
Total "B" Materials for Each System	36	32	24	20	19	22

B - Signifies a "B" material for that system

A Blank - Signifies either an A material as shown on Table 7 or a C material

Tables 12 and 13 help to explain why some of the materials are "B" materials. The materials have been separated into two tables (one for bulk materials and one for raw) because of the different screening criteria applied to each group. An "X" in any column for a particular materials means that the material has exceeded the set threshold level. For example, look at antimony in Table 12. Antimony is 100% supplied as a byproduct so an "X" is placed in that column because the threshold level of 50% has been exceeded. The last column in the table (number of individual photovoltaic systems that contain each "B" material) gives the reader an idea about how widespread the problem may be; whether it is system specific or whether it is a problem in all of the designs.

Some of the bulk materials are automatically triggered as "B" materials if any of the following screening criteria have been exceeded: percent supplied as a byproduct, percent from the largest country, or net percent imported. These criteria say:

1. More than 50% of the supply comes as a byproduct whose production is limited by the production rate of the principal product, or
2. More than 35% is produced by a single foreign country, or
3. More than 50% of the U.S. supply is imported.

If the dollars per kilowatt or solar's percent of world consumption threshold levels have also been exceeded, then the material is an "A" material. This means that a material will be a "B" material if its metric ton usage is less than 10% of world year 2000 consumption and less than \$50 per kilowatt.

Since the solar share of world consumption is low for each "B" material, the material will be available in the quantities required by solar even if the total U.S. supply is limited severely by cartels, political action or decrease in production. Under conditions of limited supply and hence, increased competition

TABLE 12. Criteria Exceeded by "B" Bulk Materials
in the Photovoltaic Systems for the 50 GWe
Combined Scenario.

Materials	Percent Supplied as a Byproduct	Percent from the Largest Country	Net Percent Imported	Number of Individual P.V. Systems that Contain Each "B" Material
Antimony	X		X	15
Arsenic	X			2
Boron		X		4
Cadmium	X		X	4
Chromium			X	6
Ferromanganese	X		X	15
Nickel			X	6
Palladium	X		X	2
Platinum	X	X	X	1
Selenium	X	X	X	1
Silver				2
Tantalum	X	X	X	3
Tellurium	X			0 ^(a)
Tin			X	15
Titanium		X	X	4
Zinc			X	15
Ferrochrome			X	12
Copper	Rule of reason: (\$37/kW, 45% imported)			15

(a) It is encountered only as an "A" material in the individual systems.

TABLE 13. Criteria Exceed by "B" Raw Materials
in the Photovoltaic Systems For the
50 GWe Combined Scenario

Materials	CRITERIA				Number of Individual P.V. Systems that Contain each "B" Material
	Percent U.S. Reserves Consumed by 2000	Percent U.S. Resources Consumed by 2000	Percent From the Largest Foreign Country	Net Percent Imported	
Antimony Ore	X	X		X	15
Arsenic Trioxide				X	2
Asbestos	X			X	15
Chromite				X	15
Copper Ore	X	X			15
Fluorospars	X			X	15
Manganese Ore				X	15
Nickel Ore	X	X		X	15
Petroleum	X				15
Rutile			X	X	4
Tantalum Ore		X		X	3
Tin Ore	X	X		X	15
Zinc Ore				X	15
Zinc Byproduct				X	5

for the material, increased prices are; however, anticipated. Even then, a large price increase would be required to push the already low materials cost to solar (cost/kW) to an unacceptable level and force the use of substitutes.

The same type of reasoning was used in classifying the "B" raw materials. The specific criteria exceeded by each "B" raw material is shown in Table 13. Two criteria are identical to those just discussed - Net Percent Imported and Percent From Largest Foreign Country. The effect of these two raw material criteria on solar is minimal because the solar use is less than 10% of world consumption and cost to solar for each of these "B" raw materials is less than \$50/kW.

Exceeding the criteria for United States reserves and resources means either that more of the raw material will have to be imported in the future or that U.S. reserves and resources will have to increase. Historically, reserves and resources have generally increased with time due to continued exploration, development, and improved technology or increased prices which shift previously uneconomic deposits into the reserve category. Whether or not U.S. reserves and resources increase, the raw materials will be available worldwide in sufficient amounts if the criteria for world reserves and resources were not exceeded. Again, supply disruptions will have little effect because solar usage and cost to solar are small for all "B" materials.

Taking a broader perspective, one sees that all the other criteria that were exceeded by "B" materials, both bulk and raw, are largely independent of solar demand. They are exogenous criteria. Any material in a solar device that exceeds at least one of the exogenous criteria is always classed as a "B" material or higher. So long as the material's share of world consumption or its cost to the solar device are low, it remains a "B" material.

If solar usage of a "B" material increases enough, either one or both of the endogenous criteria (solar's share of world consumption and the cost of solar) will be exceeded. When these endogenous criteria are exceeded, the material is classified as an "A" material. In that situation, exogenous factors could significantly affect the availability and cost of the material to solar.

In summary, materials which are present in a solar device and exceed any of the exogenous criteria are classified as "B" materials so long as their use in the solar device is small. Their impacts on photovoltaic systems will be negligible - unless extreme shifts occur in the current pattern of supply, or unless solar usage increases sufficiently to put them into the "A" material category.

DETAILED "A" MATERIAL DISCUSSION

LEAD CONCERNS

Lead is used by all photovoltaic designs in the energy storage units lead-acid batteries. The screening process has identified a possible cost constraint for lead at \$56/kW (only \$6/kW above the threshold level). Many contemporary photovoltaic designs do not include energy storage for economic reasons. There are four possible mitigating strategies:

- Use alternative batteries that do not contain lead.
- Design new lead-acid batteries that require less lead.
- Do not use batteries for energy storage in the design
- Reduce economic impact of lead.

Alternate materials for lead in storage batteries include nickel-cadmium and zinc. Further research is going on in this area to develop less costly storage battery substitutes.

More than half of the U.S. production of lead is consumed in manufacturing storage batteries. Since battery life is related to the thickness of the battery plates (or amount of lead in the battery), a reduction in amount of lead in a battery could mean a shorter lifetime. Much research has already been done on optimizing battery performance and life. Therefore new lead-acid battery designs that require much less lead are not anticipated. When scenarios were run on the computer with energy storage deleted lead was, of course, is not a problem.

The price history of lead is presented in Figure 7 (in constant 1976 dollars). These estimates indicate that we can expect at best only a modest fall in the price of lead (in real terms) over the next twenty years. This forecast is based on the assumption that the use of lead in gasoline will continue to decline.

FIGURE 7. Price History and Future Price Estimates for Lead
(Constant 1976 dollars)

Future lead production constraints will be minimal since there are an estimated 54 million metric tons of contained lead reserves and 108 million metric tons of contained lead resources in the U.S. Also, many lead products such as automotive batteries remain virtually unchanged over their lifetimes and recovery of this lead from scrap is not difficult. Approximately 80 percent of the lead used in manufacturing storage batteries is recycled in the U.S. Thus, a portion of the initial investment in solar storage batteries may be recovered when these batteries are scrapped.

Increased environmental costs could cause substantial price increases in the future. An alternative may be for low interest loans to be offered (government subsidy) for investment in lead storage batteries; thus, lessening the economic impact.

ARSENIC CONCERNS

The screening process identified arsenic to have a possible availability problem in one system: Ga As 1-XTL Heterojunction. This system would require 22% of the world's estimated consumption in the year 2000. However, several potential sources of increased arsenic production are possible.

The potential exists for recovering arsenic as a byproduct of copper, zinc and lead processing, and this would be adequate to meet future U.S. consumption needs. Environmental constraints, such as increasingly stringent regulations on the use of insecticides and herbicides containing arsenic and consumer resistance to the use of these products has forced a reduction in the current recovery of arsenic from these sources. Arsenic pollution abatement also may provide an additional source of arsenic through recovery of arsenical residues and flue dusts. The lack of availability of arsenic is an artificially imposed problem due to its toxicity. Adequate amounts of arsenic should become available for future use in photovoltaic cells, through normal market mechanisms.

The price history of arsenic is presented in Figure 8 (in constant 1976 dollars). Instability in consumer's use of arsenic (particularly as a pesticide), and occasional short run production shortages (since it's a byproduct) have both contributed to the fluctuating price of arsenic.

The future price of arsenic is expected to remain fairly constant (between \$0.20-0.30 Kg) in real terms, over the next twenty years.

FIGURE 8. Price History and Future Price Estimates for Arsenic.
(Constant 1976 dollars)

GOLD CONCERNS

The screening process has identified potential cost and availability problems for gold usage. The cost of gold ranged from \$150/kW to \$460/kW, and consumption for solar use ranged from 10 to 58% of world 2000 consumption. Gold problems occurred in three systems: Cad S/Cu In Se, Cad Sulfide/Indium Phos, and Ga As 1-XTL Hetero. There are two possible mitigating strategies:

- Redesign the photovoltaic cells to minimize the amount of gold used.
- Substitute other conductive materials for gold.

If the efficiency of the cells were increased less gold would be required for the same power output. If better geometric packing factors for the cells could be developed, gold usage would decrease since gold is used as the front contact (in Ga As 1-XTL Hetero) and as a back contact (in Cad S/Cu In Se and the Cad Sulfide/Indium Phos cells) and these contacts interconnect the cells.

Gold has been used in these contacts because it is easy to work with, and it has a high work function. A work function is an electronic property, and the work function for gold matches that for the semi conductive layer. Since these cells are still within the developmental stage and attempts are being made to maximize conversion efficiency, cost and substitution considerations have not been fully addressed. In the Cad S/Cu In Se cell, silver is a possible substitute for gold. In the Cad Sulfide/Indium Phos cell, graphite may substitute for gold. In the Ga As single crystal heterojunction cell, the gold is in contact with the Ga Al As window layer. From the literature, no substitutes have been demonstrated for this specific layer. However, many substitutes have been demonstrated for a similar layer, GA AS, and these are:

Silver, cadmium, chromium, copper, and nickel. All of these materials are good candidates, but further work is needed to demonstrate their substitutability. Therefore, we recommend that further research be instituted to reduce gold usage by redesign and substitution.

Figure 9 shows the price of gold in constant (1976) dollars for 1955 to 2000. During the period from 1934 until 1968 the official price of gold was set by the U.S. Government at \$35 per ounce (\$1371.65/Kg). In 1968, a two tiered price system was established setting the official price of gold at \$35 per ounce for monetary transactions, and allowing the open market to set the price of gold on all other transactions. The restriction limiting private ownership of gold was lifted in the early 1970's, thus opening-up new markets for gold sales lifting the price of gold.

The future price of gold is difficult to predict; however, we expect it to continue to rise in the foreseeable future.

Approximately 60 million troy ounces of gold are potentially recoverable as a byproduct from processing copper, lead and zinc in the U.S. The availability of gold from this source would not be affected by increases in the price of gold. Primary gold reserves are also estimated at 60 million troy ounces, and may increase as the price of gold rises. Additional future supply sources may include official government reserves and/or stocks of gold speculators, which includes approximately 280 million troy ounces.

If the price of gold continues to rise, it appears that the quantity of gold necessary to meet future solar and non solar needs will be adequate. However, increases in the price of gold provide additional incentives to reduce the gold usage in photovoltaics, through redesign and substitution.

FIGURE 9. Price History and Future Price Estimates for Gold
(constant 1976 dollars)

TELLURIUM CONCERNS

The screening process has identified tellurium as a possible availability problem in the Cad Sulfide/Cad Telluride design at 50 GWe. Tellurium consumption for solar use in the year 2000 is projected to be 37% of total consumption.

At the present state-of-the-art, tellurium production is derived solely as a byproduct of copper refining. Demand for tellurium in the manufacture of solar cells would create future market shortages if present recovery ratios are maintained.

World production of copper is projected to grow from 7 million metric tons in 1976 to 27 million metric tons by the year 2000. The average recovery ratio between tellurium and copper from 1965 to 1975 has been 0.000025. To meet future tellurium demands, excluding solar cell production, recovery ratios would have to be 0.000024 in 1985, and 0.000022 in 2000. Thus, without solar cell demands, no future supply problems are foreseen.

Supply problems could, however, arise when we consider solar cell requirements for tellurium. Solar use of tellurium between the year 1999 and 2000 is projected to be between 8.8 metric tons (for the mixed scenario) and 202 metric tons (for 50 GWe of the cadmium sulfide/cadmium telluride design), while 2000 non solar U.S. consumption is expected to be 232 metric tons. This means that solar use for tellurium could equal nonsolar use in the year 2000.

World tellurium consumption, including solar cell requirements, to the year 2000 is forecast to be less than 3% of proven resources. The problem, therefore, is not one of primary supply but rather enhanced recovery.

Increasing the availability of tellurium for solar cell production can be accomplished in several ways:

- Enrich recovery ratios.
- Recovery from new sources.
- Substitution in other industries.

In an effort to meet solar cell demand, recovery ratios would have to increase to 0.000040 by the year 2000. Copper industry sources indicate these levels are realistic within 20 years by improved refining techniques both domestic and foreign.

In addition to increasing recovery ratios from copper, tellurium can also be extracted from lead ores. The technology exists, as the process has been used in the past. Also, if the market gains strength, the prices are elevated sufficiently, recovery from coal and uranium ores will become feasible.

Another consideration is the high degree of price cross-elasticity that exists between tellurium and bismuth in the steel industry. That is to say, as tellurium prices rise slightly, bismuth will be substituted as an alloy, thus freeing some tellurium for the solar cell market.

The above considerations, combined with the fact that the U.S. has ample primary resources, would lead to the conclusion that tellurium availability will not be a constraining factor in photovoltaic cell production. Prudent material supply management would include securing supplies through long term contracts.

The price history of tellurium is presented in Figure 10 (in constant 1976 dollars). It is expected that the price will rise slightly, in real terms, over the next twenty years.

FIGURE 10. Price History and Future Price Estimates for Tellurium
(constant 1976 dollars)

CADMIUM CONCERNS

The screening process has identified cadmium as a possible availability constraint in the implementation of the Cad/Cu Sulfide frontwall design at 50 GWe. Solar's percentage of world consumption was 13%.

The availability of cadmium should not be a constraining factor in the production of solar cells. World production, projected to the year 2000, is greater than projected world consumption. Of this world consumption of cadmium, the requirements for solar cell production can be accommodated.

Proven world cadmium reserves in 1976 were reported to be 689,000 metric tons. When this figure is combined with potentially economic cadmium ores, the total resources jump to 18.125 million metric tons. By the year 2000 total the nonsolar consumption has been forecast to be 37,000 metric tons and only 5700 metric tons would be utilized in the Solar Sector in that year.

In addition to sufficient future supplies of cadmium, there is minimal risk of this supply being disrupted by cartels. The U.S. controls 30% of all world proven reserves, while another 30% are distributed among major industrial noncommunist countries. Further, the U.S. General Services Administration stockpiles sufficient cadmium to discourage cartel action.

Therefore, bulk supplies of cadmium should not be viewed as a constraint in the development and production of cadmium-based solar cells.

The domestic price history of cadmium is presented in Figure 11 (in constant 1976 dollars). This price is determined by six producers and fluctuates widely. In the future trend in the price of cadmium is difficult to predict, however, it is expected that the price will rise slightly.

FIGURE 11. Price History and Future Price Estimates for Cadmium
(constant 1976 dollars)

INDIUM CONCERNS

The screening data has identified probable availability problems with indium in the following systems: 50 GWe combined scenario, 100 GWe combined scenario, cad sulfide/cad telluride, cadmium sulfide/Cu-In-Se, Cad Sulfide/Indium Phos., Ga As 1-XTL 500X fresnel, and Indium Tin Oxide/P-Si. Solar's percentage of world consumption ranged from 17% (in the Ga As 1-XTL 500X Fresnel System) to 76% (in the Cadmium Sulfide/Indium Phos. design).

Proposed solar cell requirements for indium almost certainly will lead to consumption exceeding production by the 1990's.

Presently, the sole source of indium is from secondary recovery in the zinc refining process. If world zinc output continues to grow at a 2.8% annual rate, the world's indium needs, excluding solar cell could be satisfied. However, given the projected requirements for indium in the production of solar cells, the consumption of indium is expected to reach 51 metric tons in the year 2000 for the 50 GWe mixed scenario. This amount represents more than the forecast U.S. year 2000 consumption for end uses, excluding solar.

The most significant underlying cause of indium supply problems arise from its total dependence on zinc production. Indium concentration in zinc ore varies widely throughout the world. Since zinc ore is not assayed to determine its indium content, reserves are difficult to estimate. Domestic production of indium has declined due to the closing of western zinc mines that have higher indium concentrations than eastern mines. Also, recovery methods from zinc ores are inefficient.

There are several alternatives to resolving the predicted indium shortage with respect to the production of solar cells:

- Develop new sources of indium.
- Increase recovery techniques.

The possibility of recovering indium from tin, tungsten and iron ores has largely been unexplored. This could provide an additional source of the material and may ease future supply shortages that are expected to occur near the end of this century. However, because of its byproduct nature, this would be subject to the problems now experienced with zinc ore.

Increased recovery techniques could substantially boost future indium production. At present, not all zinc residues are being processed for their indium content. Many industry sources feel this area has encouraging potential. Also, improved smelting techniques would lead to a greater availability of indium. While both of these alternatives appear promising, available information does not indicate that they can fulfill future solar cell demand (at 50 GWe).

We conclude that there will not be a sufficient amount of indium in the future to meet solar and non solar used. Therefore, R&D funding must be provided to identify new sources of indium; possibly from tin, tungsten and iron ores. Additional funding should be channeled into improving indium recovery techniques.

The price history of indium is presented in Figure 12 (in constant 1976 dollars). The price of indium reached a high in the early 1970's due to indium shortages abroad and the zinc industries shift to mining sites low in indium content. Future prices are expected to increase, if indium is used in photovoltaic cells. Excluding indium's use in solar cells, the price of indium is expected to level off and decline slightly.

FIGURE 12. Price History and Future Price Estimates for Indium
(constant 1976 dollars)

ALUMINUM CONCERNS

The screening process identified two potential problems with aluminum bulk materials necessary to produce 50 GWe of peak power capacity (See Table 7). The first problem is associated with the high consumption of aluminum. The second and related problem is the high cost of aluminum per kilowatt of peak capacity. There are two possibilities for mitigating these problems. They are as follows.

- Redesign these photovoltaic systems to minimize the use of aluminum.
- Find new and innovative ways to reduce the real cost of aluminum.

Reducing the usage of aluminum in these solar systems offers the best possibility for eliminating the aluminum bulk materials problems. The reference designs were intended principally as a technical demonstration and not as a commercial prototype. For this reason, it is highly likely that the aluminum content can be significantly reduced in future designs in one or more ways:

- using thinner or smaller structural members,
- developing higher efficiency cells requiring fewer support members,
- developing cells with better packing factors, requiring fewer support members, and
- substituting other materials for aluminum.

Through design improvements or material substitutions the aluminum requirements for commercial photovoltaic systems could be substantially reduced over these experimental designs. Therefore, potential problems with respect to high bulk aluminum consumption are likely to be eliminated.

The criteria for selecting aluminum in the reference designs are unknown at this time. However, much of the aluminum is used in supporting frames for the photovoltaic cells, and it appears that other structural materials could be readily substituted. For this reason, we recommend that additional development

of these photovoltaic designs be directed toward the identification and development of less costly substitute materials for aluminum.

The more serious problem is the high cost of aluminum per kilowatt of capacity, \$197/kW to \$350/kW (See Appendix A). Even assuming greatly reduced usage in the commercial designs, the cost of aluminum components will probably be a significant fraction of the photovoltaic system cost.

The possibility of reducing the real cost of aluminum does not appear promising. Aluminum prices in constant dollars have shown significant cost reductions in the past (Figure 13). Figure 13 shows three projections of the probable future constant dollar costs of aluminum. The most likely projection is for a 50% price increase caused primarily by substantially higher energy and environmental control costs. The pessimistic estimate assumes a cartel scenario which restricts bauxite production forcing the substitution of higher cost domestic clays, thus adding further to the price pressures caused by energy and environmental control costs. The optimistic estimate assumes technology development will offset cost increases in energy and environmental control. However, because of the maturity of the aluminum industry, it would not be prudent to base a solar design strategy on expectations of major price reductions resulting from technology improvements in aluminum production.

Because of the reliance on imports for bauxite, the potential exists for cartels or foreign political actions to disrupt the normal supply of bauxite. A similar situation exists for foreign supplies of petroleum, thus bringing the OPEC cartel into existence. However, cartel formation appears unlikely for bauxite, as compared to petroleum, because: 1) bauxite deposits are plentiful and dispersed around the world, and 2) domestic clays can be used to produce aluminum at a modest increase in cost. Large domestic deposits of these clays

FIGURE 13. Price History and Future Price Estimates for Bulk Aluminum in 1976 Dollars

have been identified. These two factors tend to discourage the formation of constraints for the world bauxite market.

The probable reduction in the usage of aluminum in commercial photovoltaic systems, resulting from improved designs and materials substitution, should eliminate the other concerns regarding aluminum.

ANTIMONY CONCERNS

Although the screening process flags antimony in the 100 GWe mixed scenario (the largest peak capacity investigated), antimony is not likely to be a significant problem to the development of photovoltaic systems. Antimony was flagged because it is almost completely obtained as a byproduct or co-product of lead production, and 55% is currently imported. However, it is unlikely that external action could effectively manipulate prices or control supply of antimony because: 1) antimony sources are dispersed (only 22% of current antimony production originates in the largest supplying country outside the U.S.), 2) the cost contribution of antimony in these designs is modest so that significant price variation could be tolerated, and 3) substitute materials for antimony in these designs are available and have proved satisfactory.

GALLIUM CONCERNS

The screening process identified gallium in the GA AS 1-XTL Heterojunction, GA AS 1-XTL 500X Fresnel, GA AS MIS, and Mixed Scenarios as a potential problem material in meeting the goal of 50 GWe in the year 2000. Gallium is almost entirely derived as a byproduct. Photovoltaic uses alone would require between 59-100% of the world gallium production. Of current world production, 45% is supplied by one foreign country and imports of gallium are 75% of the domestic requirements. Because these photovoltaic systems would consume nearly all of the gallium production and because of the potential for cartels or foreign political actions to restrict supplies, serious supply price and capacity disruptions could develop. Since gallium is essential to these designs, there is concern both to the stability of the price and supply. Under current prices, gallium contributes between \$6-\$1227/kW to the capital cost of the systems (see Appendix A).

Gallium is presently recovered as a byproduct of zinc and aluminum production. A potential constraint arises if solar's needs exceed the amount available as a byproduct of producing these two materials.

In order to meet solar's gallium requirements, between 19% (for the 50 GWe mixed scenario) and 185% (for the GA AS 1-XTL Heterojunction at 50 GWe) of the world's forecasted bauxite consumption in 2000 would be used. Therefore, shortages could develop. Gallium, above the level available from aluminum and zinc production, would have to be acquired in one of two ways.

- A directly minable source would have to be located and developed, or
- Adequate supplies of mother ores must be processed annually to provide the needed byproduct gallium.

A directly minable source of gallium may be available from domestic clays. However, sufficient demand would have to exist to attract the necessary capital to develop these resources. Some clays contain about 50 grams of gallium per ton. Assuming 1/3 recovery of the gallium, it would be necessary to process about 50,000 tons of clay to get one ton of gallium. Gallium prices are approximately \$800,000/metric ton, and current U.S. annual consumption is about 8 metric tons. Since extracting gallium from clays is expected to be more costly than byproduct recovery, this would only be undertaken if foreign sources of byproduct gallium were restricted. However, because of our dependence on foreign supplies it may be necessary to initiate R&D support directed toward lower cost gallium recovery from domestic clays if cells containing gallium are pursued.

A major concern exists with respect to the cumulative production growth rate required for gallium. The annual U.S. consumption, at present, is in the range of 8 metric tons per year. Cumulative gallium usage could range from 450 metric tons in GA AS 1-XTL 500X Fresnel, to 89,000 metric tons in GA AS 1-XTL Heterojunction, both systems at 50 GWe. Rapid expansion of gallium production is required by the development of these photovoltaic systems, and significant materials management will be required in order to achieve a reasonably stable price.

Gallium production processes are extremely capital intensive. A stable long-term demand would be required to induce the needed capital investments. Early investments in R&D, along with long-term guaranteed purchases, may be necessary in order to reduce the costs of gallium production and to provide incentives for capital investment to expand production capacity.

Considerable opportunity exists for process improvement since gallium is currently produced in a batch mode. In Figure 14, we can trace the price history of gallium. This depicts the development of an industry where prices have been dramatically reduced as production increased. The dashed lines on Figure 14 indicates considerable potential for further technology development. Developing continuous gallium production processes along with a scale-up on capacity, should reduce the capital costs and unit prices of gallium. This will not be achieved without additional R&D support directed toward lower cost gallium byproduct recovery technology.

FIGURE 14. Price History for Gallium

Future gallium prices appear to be particularly uncertain since most of the gallium consumed in the U.S. is imported and world supplies of gallium originate largely in one country. The potential for price manipulation is particularly significant with gallium. Most gallium is currently recovered during the process of converting bauxite to alumina. The current trend is for conversion to be accomplished at the bauxite mines overseas. Therefore, the future sources of gallium are likely to be under greater foreign control than at present. In addition, because of the large capital investment required for gallium recovery, it is likely that only the largest bauxite producers will install a gallium recovery process. It will be difficult to encourage large capital investments overseas due to the risk and uncertainty of the future political climate. Each of these factors will tend to concentrate gallium production among a few producers which in turn may adversely impact the future price stability and supply for gallium.

While sufficient gallium may exist (depending on which gallium cell is used), significant improvements are necessary in gallium recovery techniques and large increases are necessary in gallium production capacity. New sources of gallium should be investigated, such as fly ash from coal residues. In addition, price uncertainty exists with respect to foreign control of gallium recovery processes currently held by only a few large bauxite producers. Three strategies exist for mitigating future gallium problems if these systems are seriously pursued.

- Support R&D to develop improved gallium recovery processes
- Provide long-range incentives and guarantees to inspire the capital investment necessary to rapidly increase production capacity
- Develop improved cell designs that minimize gallium requirements.

GERMANIUM CONCERNS

Germanium, potentially a critical material in the GA AS MIS, and Mixed Scenarios generates the following concerns:

- 100% supplied as a byproduct of zinc production
- Compound growth rate of 10 to 23%/year
- Almost total dominance of the market by solar (84-99%)
- High Cost contribution of \$42 to \$420/kW.

Zinc byproduct usage required to produce germanium for the GA AS MIS Cell could be as high as 2.6×10^8 metric tons for one year, which could exceed the estimated production of zinc ore in that year.

Germanium is presently recovered primarily from the sludges of zinc smelting and refining. A potential constraint arises if solar needs exceed the economically available byproduct output. In this case, germanium needs would have to be met by:

- finding a directly minable ore,
- exploiting a new byproduct source, and/or
- designing for the use of less germanium.

There is no known primary ore which has a potential for economic recovery of germanium; therefore, germanium will probably remain a byproduct of other processes. The most likely source for additional germanium is from coal combustion residues (ashes, clinkers, etc.).

Present prices for germanium are based on processing higher grade sludges from zinc recovery. We expect that meeting the goal for photovoltaics with these systems would require processing lower grade sludges. Therefore, if faced with a significantly increased demand, future germanium prices are expected to increase. A price history and our projection of future cost trends for germanium is shown in Figure 15. Our most optimistic estimate is based on offsetting the higher costs of germanium recovery from lower grade byproducts by the "learning curve" effects associated with increased production quantities. Additional R&D could

FIGURE 15. Price History and Future Price Outlook for Germanium
(Data from U.S. Geological Survey Professional Paper 820, p. 239.36)

NOTE: "If the price of germanium were to increase significantly, recovery of the metal from certain coal ashes would become economically feasible."
(Commodity Data Summaries, 1977, Bureau of Mines, U.S. Dept. of Interior)

produce a technological advance in germanium production but this cannot be assured.

At the present time research is already going on to find a replacement for the germanium layer in the Ga As MIS device. This would appear to be the best approach to mitigating germanium problems. Thinner germanium layers would also help; however, the layer thickness assumed in the reference design is already thinner than cells being produced in the laboratory.

To help resolve potential germanium supply problems, we recommend: 1) a modest R&D program to determine the feasibility of a lower cost process for deriving germanium from coal combustion residues, and 2) concurrent R&D efforts to eliminate or reduce the thickness of the germanium film in GaAs-MIS devices. Should the GaAs-MIS device begin to look especially promising compared to other photovoltaic alternatives, and should R&D efforts to reduce or eliminate the germanium layer look unpromising, then a much larger R&D program to derive a low cost process to produce germanium from coal residue would be necessary.

IRON AND STEEL CONCERNS

Iron and Steel is a potential problem in all systems studied, with a material cost of \$55 to \$140/kWe. Production in the iron and steel industry is massive when compared to these designs' requirements (at 50 GWe capacity solar uses less than 1% of total steel production). Because of this, the price of iron and steel will depend totally on nonsolar supply and demand factors. The key question then is "Whether a significant probability exists for future price decreases in steel?" In the long run, this is highly unlikely because of the domestic environmental control costs, decreasing reserves of high grade ores, and the technological maturity of the industry.

Therefore, we believe that the only practical strategy is to reduce the amount of steel in the design. Since the reference designs are engineering prototype and not a commercial design, it is highly likely this can be accomplished.

REFERENCES

1. National Solar Energy RD&D Program: Definition Report, U.S. ERDA, ERDA-49, June, 1975.
2. Solar Energy - A Status Report, U.S. Department of Energy DOE-ET-0062, June, 1978, p. 41.
3. Litchfield, J. W., R. L. Watts, W. E. Gurwell, J. N. Hartley, C. H. Bloomster, A Methodology for Identifying Materials Constraints to Implementation of Solar Energy Technologies, Pacific Northwest Laboratories, PNL-2711, July 1978.
4. Watts, R. L., W. E. Gurwell, T. A. Nelson, S. A. Smith, Some Potential Material Supply Constraints in Solar Systems for Heating and Cooling of Buildings and Process Heat, Pacific Northwest Laboratories, PNL-2972, June 1979.
5. Charles Rivers Associates, Reports on Cadmium, Tellurium, and Indium, Cambridge, MS, 1977.
6. Mineral Facts and Problems, Bureau of Mines, U.S. Department of the Interior, Washington, DC, 1976.

APPENDIX A

ACTUAL COMPUTER RUNS OF BULK AND RAW MATERIAL SCREENING FACTORS

PHOTOVOLTAIC SYSTEM IDENTIFICATIONS								
1.	AMORPHOUS SILICON	.	.	.	.	.	.	A-1
1.	CAD SULFIDE/CAD TELLURID	.	.	.	.	.	.	A-3
2.	CADMIIUM SULFIDE/CU-IN-SE	.	.	.	.	.	.	A-5
3.	CAD/CU SULFIDE BACKWALL	.	.	.	.	.	.	A-7
4.	CAD/CU SULFIDE FRONTWALL	.	.	.	.	.	.	A-9
5.	CAD SULFIDE/INDIUM PHOS	.	.	.	.	.	.	A-11
6.	COPPER OXIDE MIS	.	.	.	.	.	.	A-13
7.	GA AS 1 XTL HETEROJUNCT	.	.	.	.	.	.	A-15
8.	GA AS 1 XTL HETEROJUNCT (at 10 GWe)	.	.	.	.	.	.	A-17
9.	GA AS 1 XTO-500X FRESNEL	.	.	.	.	.	.	A-19
10.	GALLIUM ARSENIDE MIS	.	.	.	.	.	.	A-21
11.	INDIUM TIN OXIDE/P-SI	.	.	.	.	.	.	A-23
12.	SILICON MIS	.	.	.	.	.	.	A-25
13.	SI N/P 1 XTL 14 PERCENT	.	.	.	.	.	.	A-27
14.	SI 1 XTL-30X PARA TROUGH	.	.	.	.	.	.	A-29
16.	TIN OXIDE/N-SILICON	.	.	.	.	.	.	A-31
	MIXED SCENARIOS	.	.	.	.	.	.	A-33
	COLLECTOR ONLY	.	.	.	.	.	.	A-35
	ENERGY STORAGE DELETED	.	.	.	.	.	.	A-42

This appendix contains the actual computer printouts used in determining "A," "B" and "C" materials for the 15 photovoltaic designs and 2 combined scenarios (50 and 100 GWe) studied in this report. Also, the screening factors for two systems with energy storage deleted and one system with only the photovoltaic array have been included.

The short design title is at the top of each page, and the scenario used (i.e., Introduction year and cumulative capacity) is stated in the top left hand corner. Bulk material requirements (in metric tons) precedes the raw material requirements (in thousands of metric tons) for each system.

Screening criteria are listed to the right of each bulk and raw material. An asterisk (*) to the right of any number indicates that the user-defined threshold level has been exceeded.

BULK MATERIAL REQUIREMENTS FOR AMORPHOUS SILICON

PAGE 1
88-PG-72SOLAR SCENARIO:
PRODUCTION YEAR - 1985
CAPABILITY CAPACITY 2000 - 50. GWT

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODN GROWTH RATE 1976-2000	SOLAR'S % OF WORLD CONSUMPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/KW	NET PERCENT IMPORTED
THRESHOLD LEVEL 5	---	50.	10. %/YR	10.	35.	50.	50.
MATERIALS							
ALUMINUM	17821626.	0.	7.	4.	13.	350. *	14.
ANTIMONY	119700.	100. *	5.	7.	22.	9.	55. *
CEMENT	17858720.	0.	3.	0.	18.	12.	4.
CHROMIUM	7000.	0.	3.	0.	31.	0.	100. *
COPPER	1379190.	1.	6.	1.	12.	36.	45.
GLASS, FIBER	1790000.	0.	7.	0.	5.	12.	2.
GLASS, SODA LIM	1360.	0.	3.	0.	5.	0.	5.
IRON, STEEL	12747030.	1.	3.	0.	16.	87. *	10.
LEAD	5074014.	1%	0.	7.	11.	56. *	18.
MANGANESE	167479.	30.	6.	3.	26.	7.	0.
PEROWANGHANE	71891.	100. *	2.	0.	9.	0.	99. *
NICKEL	3960.	7.	3.	0.	28.	0.	75. *
PHOSPHOROUS	0.	0.	0.	0.	13.	0.	0.
PLATINUM	60.	100. *	3.	2.	45. *	7.	90. *
POKCEHAIN	680.	0.	0.	0.	18.	0.	0.
SAND, GRAVEL	35335920.	0.	4.	0.	10.	1.	0.
STONE	69453360.	0.	3.	0.	3.	4.	0.
SILICON	126958.	0.	3.	0.	14.	2.	0.
SULFURIC ACID	1452000.	20.	5.	0.	15.	1.	0.
TIN	17867.	25.	2.	1.	29.	5.	65. *
ZINC	1360.	25.	3.	0.	21.	0.	88. *
STAINLESS STEEL	1790740.	0.	3.	2.	18.	36.	15.
FERROCHROME	58618.	5.	5.	0.	18.	3.	50. *
LINSEED OIL	6800.	0.	1.	0.	5.	0.	1.
ACRYLIC	143800.	0.	7.	1.	5.	4.	1.
ALKYD RESIN	13600.	0.	7.	0.	5.	0.	1.
EPOXY RESIN	1814.	0.	7.	0.	5.	0.	5.
EPOXY - FIBERGL	480.	0.	7.	0.	5.	0.	5.
CALCIUM	86200.	0.	3.	0.	0.	0.	2.
GLUE, PHENOL FOR	20120.	0.	7.	1.	5.	0.	5.
LINDER, SFTHOOD	985880.	0.	4.	0.	20.	1.	12.
PHENOLIC RESIN	31760.	0.	7.	0.	0.	1.	1.
PLASTIC, RESIN	18800.	0.	7.	0.	5.	0.	3.
POLYESTER RESIN	8160.	0.	7.	0.	5.	0.	0.
PVC PLASTIC	10700.	0.	7.	0.	5.	0.	0.
RUBBER, SBR	29900.	0.	0.	0.	5.	0.	4.
TEFLON	3900.	0.	7.	1.	5.	1.	1.
NYLON	600.	0.	7.	0.	5.	0.	1.
POLYPROPYLENE	414000.	0.	7.	1.	5.	0.	1.
COTTON FIBERS	641.	0.	3.	0.	18.	0.	1.
KRAFT FIBERS	275.	0.	0.	0.	10.	0.	15.
TUNG OIL	20400.	0.	0.	0.	45. *	1.	70. *
LYN	299200.	0.	7.	2.	5.	4.	5.

RMB MATERIAL REQUIREMENTS FOR AMORPHOUS SILICON

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50. GWE

FACTORS	RMB MATERIAL USAGE (1000MT)	WORLD PRODUCTN GROWTH RATE	MAX. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KW OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS	-	7. %/YR	10.	100.	300.	60.	300.	200.	50.	50.
MATERIALS										
ANTHRACITE COF	12560.	5.	7.	1327. *	1230. *	22.	70.	57.	3.	50. *
BOKESITE	5.	3.	0.	539. *	28.	34.	190.	129.	0.	90. *
BAUXITE	90991.	5.	5.	2438. *	325. *	28.	15.	9.	27.	89. *
BERNITE	449.	5.	1.	11.	0.	50.	10.	0.	1.	3.
BIRNITE	31.	1.	0.	20.	2.	10.	12.	1.	0.	5.
CHRONITE	1310.	4.	4.	3475. *	440. *	27.	18.	4.	2.	66. *
CLAYS	2727.	2.	0.	0.	0.	10.	0.	0.	1.	0.
COAL	60011.	1.	0.	6.	1.	0.	13.	1.	18.	19.
COPPER ORE	203427.	0.	1.	1000. *	430. *	12.	85.	25.	12.	37.
FLUORITE	0.	3.	0.	5.	0.	10.	13.	0.	0.	5.
FLUORSPAR	1363.	5.	1.	711. *	152.	22.	201.	120.	3.	50. *
GYP-SUM	819.	3.	0.	175.	0.	10.	11.	0.	0.	37.
IRON ORE	82274.	5.	0.	56.	7.	11.	15.	6.	3.	35.
LEAD ORE	168981.	3.	7.	87.	43.	11.	129.	14.	19.	33.
MANGANESE ORE	415.	3.	0.	100.	4.	24.	6.	11.	1.	100. *
NATURAL GAS	2379.	5.	0.	245.	277.	30.	93.	9.	4.	5.
NICKEL ORE	14722.	3.	1.	4512. *	5414. *	37.	54.	23.	5.	75. *
NITROGEN, FIXED	1.	4.	0.	0.	0.	5.	0.	0.	0.	10.
PETROLEUM	2307.	3.	0.	562. *	210.	22.	110.	36.	3.	40.
PHOSPHATE ROCK	0.	0.	0.	40.	0.	13.	29.	0.	0.	0.
PROPANE	879.	1.	0.	192.	23.	10.	136.	11.	1.	5.
SALT	62652.	0.	1.	0.	0.	5.	0.	0.	30.	9.
SAND/GRAVEL	40015.	4.	0.	0.	0.	0.	0.	0.	2.	0.
STONE	69453.	3.	0.	0.	0.	3.	0.	0.	4.	0.
SULFUR	5055.	4.	1.	95.	1.	15.	90.	0.	5.	28.
TIN ORE	170668.	2.	1.	4375. *	1313. *	29.	73.	20.	2.	65. *
ZINC ORE	532.	0.	0.	146.	33.	19.	154.	8.	0.	88. *
COTTON	1.	2.	0.	0.	0.	16.	0.	0.	0.	1.
FLAX FIBER	20.	1.	0.	0.	0.	25.	0.	0.	0.	20.
MILK BYPRODUCTS	2.	3.	0.	0.	0.	20.	0.	0.	0.	1.
LUMBER	1043.	1.	0.	0.	0.	12.	0.	0.	3.	18.
SEA WATER	125964.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SOYBEAN	39.	3.	0.	0.	0.	12.	0.	0.	0.	0.
TUNG NUTS	41.	1.	5.	0.	0.	70. *	0.	0.	1.	80. *
WATER	37751.	3.	0.	17.	2.	0.	3.	0.	0.	0.
WHEAT	6.	3.	0.	0.	0.	10.	0.	0.	0.	0.
MISC.	643.	0.	0.	0.	0.	0.	0.	0.	6.	0.
STEAM	463192.	5.	1.	1.	0.	10.	0.	0.	16.	0.
LIMESTONE	83171.	3.	0.	0.	0.	5.	0.	0.	3.	2.
COAL, BY PROD	189514.	1.	1.	5.	1.	6.	13.	1.	0.	10.

BULK MATERIAL REQUIREMENTS FOR CAD SULFIDE/CAD TELLURID

SOLAR SCENARIO.
INTRODUCTION YEAR - 1985
CUMULATIVE CAPACITY 2000 - 50. ONE

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY PRODUCT	WORLD PROD GROWTH RATE 1976-2000	SOLAR'S % OF WORLD CONSUMPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/KH	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	50	10. %/YR	10	35	50	50
MATERIALS							
ALUMINUM	17821626.	0	7.	4.	13.	350. *	14.
ANTIMONY	119700.	100. *	5.	7.	22.	9.	55. *
CADMIUM	4360.	100. *	4.	2.	15.	1.	57. *
CEMENT	17053720.	0	3.	0.	18.	12.	4.
CHROMIUM	40.	0.	3.	0.	31.	0.	100. *
COPPER	1387910.	1.	6.	1.	12.	37.	45.
GLASS, FIBER	1790000.	0	7.	6.	5.	12.	2.
GLASS, SODA LIN	4801360.	0.	3.	4.	5.	28.	5.
INDIUM	500.	100. *	0.	40. *	10.	4.	75. *
IRON, STEEL	11231960.	1.	3.	0.	16.	77. *	10.
LEAD	5074514.	13.	5.	7.	11.	56. *	18.
MAGNESIUM	167479.	30.	6.	3.	26.	7.	0.
FERROMANGANESE	62915.	100. *	2.	0.	9.	0.	99. *
NICKEL	2020.	7.	3.	0.	28.	0.	75. *
PORCELAIN	600.	0.	0.	0.	10.	0.	0.
SAND ! GRAVEL	35333920.	0.	4.	0.	10.	1.	0.
STONE	69453360.	0.	3.	0.	3.	4.	0.
SILICON	125720.	0.	3.	0.	14.	2.	8.
SULFUR	920.	31.	3.	0.	15.	0.	15.
SULFURIC ACID	1452000.	20.	5.	0.	15.	1.	0.
TELLURIUM	1320.	100. *	3.	37. *	16.	1.	37.
TIN	17097.	25.	2.	1.	29.	5.	65. *
ZINC	1360.	25.	2.	0.	21.	0.	88. *
STAINLESS STEEL	1790740.	0.	3.	2.	10.	36.	15.
FERROCHROME	50618.	5.	5.	0.	18.	3.	50. *
LINSEED OIL	6000.	0.	1.	0.	5.	0.	1.
ACRYLIC	143000.	0.	7.	1.	50.	4.	1.
ALKYD RESIN	13600.	0.	7.	0.	50.	0.	1.
EPOXY RESIN	1814.	0.	7.	0.	50.	0.	5.
EPOXY - FIBERGL	400.	0.	7.	0.	50.	0.	5.
CALCIUM	86200.	0.	3.	0.	9.	0.	2.
GLUE, PHENOL FOR	20120.	0.	7.	1.	50.	0.	5.
LUMBER, SOUTHWOOD	905000.	0.	4.	0.	20.	1.	12.
PHENOLIC RESIN	31700.	0.	7.	0.	50.	1.	1.
PLASTIC, RESIN	15000.	0.	7.	0.	50.	0.	3.
POLYESTER RESIN	8160.	0.	7.	0.	50.	0.	0.
PVC PLASTIC	18700.	0.	7.	0.	50.	0.	0.
RUBBER, SBR	29900.	0.	6.	0.	50.	0.	4.
TEFLON	3900.	0.	7.	1.	50.	1.	1.
NYLON	600.	0.	7.	0.	50.	0.	1.
POLYPROPYLENE	414000.	0.	7.	1.	50.	5.	1.
COTTON FIBERS	641.	0.	3.	0.	10.	0.	1.
KRAFT FIBERS	275.	0.	3.	0.	10.	0.	15.
TUNG OIL	20400.	0.	0.	6.	45. *	1.	70. *
EVA	299200.	0.	7.	2.	50.	4.	5.

RAW MATERIAL REQUIREMENTS FOR CAD SULFIDE/CAD TELLURID

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50. GWE

FACTORS	RAW MATERIAL USAGE (1000MT)	WORLD PRODUCTION GROWTH RATE	MAX. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KWH OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS		7. %/YR	10.	400.	300.	60.	300.	200.	50.	50.
MATERIALS										
ANTIMONY ORE	12569.	5.	7.	1327.	*	1230.	*	78.	57.	3.
ASBESTOS	5.	3.	0.	539.	*	28.		190.	129.	0.
BAUXITE	99988.	5.	5.	2438.	*	325.	*	15.	9.	27.
BORATE	449.	5.	1.	11.	0.	50.		10.	0.	1.
BUTANE	34.	1.	0.	20.	2.	10.		12.	1.	0.
CHRONITE	1288.	4.	3.	3473.	*	439.	*	18.	4.	2.
CLAYS	2711.	2.	0.	0.	0.	10.		0.	0.	1.
COAL	68354.	1.	0.	6.	1.	6.		13.	1.	19.
COAL AT/TH/LIGHT	2.	1.	0.	6.	1.	6.		13.	1.	0.
COPPER ORE	385340.	6.	1.	1000.	*	438.	*	85.	25.	12.
FELDSPAR	454.	3.	1.	5.	0.	10.		13.	0.	0.
FLUORSPAR	1350.	5.	1.	711.	*	152.		201.	120.	2.
GYPNUM	819.	3.	0.	175.	0.	10.		11.	0.	0.
IRON ORE	73732.	5.	0.	55.	7.	11.		15.	6.	3.
LEAD ORE	160981.	3.	7.	87.	43.	11.		129.	14.	19.
MANGANESE ORE	365.	3.	0.	100.	4.	24.		6.	11.	1.
NATURAL GAS	2365.	5.	0.	245.	277.	30.		93.	9.	4.
NICKEL ORE	14528.	3.	1.	4511.	*	5413.	*	54.	23.	5.
NITROGEN, FIXED	1.	4.	0.	0.	0.	5.		0.	0.	0.
PETROLEUM	2253.	3.	0.	562.	*	210.		110.	36.	3.
PROPANE	879.	1.	0.	192.	23.	10.		136.	11.	1.
SALT	66339.	6.	1.	0.	0.	5.		0.	0.	40.
SAND/GRAVEL	43222.	4.	0.	0.	0.	0.		0.	0.	2.
STONE	69453.	3.	0.	0.	0.	3.		0.	0.	4.
SULFUR	5872.	4.	1.	95.	1.	15.		90.	0.	5.
TIN ORE	178968.	2.	1.	4376.	*	1313.	*	73.	20.	2.
ZINC ORE	1404.	0.	0.	146.	33.	19.		154.	0.	0.
COTTON	1.	2.	0.	0.	0.	16.		0.	0.	0.
FLAX SEED	20.	1.	0.	0.	0.	25.		0.	0.	0.
MILK BYPRODUCTS	2.	3.	0.	0.	0.	20.		0.	0.	0.
LUMBER	1042.	1.	0.	0.	0.	12.		0.	0.	3.
SEA WATER	125964.	0.	0.	0.	0.	0.		0.	0.	0.
SOYBEAN	29.	3.	0.	0.	0.	12.		0.	0.	0.
TUNG NUTS	41.	1.	5.	0.	0.	70.	*	0.	0.	1.
WATER	37977.	3.	0.	17.	2.	0.		3.	0.	0.
WHEAT	6.	3.	0.	0.	0.	10.		0.	0.	0.
MISC.	631.	0.	0.	0.	0.	0.		0.	0.	6.
STEAM	462534.	5.	1.	1.	0.	10.		0.	0.	16.
LIMESTONE	86139.	3.	3.	0.	0.	5.		0.	0.	3.
ZINC, BY PRODUCT	3136.	0.	0.	147.	33.	19.		154.	8.	0.
COAL, BY PROD	199514.	1.	1.	6.	1.	6.		13.	1.	0.
ELECTRICITY	2232330.	3.	0.	0.	0.	0.		0.	0.	0.
CU BYPROD 1	10560.	6.	0.	101.	44.	12.		495.	*	23.

BULK MATERIAL REQUIREMENTS FOR CADMIUM SULFIDE/CU-IN-SE

SOLAR SCENARIO:
INTRODUCTION YEAR - 1985
CAPACITIVE CAPACITY 2000 - 50. GNE

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODN GROWTH RATE 1976-2000	SOLAR'S % OF WORLD CAP. CAPTION	% FROM LARGEST COUNTRY	COST PLR UNIT OUTPUT \$/KW	NET PERCENT IMPORTED
THRESHOLD LEVEL 5	---	50.	10. %/YR	10.	70.	50.	50.
MATERIALS							
ALUMINIUM	17821966.	0.	7.	4.	13.	300. *	14.
ANTIMONY	119700.	100. *	5.	7.	22.	9.	55. *
CADMIUM	3750.	100. *	4.	2.	15.	0.	57. *
CEMENT	17858720.	0.	3.	0.	10.	12.	4.
COPPER	1387570.	1.	6.	1.	12.	37.	45.
GLASS, FIBER	1796000.	0.	7.	6.	5.	12.	2.
GLASS, SODA LIM	4801360.	0.	3.	4.	5.	20.	5.
GRID	4040.	40.	3.	27. *	50. *	400. *	58. *
IN-LUM	900.	100. *	7.	60. *	10.	6.	75. *
IRON, STEEL	11231945.	1.	3.	0.	10.	77. *	10.
LEAD	5074514.	13.	5.	7.	11.	56. *	18.
MAGNESIUM	167179.	30.	6.	3.	26.	7.	0.
PERRANINGANESE	62915.	100. *	2.	0.	9.	0.	99. *
POWDERATH	680.	0.	0.	0.	10.	0.	0.
SAND, GRAVEL	35335920.	0.	4.	0.	10.	1.	0.
STONE	69453360.	0.	0.	0.	3.	4.	0.
SELENIUM	1360.	100. *	0.	6.	37. *	0.	59. *
SILICON	125728.	0.	0.	0.	14.	2.	8.
SULFUR	1000.	31.	0.	0.	15.	0.	15.
SULFURIC ACID	1452000.	20.	0.	0.	15.	1.	0.
TIN	17867.	25.	2.	1.	29.	5.	65. *
ZINC	1360.	25.	0.	0.	21.	0.	88. *
STAINLESS STEEL	1790740.	0.	0.	2.	10.	36.	15.
FERROCHROME	58618.	5.	0.	0.	10.	3.	50. *
LINSEED OIL	6800.	0.	1.	0.	5.	0.	1.
ACRYLIC	143000.	0.	7.	1.	50.	4.	1.
ALKYD RESIN	13600.	0.	7.	0.	50.	0.	1.
EPOXY RESIN	1814.	0.	7.	0.	50.	0.	5.
EPOXY - FIBERGL	480.	0.	7.	0.	50.	0.	5.
CALCIUM	86200.	0.	3.	0.	9.	0.	2.
GLUE, PHENOL FOR	20120.	0.	7.	1.	50.	0.	5.
LUMBER, SOFTWOOD	985800.	0.	4.	0.	20.	1.	12.
PHENOLIC RESIN	31766.	0.	7.	0.	50.	1.	1.
PLASTIC, RESIN	18000.	0.	7.	0.	50.	0.	3.
POLYESTER RESIN	8160.	0.	7.	0.	50.	0.	0.
PVC PLASTIC	18780.	0.	7.	0.	50.	0.	0.
RUBBER, SBR	29900.	0.	6.	0.	50.	0.	4.
TEFLON	3900.	0.	7.	1.	50.	1.	1.
NYLON	600.	0.	7.	0.	50.	0.	1.
POLYPROPYLENE	414000.	0.	7.	1.	50.	0.	1.
COTTON FIBERS	641.	0.	0.	0.	16.	0.	1.
KRAFT FIBERS	275.	0.	0.	0.	10.	0.	15.
TUNG OIL	20400.	0.	0.	6.	45. *	1.	70. *
EVA	299200.	0.	7.	2.	50.	4.	5.

RAW MATERIAL REQUIREMENTS FOR CADMIUM SULFIDE/CO-IN-SE

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50. GWE

FACTORS	RAW MATERIAL USAGE (1000MT)	WORLD PRODUCTN GROWTH RATE	MAX. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KWH OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS		2. %/YR	10.	400.	300.	60.	300.	200.	50.	50.
MATERIALS										
ANTIMONY ORE	12562.	5.	7.	1327. *	1230. *	22.	78.	67.	3.	55. *
ASBESTOS	5.	3.	0.	539. *	28.	34.	156.	129.	0.	90. *
BAUXITE	98991.	5.	5.	2438. *	325. *	28.	15.	9.	27.	88. *
BORATE	449.	5.	1.	11.	0.	50.	10.	0.	1.	3.
BUTANE	34.	1.	0.	20.	2.	10.	12.	1.	0.	0.
CHROMITE	1288.	4.	3.	3473. *	439. *	27.	18.	4.	2.	66. *
CLAYS	2714.	2.	0.	0.	0.	10.	0.	0.	1.	0.
COAL	61479.	1.	0.	0.	1.	6.	13.	1.	19.	10.
COAL BITUM/LIGNT	2.	1.	0.	0.	1.	6.	13.	1.	0.	10.
COPPER ORE	305265.	6.	1.	1000. *	438. *	12.	85.	25.	12.	37.
FELDSPAR	454.	3.	1.	5.	0.	10.	13.	0.	0.	5.
FLUORSPAR	1353.	5.	1.	711. *	152.	22.	201.	120.	3.	50. *
GOLD ORE	484000.	3.	27. *	3824. *	159.	58.	123.	31.	154. *	89. *
GYPSUM	819.	3.	0.	175.	0.	10.	11.	0.	0.	37.
IRON ORE	75234.	5.	0.	56.	7.	11.	15.	6.	3.	35.
LEAD ORE	168981.	3.	7.	87.	43.	11.	129.	14.	19.	33.
MANGANESE ORE	373.	3.	0.	100.	4.	24.	6.	11.	1.	100. *
NATURAL GAS	2819.	5.	0.	245.	277.	30.	93.	9.	5.	5.
NICKEL ORE	14326.	3.	1.	4509. *	5411. *	37.	54.	23.	5.	75. *
NITROGEN, FIXED	1.	4.	0.	0.	0.	5.	0.	0.	0.	10.
PETROLEUM	2405.	3.	0.	562. *	210.	22.	110.	36.	4.	40.
PROPANE	879.	1.	0.	192.	23.	10.	136.	11.	1.	5.
SALT	68771.	6.	2.	0.	0.	5.	0.	0.	41.	9.
SAND/GRAVEL	43222.	4.	0.	0.	0.	0.	0.	0.	2.	0.
SHALE	10113.	3.	0.	0.	0.	3.	0.	0.	4.	0.
SULFUR	8865.	4.	1.	95.	1.	15.	90.	0.	5.	28.
TIN ORE	109001.	2.	1.	1475. *	1313. *	29.	73.	20.	2.	65. *
ZINC ORE	12307.	8.	0.	147.	33.	19.	151.	0.	1.	88. *
ALUMINA	1.	2.	0.	0.	0.	16.	0.	0.	0.	1.
BLACK SLED	20.	1.	0.	0.	0.	25.	0.	0.	0.	20.
MILK PRODUCTS	2.	3.	0.	0.	0.	20.	0.	0.	0.	1.
MURDER	1042.	1.	0.	0.	0.	12.	0.	0.	3.	18.
OLD WATER	120064.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SAVING	30.	3.	0.	0.	0.	12.	0.	0.	0.	0.
TUNG NUTS	41.	1.	5.	0.	0.	70. *	0.	0.	1.	80. *
WATER	82155.	3.	0.	17.	2.	0.	3.	0.	0.	0.
WHEAT	6.	3.	0.	0.	0.	10.	0.	0.	0.	0.
WISC	872.	0.	0.	0.	0.	0.	0.	0.	9.	0.
STEAM	465288.	5.	1.	1.	0.	10.	0.	0.	16.	0.
LIMESTONE	94171.	3.	4.	0.	0.	5.	0.	0.	4.	2.
ZINC, BY PRODUCT	5463.	0.	0.	147.	34.	19.	154.	0.	0.	88. *
COAL, BY PROD	189814.	1.	1.	6.	1.	6.	13.	1.	0.	10.
ELECTRICITY	1925136.	3.	0.	0.	0.	0.	0.	0.	0.	0.
CU BYPROD 1	2778.	6.	0.	984. *	431. *	12.	85.	24.	0.	37.

BULK MATERIAL REQUIREMENTS FOR CAD/CU SULFIDE BACKMILL

SOLAR SCENARIO:
 INTRODUCTION YEAR - 1985
 CUMULATIVE CAPACITY 2000 - 50 GHE

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODN GROWTH RATE 1976-2000	SOLAR'S % OF WORLD CONSUMPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/KWH	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	50.	10. %/YR	10.	35.	50.	50.
MATERIALS							
ALUMINUM	17821884.	0.	7.	4.	13.	350 *	14.
ANTIMONY	119700.	100. *	5.	7.	22.	9.	55. *
CADMIUM	2900.	100. *	4.	1.	15.	0.	57. *
CEMENT	17055728.	0.	3.	0.	18.	12.	4.
CHROMIUM	40.	0.	3.	0.	31.	0.	100. *
COPPER	1384870.	1.	6.	1.	12.	37.	45.
GLASS, FIBER	1796880.	0.	7.	6.	5.	12.	2.
GLASS, SODA LIM	4881300.	0.	3.	4.	5.	23.	5.
IRON, STEEL	11231966.	1.	3.	0.	18.	72 *	18.
LEAD	5834114.	13.	5.	7.	11.	56. *	18.
MAGNESIUM	167479.	30.	0.	3.	26.	7.	0.
FERROMANGANESE	62915.	100. *	2.	0.	9.	0.	99. *
NICKEL	120.	7.	3.	0.	28.	0.	75. *
PORCELAIN	690.	0.	0.	0.	10.	0.	0.
SAND + GRAVEL	35335920.	0.	4.	0.	10.	1.	0.
STONE	69453360.	0.	3.	0.	3.	4.	0.
SILICON	125728.	0.	3.	0.	14.	2.	8.
SULFUR	1300.	31.	3.	0.	15.	0.	15.
SULFURIC ACID	1452800.	20.	5.	0.	15.	1.	0.
TIN	18687.	25.	2.	1.	29.	5.	65. *
ZINC	1360.	25.	3.	0.	21.	0.	88. *
STAINLESS STEEL	1790740.	0.	3.	2.	10.	30.	15.
FERROCHROME	58618.	5.	5.	0.	18.	3.	50. *
LINSEED OIL	6800.	0.	1.	0.	5.	0.	1.
ACRYLIC	143800.	0.	7.	1.	0.	4.	1.
ALKYD RESIN	13600.	0.	7.	0.	0.	1.	1.
EPOXY RESIN	1814.	0.	7.	0.	5.	0.	5.
EPOXY - FIBERGL.	480.	0.	7.	0.	5.	0.	5.
CALCIUM	86280.	0.	3.	0.	9.	0.	2.
GLUE, PHENOL FOR	20120.	0.	7.	1.	5.	0.	5.
LUMBER, SOFTWOOD	985880.	0.	4.	0.	20.	1.	12.
PHENOLIC RESIN	31766.	0.	7.	0.	5.	1.	1.
PLASTIC, RESIN	18000.	0.	7.	0.	5.	0.	3.
POLYESTER RESIN	8160.	0.	7.	0.	0.	0.	0.
PVC PLASTIC	18780.	0.	7.	0.	0.	0.	0.
RUBBER, SBR	29980.	0.	0.	0.	0.	0.	4.
TEFLON	3900.	0.	7.	1.	0.	1.	1.
NYLON	600.	0.	7.	0.	0.	1.	1.
POLYPROPYLENE	414000.	0.	7.	1.	5.	0.	1.
COTTON FIBERS	641.	0.	3.	0.	16.	0.	1.
KRAFT FIBERS	275.	0.	3.	0.	16.	0.	15.
TUNG OIL	20400.	0.	0.	6.	45. *	1.	70. *
EVA	299200.	0.	7.	2.	5.	4.	5.

RAW MATERIAL REQUIREMENTS FOR CAD/CU SULFIDE BACKWALL

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50 GME

FACTORS	RAW MATERIAL USAGE (1000MT)	WORLD PRODUCTN GROWTH RATE	MAX. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KW OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	7. %/YR	10.	400.	300.	60.	300.	200.	50.	50.
MATERIALS										
ANTIMONY ORE	12500.	5.	7.	1327 *	1230. *	22.	78.	67.	3.	55. *
ASBESTOS	5.	3.	0.	539. *	28.	34.	190.	129.	0.	90. *
BAUXITE	90900.	9.	5.	2438. *	325. *	28.	15.	9.	27.	89. *
BORATE	449.	5.	1.	11.	0.	50.	10.	0.	1.	3.
BUTANE	34.	1.	0.	20.	2.	10.	12.	1.	0.	5.
CHROMITE	1288.	4.	3.	3473 *	439. *	27.	18.	4.	2.	66. *
CLAYS	2711.	2.	0.	0.	0.	10.	0.	0.	1.	0.
COAL	60303.	1.	0.	6.	1.	6.	13.	1.	19.	10.
COAL BITUM./LIGHT	1.	1.	0.	6.	1.	6.	13.	1.	0.	10.
COPPER ORE	304671.	6.	1.	1000. *	438. *	12.	85.	25.	12.	37.
FELDSPAR	454.	3.	1.	5.	0.	10.	13.	0.	0.	5.
FLUORSPAR	1350.	5.	1.	711. *	152.	22.	201.	120.	3.	50. *
GYPNUM	819.	3.	0.	175.	0.	10.	11.	0.	0.	37.
IRON ORE	73725.	10.	0.	55.	7.	11.	15.	6.	3.	35.
LEAD ORE	169301.	3.	7.	87.	43.	11.	129.	14.	19.	33.
MANGANESE ORE	365.	3.	0.	100.	4.	24.	6.	11.	1.	100. *
NATURAL GAS	2362.	5.	0.	245.	277.	30.	93.	9.	4.	5.
NICKEL ORE	14338.	3.	1.	4510. *	5411. *	37.	54.	23.	5.	75. *
NITROGEN, FIXED	1.	4.	0.	0.	0.	5.	0.	0.	0.	10.
PETROLEUM	2253.	3.	0.	562. *	210.	22.	110.	26.	3.	40.
PROPANE	879.	1.	0.	192.	23.	10.	136.	11.	1.	5.
SALT	66320.	6.	1.	0.	0.	5.	0.	0.	40.	9.
SAND/GRAVEL	43222.	4.	0.	0.	0.	0.	0.	0.	2.	0.
STONE	69453.	3.	0.	0.	0.	3.	0.	0.	4.	0.
SULFUR	5065.	4.	1.	95.	1.	15.	90.	0.	5.	20.
TIN ORE	186868.	2.	1.	4377. *	1313. *	29.	73.	20.	2.	65. *
ZINC ORE	1113.	0.	0.	146.	33.	19.	154.	8.	0.	88. *
COTTON	1.	2.	0.	0.	0.	16.	0.	0.	0.	1.
FLAX SEED	20.	1.	0.	0.	0.	25.	0.	0.	0.	20.
MILK BYPRODUCTS	2.	3.	0.	0.	0.	20.	0.	0.	0.	1.
LUMBER	1042.	1.	0.	0.	0.	12.	0.	0.	3.	18.
SEA WATER	125974.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SOYBEAN	39.	3.	0.	0.	0.	12.	0.	0.	0.	0.
TUNG NUTS	41.	1.	5.	0.	0.	70. *	0.	0.	1.	80. *
WATER	37957.	3.	0.	17.	2.	0.	3.	0.	0.	0.
WHEAT	6.	3.	0.	0.	0.	10.	0.	0.	0.	0.
MISC.	629.	0.	0.	0.	0.	0.	0.	0.	6.	0.
STEAM	462537.	50.	1.	1.	0.	10.	0.	0.	16.	0.
LIMESTONE	86137.	3.	3.	0.	0.	5.	0.	0.	2.	2.
COAL, BY PROD	189514.	1.	1.	6.	1.	6.	13.	1.	0.	10.
ELECTRICITY	1404000.	3.	0.	0.	0.	0.	0.	0.	0.	0.

BULK MATERIAL REQUIREMENTS FOR CAD/CU SULFIDE FRONTIALL

SOLAR SCENARIO:
INTRODUCTION YEAR - 1985
CUMULATIVE CAPACITY 2000 - 50 GME

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODN GROWTH RATE 1976-2000	SOLAR'S % OF WORLD CONSUMPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/KJH	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	50.	10. %/YR	10.	35.	50.	50.
MATERIALS							
ALUMINUM	17821626.	0.	7.	4.	13.	350. *	14.
ANTIMONY	119700.	100. *	5.	7.	22.	9.	55. *
CADMIUM	37400.	100. *	4.	13. *	15.	5.	57. *
CEMENT	17858720.	0.	3.	0.	13.	12.	4.
COPPER	1424690.	1.	6.	1.	12.	38.	45.
GLASS, FIBER	1796000.	0.	7.	6.	5.	12.	2.
GLASS, SODA LIM	1360.	0.	3.	0.	5.	0.	5.
IRON, STEEL	11231945.	1.	3.	0.	16.	77. *	10.
LEAD	5074514.	13.	5.	7.	11.	56. *	18.
MAGNESIUM	167479.	30.	6.	3.	26.	7.	0.
FERROMANGANESE	62915.	100. *	2.	0.	9.	0.	99. *
PORCELAIN	600.	0.	0.	0.	10.	0.	0.
SAND & GRAVEL	35335020.	0.	4.	0.	10.	1.	0.
STONE	69453360.	0.	3.	0.	3.	4.	0.
SILICON	125728.	0.	3.	0.	14.	2.	0.
SULFUR	10020.	31.	0.	0.	15.	0.	15.
SULFURIC ACID	1452000.	20.	5.	0.	15.	1.	0.
TIN	17067.	25.	2.	1.	29.	5.	65. *
ZINC	3120.	25.	3.	0.	21.	0.	88. *
STAINLESS STEEL	1796740.	0.	3.	2.	10.	36.	15.
FERROCHROME	50618.	5.	5.	0.	10.	3.	50. *
LINSEED OIL	6000.	0.	1.	0.	5.	0.	1.
ACRYLIC	143000.	0.	7.	1.	5.	4.	1.
ALKYD RESIN	13600.	0.	7.	0.	5.	0.	1.
EPOXY RESIN	1814.	0.	7.	0.	5.	0.	5.
EPOXY - FIBERGL	400.	0.	7.	0.	5.	0.	0.
CALCIUM	86200.	0.	3.	0.	9.	0.	0.
GLUE, PHENOL, FOR	20120.	0.	7.	1.	5.	0.	5.
LUMBER, SOFTWOOD	905000.	0.	4.	0.	20.	1.	12.
PHENOLIC RESIN	31766.	0.	7.	0.	5.	1.	1.
PLASTIC, RESIN	18000.	0.	7.	0.	5.	0.	3.
POLYESTER RESIN	8160.	0.	7.	0.	5.	0.	0.
PVC PLASTIC	10700.	0.	7.	0.	5.	0.	0.
RUBBER, SBR	29900.	0.	5.	0.	5.	0.	4.
TEFLON	3900.	0.	7.	1.	5.	1.	1.
NYLON	600.	0.	7.	0.	5.	0.	1.
POLYPROPYLENE	414000.	0.	7.	1.	5.	0.	1.
COTTON FIBERS	641.	0.	3.	0.	16.	0.	1.
KRAFT FIBERS	275.	0.	3.	0.	10.	0.	15.
TUNG OIL	20400.	0.	0.	6.	45. *	1.	70. *
EVA	299200.	0.	7.	2.	5.	4.	5.

RHM MATERIAL REQUIREMENTS FOR CAD/CU SULFIDE FRONTWALL

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50. GWE

FACTORS	RHM MATERIAL USAGE (1000MT)	WORLD PRODUCTN GROWTH RATE	MAX. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KWH OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	7. %/YR	10.	400.	300.	60.	300.	200.	50.	50.
MATERIALS										
ANTHONY ORE	12000.	5.	7.	1327.	*	1239.	*	22.	78.	67.
ASBESTOS	5.	3.	0.	539.	*	28.	34.	190.	199.	0.
BAUXITE	90987.	5.	5.	2439.	*	325.	*	28.	15.	9.
BORATE	440.	5.	1.	11.	0.	50.	10.	0.	27.	1.
BUTANE	34.	1.	0.	20.	2.	10.	12.	1.	0.	0.
CHROMITE	1288.	4.	3.	3473.	*	439.	*	27.	18.	4.
CLAYS	2711.	2.	0.	0.	0.	10.	0.	0.	1.	0.
COAL	50321.	1.	0.	0.	1.	0.	13.	1.	10.	10.
COAL BITUM/LIGHT	12.	1.	0.	0.	1.	0.	13.	1.	0.	0.
COPPER ORE	313432.	6.	1.	1000.	*	438.	*	12.	85.	25.
FELDSPAR	0.	3.	0.	5.	0.	10.	13.	0.	0.	0.
FLUORSPAR	1351.	5.	1.	711.	*	152.	22.	201.	120.	2.
GYPSUM	819.	3.	0.	175.	0.	10.	11.	0.	0.	0.
IRON ORE	73816.	5.	0.	56.	7.	11.	15.	6.	3.	35.
LEAD ORE	168981.	3.	7.	87.	43.	11.	129.	14.	19.	13.
MANGANESE ORE	365.	3.	0.	100.	4.	24.	6.	11.	1.	100.
NATURAL GAS	2402.	5.	0.	245.	277.	30.	93.	9.	5.	5.
NICKEL ORE	14326.	3.	1.	4509.	*	5411.	*	37.	54.	23.
NITROGEN, FIXED	1.	4.	0.	0.	0.	5.	0.	0.	0.	0.
PETROLEUM	2254.	3.	0.	562.	*	210.	22.	110.	36.	3.
PROPANE	879.	1.	0.	192.	23.	10.	136.	11.	1.	5.
SALT	62637.	6.	1.	0.	0.	5.	0.	0.	30.	9.
SAND/GRAVEL	40011.	4.	0.	0.	0.	0.	0.	0.	2.	0.
STONE	69453.	3.	0.	0.	0.	3.	0.	0.	4.	0.
SULFUR	5171.	4.	1.	95.	1.	15.	90.	0.	5.	20.
TIN ORE	179668.	2.	1.	4375.	*	1313.	*	29.	73.	20.
ZINC ORE	8055.	0.	1.	140.	34.	19.	154.	0.	0.	22.
COTTON	1.	2.	0.	0.	0.	16.	0.	0.	0.	0.
FLAX SEED	20.	1.	0.	0.	0.	25.	0.	0.	0.	0.
MILK BYPRODUCTS	2.	3.	0.	0.	0.	20.	0.	0.	0.	0.
LUMBER	1042.	1.	0.	0.	0.	12.	0.	0.	3.	18.
SEA WATER	125964.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SOYBEAN	29.	3.	0.	0.	0.	12.	0.	0.	0.	0.
TUNG NUTS	41.	1.	5.	0.	0.	70.	*	0.	1.	80.
WATER	37826.	3.	0.	17.	2.	0.	3.	0.	0.	0.
WHEAT	6.	3.	0.	0.	0.	10.	0.	0.	0.	0.
MISC.	641.	0.	0.	0.	0.	0.	0.	0.	6.	0.
STEAM	461545.	5.	1.	1.	0.	10.	0.	0.	16.	0.
LIMESTONE	82391.	3.	3.	0.	0.	5.	0.	0.	2.	0.
COAL, BY PROD	189514.	1.	1.	6.	1.	6.	13.	1.	0.	10.
ELECTRICITY	19179520.	3.	0.	0.	0.	0.	0.	0.	1.	0.

BULK MATERIAL REQUIREMENTS FOR CAD SULFIDE/INDIUM PHOS.

SOLAR SCENARIO:
INTRODUCTION YEAR 1985
CUMULATIVE CAPACITY 2000 = 50. GWE

FEATURES	MATERIAL USAGE MT	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODN GROWTH RATE 1976-2000	SOLAR'S % OF WORLD CON. CAPTION	% FROM LOWEST COUNTRY	COST PER UNIT OUTPUT \$/KW	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	50.	10. %/YR	10.	35.	50.	50.
MATERIALS							
ALUMINUM	17821626.	0.	7.	4.	13.	350. *	14.
ANTIMONY	119700.	100. *	5.	7.	22.	9.	55. *
CADMIUM	3100.	100. *	4.	1.	15.	0.	57. *
CEMENT	17655720.	0.	3.	0.	10.	12.	4.
CHROMIUM	40.	0.	3.	0.	31.	0.	100. *
COPPER	1387910.	1.	6.	1.	12.	37.	45.
GLASS, FIBER	1796800.	0.	7.	6.	5.	10.	2.
GLASS, SODA LTH	4661760.	0.	3.	4.	0.	28.	0.
GOLD	3000.	40.	3.	22. *	00. *	340. *	50. *
INDIUM	2160.	100. *	10. *	76. *	19.	14.	75. *
IRON, STEEL	11231966.	1.	3.	0.	16.	77. *	10.
LEAD	5074514.	13.	5.	7.	11.	56. *	18.
MAGNESIUM	167470.	30.	6.	3.	20.	7.	0.
MANGANESE	62215.	100. *	2.	0.	9.	0.	99. *
NICKEL	120.	7.	3.	0.	28.	0.	75. *
PHOSPHOROUS	440.	0.	0.	0.	13.	0.	0.
PORCELAIN	680.	0.	0.	0.	10.	0.	0.
SAND & GRAVEL	35335920.	0.	4.	0.	10.	1.	0.
STONE	69453360.	0.	3.	0.	3.	4.	0.
SILICON	125728.	0.	0.	0.	14.	2.	0.
SULFUR	920.	31.	3.	0.	15.	0.	15.
SULFURIC ACID	1452000.	20.	0.	0.	15.	1.	0.
TIN	17097.	25.	0.	1.	29.	5.	65. *
ZINC	1500.	25.	3.	0.	21.	0.	88. *
STAINLESS STEEL	1790740.	0.	3.	2.	10.	36.	15.
FERROCHROME	58618.	5.	5.	0.	18.	3.	50. *
LINSEED OIL	6800.	0.	1.	0.	5.	0.	1.
ACRYLIC	143800.	0.	7.	1.	5.	4.	1.
ALKYD RESIN	13600.	0.	7.	0.	5.	0.	1.
EPOXY - FIBERGL	2294.	0.	7.	0.	5.	0.	5.
CALCIUM	86280.	0.	3.	0.	9.	0.	2.
GLUE, PHENOL FOR	20120.	0.	7.	1.	5.	0.	5.
LUMBER, SOFTWOOD	985300.	0.	4.	0.	20.	1.	12.
PHENOLIC RESIN	31760.	0.	7.	0.	0.	1.	1.
PLASTIC, RESIN	18000.	0.	7.	0.	0.	0.	3.
POLYESTER RESIN	8160.	0.	7.	0.	5.	0.	0.
PVC PLASTIC	18780.	0.	7.	0.	5.	0.	0.
RUBBER, SBR	29980.	0.	6.	0.	5.	0.	4.
TEFLON	3900.	0.	7.	1.	5.	1.	1.
NYLON	600.	0.	7.	0.	5.	0.	1.
POLYPROPYLENE	414000.	0.	7.	1.	5.	0.	1.
COTTON FIBERS	641.	0.	3.	0.	16.	0.	1.
KRAFT FIBERS	275.	0.	3.	0.	10.	0.	15.
TUNG OIL	20400.	0.	0.	6.	45. *	1.	70. *
EVA	299200.	0.	7.	2.	5.	4.	5.

RAW MATERIAL REQUIREMENTS FOR CRD SULFIDE/INDIUM PHOS.

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50. GWE

FACTORS	RAW MATERIAL USAGE (1000MT)	WORLD PRODUCTN GROWTH RATE	MAX. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KW OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	7. %/YR	10.	400.	300.	60.	300.	200.	50.	50.
MATERIALS										
ANTIMONY ORE	12569.	5.	7.	1327.	*	1230.	*	22.	78.	67.
ASBESTOS	5.	3.	0.	539.	*	28.		34.	190.	179.
BAUXITE	90998.	5.	5.	2438.	*	325.	*	28.	15.	9.
BORATE	449.	5.	1.	11.		0.		50.	10.	0.
BUTANE	34.	1.	0.	20.		2.		10.	12.	1.
CHROMITE	1288.	4.	3.	3473.	*	479.	*	27.	18.	4.
CLAYS	2713.	2.	0.	0.		0.		10.	0.	0.
COAL	61282.	1.	0.	6.		1.		6.	13.	1.
COAL BITUM./LIGHT	2.	1.	0.	6.		1.		6.	13.	1.
COPPER ORE	305340.	6.	1.	1000.	*	438.	*	12.	85.	25.
FELDSPAR	454.	3.	1.	5.		0.		10.	13.	0.
FLUORSPAR	1352.	5.	1.	711.	*	152.		22.	201.	120.
GOLD ORE	366000.	22.	*	3445.	*	144.		58.	120.	79.
GYPSUM	819.	3.	0.	175.		0.		10.	11.	0.
IRON ORE	74868.	5.	0.	56.		7.		11.	15.	6.
LEAD ORE	168981.	3.	7.	87.		43.		11.	129.	14.
MANGANESE ORE	371.	3.	0.	100.		4.		24.	6.	11.
NATURAL GAS	2709.	5.	0.	245.		277.		30.	93.	9.
NICKEL ORE	14338.	3.	1.	4510.	*	5411.	*	37.	54.	23.
NITROGEN, FIXED	1.	4.	0.	0.		0.		5.	0.	0.
PETROLEUM	2368.	3.	0.	562.	*	210.		22.	110.	36.
PHOSPHATE ROCK	5.	6.	0.	48.		0.		13.	29.	0.
PROPANE	878.	1.	0.	192.		23.		10.	136.	11.
SALT	68154.	6.	1.	0.		0.		5.	0.	0.
SAND/GRAVEL	43222.	4.	0.	0.		0.		0.	0.	0.
STONE	69453.	3.	0.	0.		0.		3.	0.	0.
SULFUR	5096.	4.	1.	95.		1.		15.	90.	0.
TIN ORE	170968.	2.	1.	4376.	*	1313.	*	29.	73.	30.
ZINC ORE	1808.	0.	0.	147.		33.		19.	154.	0.
COTTON	1.	2.	0.	0.		0.		16.	0.	0.
FLAX SEED	20.	1.	0.	0.		0.		25.	0.	0.
MILK BYPRODUCTS	2.	3.	0.	0.		0.		20.	0.	0.
LUMBER	1042.	1.	0.	0.		0.		12.	0.	0.
SEA WATER	125964.	0.	0.	0.		0.		0.	0.	0.
SOYBEAN	39.	3.	0.	0.		0.		12.	0.	0.
TUNG NUTS	41.	1.	5.	0.		0.	*	70.	0.	0.
WATER	71382.	3.	0.	17.		2.		0.	3.	0.
WHEAT	6.	3.	0.	0.		0.		10.	0.	0.
MISC.	813.	0.	0.	0.		0.		0.	0.	0.
STEAM	464583.	5.	1.	1.		0.		10.	0.	0.
LIMESTONE	92203.	3.	4.	0.		0.		5.	0.	0.
ZINC, BY PRODUCT	12096.	0.	1.	149.		34.		19.	155.	0.
COAL, BY PROD	188624.	1.	1.	6.		1.		6.	13.	1.
ELECTRICITY	1628196.	3.	0.	0.		0.		0.	0.	0.

BULK MATERIAL REQUIREMENTS FOR COPPER OXIDE MIS

SOLAR SCENARIO:
 INTRODUCTION YEAR - 1985
 CUMULATIVE CAPACITY 2000 - 50 GWE

FACTORS	MATERIAL USAGE MT	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODN GROWTH RATE 1976-2000	SOLAR'S % OF WORLD CONSUMPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/KW	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	50.	10. %/YR	10.	35.	50.	50.
MATERIALS							
ALUMINUM	17821626.	0.	7.	4.	13.	250. *	14.
ANTIMONY	119700.	100. *	5.	7.	22.	9.	55. *
CEMENT	17050720.	0.	3.	0.	18.	12.	4.
COPPER	1423010.	1.	6.	1.	12.	30.	45.
GLASS, FIBER	1796000.	0.	7.	6.	5.	12.	2.
GLASS, SODA LIM	1360.	0.	3.	0.	5.	0.	5.
IRON, STEEL	12718970.	1.	3.	0.	16.	87. *	10.
LEAD	5074514.	13.	7.	7.	11.	56. *	18.
MAGNESIUM	167479.	30.	6.	3.	26.	7.	0.
FERROMANGANESE	71891.	100. *	22.	0.	9.	0.	99. *
PORCELAIN	600.	0.	0.	0.	10.	0.	0.
SAND & GRAVEL	35335920.	0.	4.	0.	10.	1.	0.
STONE	69453360.	0.	3.	0.	3.	4.	0.
SILICON	125728.	0.	3.	0.	14.	2.	0.
SULFURIC ACID	1452000.	20.	5.	0.	15.	1.	0.
TIN	17067.	25.	1.	1.	29.	5.	65. *
ZINC	1300.	25.	3.	0.	21.	6.	88. *
STAINLESS STEEL	1790740.	0.	2.	2.	10.	35.	15.
FERROCHROME	50618.	5.	5.	0.	10.	3.	50. *
LINSEED OIL	6000.	0.	1.	0.	5.	0.	1.
ACRYLIC	143800.	0.	7.	1.	5.	4.	1.
ALKYD RESIN	13600.	0.	7.	0.	5.	0.	1.
EPONY RESIN	1014.	0.	7.	0.	5.	0.	5.
EPONY - FIBERGL	400.	0.	7.	0.	5.	0.	5.
CALCIUM	86200.	0.	3.	0.	9.	0.	7.
GLUE, PHENOL, FOR	20120.	0.	7.	1.	5.	0.	5.
LUMBER, SOFTWOOD	985800.	0.	4.	0.	20.	1.	12.
PHENOLIC RESIN	31766.	0.	7.	0.	5.	1.	1.
PLASTIC, RESIN	10000.	0.	7.	0.	5.	0.	3.
POLYESTER RESIN	0160.	0.	7.	0.	5.	0.	0.
PVC PLASTIC	10700.	0.	7.	0.	5.	0.	0.
RUBBER, SBR	29900.	0.	6.	0.	5.	0.	4.
TEFLON	3000.	0.	7.	1.	5.	1.	1.
NYLON	600.	0.	7.	0.	5.	0.	1.
POLYPROPYLENE	414000.	0.	7.	1.	5.	0.	1.
COTTON FIBERS	641.	0.	3.	0.	16.	0.	1.
KRAFT FIBERS	275.	0.	3.	0.	10.	0.	15.
TUNG OIL	20400.	0.	0.	6.	45. *	1.	70. *
EVA	299200.	0.	7.	0.	5.	4.	5.

RAW MATERIAL REQUIREMENTS FOR COPPER OXIDE MTS

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50 GWE

FACTORS	RAW MATERIAL USAGE (1000MT)	WORLD PRODUCTN GROWTH RATE	MAX. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KWH OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS		7. %/YR	10.	400.	300.	50.	300.	200.	50.	50.
MATERIALS										
ANTIMONY ORE	12569.	5.	7.	1327. *	1230. *	22.	78.	67.	3.	50. *
ASBESTOS	5.	3.	0.	539. *	28.	34.	190.	129.	0.	90. *
BAUXITE	90991.	5.	5.	2438. *	325. *	28.	15.	9.	27.	89. *
BORATE	449.	5.	1.	11.	0.	50.	10.	0.	1.	3.
BUTANE	34.	1.	0.	20.	2.	10.	12.	1.	0.	0.
CHROMITE	1280.	4.	3.	3473. *	439. *	27.	18.	4.	0.	66. *
CLAYS	2727.	2.	0.	0.	0.	10.	0.	0.	1.	0.
COAL	59950.	1.	0.	0.	1.	0.	13.	1.	18.	10.
COPPER ORE	313270.	0.	1.	1000. *	430. *	12.	85.	75.	12.	37.
FELDSPAR	0.	3.	0.	5.	0.	10.	13.	0.	0.	5.
FLUORSPAR	1362.	5.	1.	711. *	152.	22.	201.	100.	2.	50. *
GYPSUM	819.	3.	0.	175.	0.	10.	11.	0.	0.	37.
IRON ORE	82209.	5.	0.	56.	7.	11.	15.	6.	3.	35.
LEAD ORE	158981.	3.	7.	87.	43.	11.	129.	14.	10.	33.
MANGANESE ORE	414.	3.	0.	100.	4.	24.	6.	11.	1.	100. *
NATURAL GAS	2401.	5.	0.	245.	277.	30.	93.	9.	5.	5.
NICKEL ORE	14326.	3.	1.	4509. *	5411. *	37.	54.	23.	0.	70. *
NITROGEN, FIXED	1.	4.	0.	0.	0.	5.	0.	0.	0.	10.
PETROLEUM	2307.	3.	0.	562. *	210.	22.	110.	36.	3.	40.
PROPANE	879.	1.	0.	192.	23.	10.	136.	11.	1.	5.
SALT	62614.	6.	1.	0.	0.	5.	0.	0.	30.	9.
SAND/GRAVEL	40012.	4.	0.	0.	0.	0.	0.	0.	0.	0.
STONE	69453.	3.	0.	0.	0.	3.	0.	0.	4.	0.
SULFUR	5056.	4.	1.	95.	1.	15.	90.	0.	0.	20.
TIN ORE	178503.	2.	1.	4375. *	1313. *	20.	73.	20.	2.	60. *
ZINC ORE	532.	0.	0.	146.	33.	19.	154.	0.	0.	88. *
COTTON	1.	2.	0.	0.	0.	16.	0.	0.	0.	1.
FLAX SEED	20.	1.	0.	0.	0.	25.	0.	0.	0.	20.
MILK BYPRODUCTS	2.	3.	0.	0.	0.	20.	0.	0.	0.	1.
LUMBER	1043.	1.	0.	0.	0.	12.	0.	0.	3.	10.
SEA WATER	125964.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SOYBEAN	39.	3.	0.	0.	0.	12.	0.	0.	0.	0.
TUNG NUTS	41.	1.	5.	0.	0.	70. *	0.	0.	1.	80. *
WATER	37942.	3.	0.	17.	2.	0.	3.	0.	0.	0.
WHEAT	6.	3.	0.	0.	0.	10.	0.	0.	0.	0.
MISC.	654.	0.	0.	0.	0.	0.	0.	0.	7.	0.
STEAM	463178.	5.	1.	1.	0.	10.	0.	0.	16.	0.
LIMESTONE	83159.	3.	3.	0.	0.	5.	0.	0.	3.	2.
COAL, BY PROD	189514.	1.	1.	6.	1.	6.	13.	1.	0.	10.

BULK MATERIAL REQUIREMENTS FOR GARS 1 XTL HETEROJUNCT.

SOLAR SCENARIO:
INTRODUCTION YEAR - 1985
CUMULATIVE CAPACITY 2000 - 50 GWE

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODN GROWTH RATE 1975-2000	SOLAR'S % OF WORLD CONSUMPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/KW	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	50.	10. %/YR	10.	35.	50.	50.
MATERIALS							
ALUMINUM	10010001.	0.	7.	2.	13.	197. *	14.
ANTIMONY	119700.	100. *	5.	7.	22.	9.	55. *
ARSENIC	95720.	100. *	2.	22. *	34.	1.	37.
CEMENT	9560000.	0.	3.	0.	10.	7.	4.
COPPER	942330.	1.	6.	1.	12.	25.	45.
GALLIUM	89040.	100. *	33. *	100. *	45. *	1227. *	75. *
GERMANIUM	2.	100. *	2.	0.	29.	0.	19.
GLASS, FIBER	1730000.	0.	7.	6.	5.	12.	2.
GLASS, SODA LIM	1509940.	0.	3.	1.	5.	9.	5.
GOLD	2140.	40.	3.	14. *	50. *	203. *	50. *
IRON, STEEL	11203040.	1.	3.	0.	16.	77. *	10.
LEAD	5669044.	13.	5.	7.	11.	56. *	18.
MAGNESIUM	93000.	30.	6.	2.	26.	4.	0.
FERROMANGANESE	63741.	100. *	2.	0.	9.	0.	99. *
PORCELAIN	600.	0.	0.	0.	10.	0.	0.
SAND + GRAVEL	19915118.	0.	4.	0.	10.	1.	0.
STONE	38946956.	0.	3.	0.	3.	2.	0.
SILICON	81040.	0.	3.	0.	14.	2.	8.
SULFURIC ACID	1452000.	20.	5.	0.	15.	1.	0.
TIN	17916.	25.	2.	1.	29.	5.	65. *
TITANIUM	44.	0.	0.	0.	50. *	0.	50. *
ZINC	1560.	25.	0.	0.	21.	0.	88. *
STAINLESS STEEL	1332800.	0.	0.	2.	10.	27.	15.
FERROCHROME	32550.	5.	0.	0.	18.	1.	50. *
LINSEED OIL	6000.	0.	1.	0.	5.	0.	1.
ACRYLIC	100000.	0.	7.	1.	50.	3.	1.
ALKYD RESIN	17600.	0.	7.	0.	50.	0.	1.
EPOXY RESIN	1814.	0.	7.	0.	50.	0.	5.
EPOXY - FIBERGL	400.	0.	7.	0.	5.	0.	5.
CALCIUM	86200.	0.	3.	0.	9.	0.	2.
GLUE, PHENOL FOR	20120.	0.	7.	1.	50.	0.	5.
LUMBER, SOFTWOOD	905000.	0.	4.	0.	20.	1.	12.
PHENOLIC RESIN	31760.	0.	7.	0.	50.	1.	1.
PLASTIC, RESIN	17700.	0.	7.	0.	50.	0.	3.
POLYESTER RESIN	8160.	0.	7.	0.	50.	0.	0.
PVC PLASTIC	12200.	0.	7.	0.	50.	0.	0.
RUBBER, SGR	16500.	0.	6.	0.	50.	0.	4.
TEFLON	2100.	0.	7.	0.	50.	0.	1.
NYLON	340.	0.	7.	0.	50.	0.	1.
POLYPROPYLENE	414000.	0.	7.	1.	50.	5.	1.
COTTON FIBERS	641.	0.	3.	0.	16.	0.	1.
KRAFT FIBERS	275.	0.	3.	0.	10.	0.	15.
TUNG OIL	20400.	0.	0.	0.	45. *	1.	70. *

RAW MATERIAL REQUIREMENTS FOR GAS J. VTL HETEROJUNCT.

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50. GWE

FACTORS	RAW MATERIAL USAGE (1000MT)	WORLD PRODUCTN GROWTH RATE	RAW % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KW OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS		7. 2%/YR	10.	400.	300.	60.	300.	200.	50.	50.
MATERIALS										
ANTIMONY ORE	12560.	5.	7.	1327.	1230.	22.	70.	67.	3.	50.
ARSENIC TRIOXIDE	153.	2.	22.	141.	20.	34.	33.	59.	1.	96.
ASBESTOS	5.	2.	0.	539.	28.	34.	190.	129.	0.	90.
BAUXITE	51530.	5.	3.	2339.	312.	28.	14.	9.	15.	89.
BOURITE	449.	5.	1.	11.	0.	50.	10.	0.	1.	3.
BUTANE	19.	1.	0.	20.	2.	10.	12.	1.	0.	5.
CHROMITE	931.	4.	3.	3438.	435.	27.	18.	4.	1.	60.
CLAYS	1504.	2.	0.	0.	0.	10.	0.	0.	1.	0.
COAL	53608.	1.	0.	6.	1.	6.	13.	1.	17.	10.
COPPER ORE	207313.	0.	0.	995.	436.	12.	85.	24.	0.	37.
FELDSPAR	146.	3.	0.	5.	0.	10.	13.	0.	0.	5.
FLUORSPAR	803.	5.	0.	707.	152.	22.	201.	120.	2.	50.
GOLD ORE	214000.	14.	*	2958.	123.	58.	115.	76.	60.	89.
GYPSON	459.	0.	0.	175.	0.	10.	11.	0.	0.	37.
IRON ORE	71633.	5.	0.	55.	7.	11.	15.	6.	0.	30.
LEAD ORE	168826.	7.	0.	87.	43.	11.	129.	14.	19.	33.
MANGANESE ORE	367.	0.	0.	100.	4.	24.	6.	11.	1.	100.
NATURAL GAS	1530.	5.	0.	245.	277.	30.	93.	9.	0.	5.
NICKEL ORE	10663.	1.	4489.	0.	5387.	37.	54.	23.	0.	75.
NITROGEN, FIXED	1.	4.	0.	0.	0.	5.	0.	0.	0.	10.
PETROLEUM	1521.	3.	0.	562.	210.	22.	110.	36.	2.	40.
PROPANE	547.	1.	0.	192.	23.	10.	136.	11.	0.	5.
RUTILE	0.	1.	0.	221.	81.	90.	44.	17.	0.	100.
SALT	49944.	6.	1.	0.	0.	5.	0.	0.	30.	9.
SAND/GRAVEL	24490.	4.	0.	0.	0.	0.	0.	0.	1.	0.
STONE	38947.	3.	0.	0.	0.	3.	0.	0.	0.	0.
SULFUR	3436.	2.	0.	94.	1.	15.	90.	0.	0.	20.
TIN ORE	179162.	2.	1.	4370.	1313.	23.	73.	20.	0.	60.
ZINC ORE	904.	0.	0.	140.	33.	10.	151.	0.	0.	80.
COTTON	1.	2.	0.	0.	0.	16.	0.	0.	0.	1.
FLAX SEED	20.	1.	0.	0.	0.	25.	0.	0.	0.	20.
MILK BYPRODUCTS	2.	3.	0.	0.	0.	20.	0.	0.	0.	1.
LUMBER	1027.	1.	0.	0.	0.	12.	0.	0.	0.	10.
SEA WATER	72268.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SOYBEAN	39.	3.	0.	0.	0.	12.	0.	0.	0.	0.
TUNG NUTS	41.	1.	5.	0.	0.	70.	0.	0.	1.	80.
WATER	54324.	3.	0.	17.	2.	0.	3.	0.	0.	0.
WHEAT	6.	3.	0.	0.	0.	10.	0.	0.	0.	0.
MISC.	583.	0.	0.	0.	0.	0.	0.	0.	10.	0.
STEAM	301980.	5.	1.	0.	0.	10.	0.	0.	0.	0.
LIMESTONE	155831.	3.	6.	0.	0.	5.	0.	0.	0.	2.
BAUXITE, BY PROD	4452001.	11.	*	74.	13340.	28.	33.	20.	0.	89.
ZINC, BY PRODUCT	17.	0.	0.	146.	33.	19.	154.	0.	0.	88.
COAL, BY PROD	186373.	1.	1.	6.	1.	6.	13.	1.	0.	10.
ZINC 3 BYPRODUCT	17.	0.	0.	146.	33.	19.	154.	0.	0.	88.
ZINC 2 BYPRODUCT	17.	0.	0.	146.	33.	19.	154.	0.	0.	88.

BULK MATERIAL REQUIREMENTS FOR GAAS 1 XTL HETERODJUNCT

SOURCE SCENARIO:
 INTRODUCTION YEAR - 1985
 CONSTRUCTION CAPACITY 2000 - 30 G/S

FACTORS	MATERIAL USAGE MT	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODN GROWTH RATE 1976-2000	SOLAR'S % OF WORLD PROD. OPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/WH	NET PERCENT IMPORTED
THRESHOLD LEVELS	- -	50.	10. %/YR	10.	35	50.	50
MATERIALS							
ALUMINUM	2604000.	0.	7.	1.	13.	197. *	14.
ANTIMONY	23940.	100. *	5.	2.	22.	9.	55. *
ARSENIC	19141.	100. *	1.	5.	34.	1.	37.
GERMANIUM	1911131.	0.	3.	0.	10.	7.	4.
COPPER	188166.	1.	6.	0.	12.	25.	45.
GALLIUM	17008.	100. *	24. *	98. *	45. *	1227. *	75. *
GERMANIUM	9.	100. *	2.	0.	29.	0.	19.
GLASS, FIBER	370200.	0.	7.	1.	5.	12.	2.
GLASS, SOLAR CELL	313000.	0.	3.	0.	5.	9.	5.
GOLD	428.	40.	2.	3.	58. *	203. *	58. *
IRON, STEEL	2240688.	1.	3.	0.	16.	77. *	10.
LEAD	1013969.	13.	5.	1.	11.	56. *	10.
NIOBIUM	10000.	30.	0.	0.	26.	4.	0.
FLUORINE/NIOBIUM	12143.	100. *	2.	0.	9.	0.	99. *
PORCELAIN	136.	0.	0.	0.	10.	0.	0.
SAND & GRAVEL	3963024.	0.	4.	0.	10.	1.	0.
STONE	7709392.	0.	3.	0.	3.	2.	0.
SILICON	16200.	0.	3.	0.	14.	2.	0.
SULFURIC ACID	290400.	20.	5.	0.	15.	1.	0.
TIN	3583.	25.	2.	0.	29.	5.	65. *
TITANIUM	9.	0.	5.	0.	50. *	0.	50. *
ZINC	312.	25.	3.	0.	21.	0.	88. *
STAINLESS STEEL	266576.	0.	3.	0.	10.	27.	15.
FERROCHROME	6510.	5.	5.	0.	18.	1.	50. *
LINSEED OIL	1360.	0.	1.	0.	5.	0.	1.
ACRYLIC	21200.	0.	7.	0.	5.	3.	1.
ALKYD RESIN	2720.	0.	7.	0.	5.	0.	1.
EPOXY RESIN	363.	0.	7.	0.	5.	0.	5.
EPOXY - FIBERGLASS	96.	0.	7.	0.	5.	0.	5.
CALCIUM	17256.	0.	3.	0.	9.	0.	2.
GLASS, PHENOL FOR	4824.	0.	7.	0.	5.	0.	5.
LUMBER, SOFTWOOD	197176.	0.	4.	0.	28.	1.	12.
PHENOLIC RESIN	6203.	0.	7.	0.	5.	1.	1.
PLASTIC, RESIN	3540.	0.	7.	0.	5.	0.	3.
POLYESTER RESIN	1632.	0.	7.	0.	5.	0.	0.
PVC PLASTIC	2456.	0.	7.	0.	5.	0.	0.
RUBBER, SBR	3316.	0.	6.	0.	5.	0.	4.
TEFLON	436.	0.	7.	0.	5.	0.	1.
NYLON	68.	0.	7.	0.	5.	0.	1.
POLYPROPYLENE	82000.	0.	7.	0.	5.	5.	1.
COTTON FIBERS	128.	0.	3.	0.	10.	0.	1.
KRAFT FIBERS	55.	0.	3.	0.	10.	0.	15.
TUNG OIL	4088.	0.	0.	1.	45. *	1.	70. *

RAW MATERIAL REQUIREMENTS FOR GAS 1 X 11 HETEROJUNCTION

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 10. GWE

FACTORS	RAW MATERIAL USAGE (100GWT)	WORLD PRODUCTN GROWTH RATE	RAW % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KWH OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVEL 5		% /YR	10.	400	300.	60.	300.	200.	50.	50.
MATERIALS										
ANTIMONY ORE	2011.	5.	2.	1239.	*	1149.	*	22.	76.	35.
ARSENIC TRIOXIDE	31.	1.	5.	124.		18.		34.	31.	46.
ASBESTOS	1.	3.	0.	539.	*	28.		34.	190.	179.
BAUXITE	10300.	5.	1.	2236.	*	290.		20.	14.	9.
BORATE	90.	5.	0.	11.		0.		50.	10.	0.
BUTANE	4.	1.	0.	20.		2.		10.	12.	1.
CHROMITE	106.	3.	1.	3367.	*	426.	*	27.	17.	4.
CLAYS	319.	2.	0.	0.		0.		10.	0.	0.
COAL	10732.	1.	0.	6.		1.		6.	13.	1.
COPPER ORE	41463.	6.	0.	986.	*	432.	*	12.	85.	24.
FELDSPAR	29.	3.	0.	5.		0.		10.	13.	0.
FLUORSPAR	161.	5.	0.	703.	*	151.		22.	200.	120.
GOLD ORE	42800.	3.	3.	2410.	*	101.		58.	110.	73.
GYPNUM	92.	0.	0.	175.		0.		10.	11.	0.
IRON ORE	14327.	5.	0.	55.		7.		11.	15.	6.
LEAD ORE	33765.	1.	0.	79.		39.		11.	126.	14.
MANGANESE ORE	73.	5.	0.	100.		4.		24.	6.	11.
NATURAL GAS	306.	5.	0.	245.		277.		30.	93.	9.
NICKEL ORE	2133.	3.	0.	4442.	*	5330.	*	37.	54.	23.
NITROGEN, FIXED	0.	4.	0.	0.		0.		5.	0.	0.
PETROLEUM	304.	3.	0.	562.	*	210.		22.	110.	36.
PROPANE	109.	1.	0.	191.		23.		10.	136.	11.
RUTILE	0.	1.	0.	221.		81.		90.	44.	17.
SALT	9989.	6.	0.	0.		0.		5.	0.	0.
SAND/GRAVEL	4900.	4.	0.	0.		0.		0.	0.	0.
STONE	7759.	3.	0.	0.		0.		3.	0.	0.
SULFUR	627.	3.	0.	93.		1.		15.	90.	0.
TIN ORE	35032.	2.	0.	4341.	*	1302.	*	29.	73.	70.
ZINC ORE	151.	0.	0.	146.		33.		19.	154.	8.
COTTON	0.	2.	0.	0.		0.		16.	0.	0.
FLAX SEED	4.	1.	0.	0.		0.		25.	0.	0.
MILK BYPRODUCTS	0.	3.	0.	0.		0.		20.	0.	0.
LUMBER	205.	1.	0.	0.		0.		12.	0.	0.
SEA WATER	14451.	0.	0.	0.		0.		0.	0.	0.
SOYBEAN	8.	0.	0.	0.		0.		12.	0.	0.
TUNG NUTS	8.	0.	1.	0.		0.		70.	0.	1.
WATER	10865.	3.	0.	17.		0.		2.	0.	0.
WHEAT	1.	0.	0.	0.		0.		10.	0.	0.
MISC.	117.	5.	0.	0.		0.		0.	0.	0.
STEAM	60396.	5.	0.	1.		0.		10.	0.	10.
LIMESTONE	31166.	3.	1.	0.		0.		5.	0.	6.
BAUXITE, BY PROD	890400.	7.	*	36.	*	4436.	*	592.	18.	11.
ZINC, BY PRODUCT	3.	0.	0.	146.		33.		19.	154.	8.
COAL, BY PROD	37275.	1.	0.	6.		1.		6.	13.	1.
ZINC 3 BYPRODUCT	3.	0.	0.	146.		33.		19.	154.	8.
ZINC 2 BYPRODUCT	3.	0.	0.	146.		33.		19.	154.	8.

BULK MATERIAL REQUIREMENTS FOR GA AS 1 XTL-500X FRESNEL

SOLAR SCENARIO:
INTRODUCTION YEAR 1985
CUMULATIVE CAPACITY 2000 50 GWE

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY PRODUCT	WORLD PROD GROWTH RATE 1976-2000	SOLAR'S % OF WORLD CONSUMPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/KW	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	50.	10. %/YR	10.	35.	50.	50.
MATERIALS							
ALUMINUM	7718001.	0	7.	2	13	152 *	14.
ANTIMONY	119700.	100 *	5.	7.	22	9	55. *
ARSENIC	473.	100 *	0.	0.	31	0.	37.
CEMENT	2200720.	0	3.	0.	12	2.	4.
COPPER	1652960.	1.	6.	1.	12	44.	45.
GALLIUM	446	100 *	9.	59 *	45 *	6.	75. *
GERMANIUM	0.	100 *	0.	0.	29	0.	19.
GLASS, FIBER	1790000.	0.	7.	6.	5	12	2.
GLASS, SODA LIN	1360.	0.	3.	0.	0.	0.	0.
GOLD	5.	40.	0.	0.	58 *	1.	58. *
INDIUM	140.	100 *	4.	17 *	19	1.	75. *
IRON, STEEL	20622916.	1.	3.	0.	16	141 *	10.
LEAD	5076000.	13.	5.	7.	11.	56 *	18.
PERMANGANATE	112765.	100 *	0.	0.	9	0.	90. *
MOLYBDENUM	120.	42.	5.	0.	16	0.	4.
NICKEL	20.	7.	0.	0.	28	0.	75. *
PORCELAIN	680.	0.	0.	0.	10	0.	0.
SAND, GRAVEL	4602920.	0.	4.	0.	10	0.	0.
STONE	9204360.	0.	3.	0.	3	0.	0.
SILICON	27140.	0.	0.	0.	14	1.	8.
SULFURIC ACID	1452000.	20.	5.	0.	15	1.	0.
TIN	21420.	25.	1.	1.	29	5.	65. *
TITANIUM	0.	0	0.	0.	50 *	0.	50. *
ZINC	1360.	25.	0.	0.	21	0.	88. *
STAINLESS STEEL	1061800.	0.	2.	1.	10	21	15.
LINSEED OIL	6000.	0.	1.	0.	5	0.	1.
ACRYLIC	1472000.	0.	N.	0.	5	36	1.
ALKYD RESIN	13600.	0.	N.	0.	5	0.	1.
EPOXY RESIN	1814.	0.	N.	0.	5	0.	5.
EPOXY - FIBERGL	480.	0.	N.	0.	5	0.	5.
CALCIUM	86280.	0.	N.	0.	5	0.	2.
GLUE, PHENOL FOR	20120.	0.	N.	1.	5	0.	5.
LUMBER, SOFTWOOD	905000.	0.	4.	0.	20	1.	12.
PHENOLIC RESIN	37766.	0.	N.	0.	5	1.	1.
PLASTIC, RESIN	19020.	0.	N.	0.	5	0.	3.
POLYESTER RESIN	8160.	0.	N.	0.	5	0.	0.
PVC PLASTIC	21200.	0.	N.	0.	5	0.	0.
RUBBER, SBR	416000.	0.	0.	0.	5	5.	4.
TEFLON	4700.	0.	N.	1.	5	1.	1.
NYLON	720.	0.	N.	0.	5	0.	1.
POLYPROPYLENE	414000.	0.	N.	1.	5	5.	1.
COTTON FIBERS	641.	0.	N.	0.	16	0.	1.
KRAFT FIBERS	275.	0.	N.	0.	10	0.	15.
TUNG OIL	20400.	0.	0.	0.	45 *	1.	70. *
ABS	2224000.	0.	N.	0.	5	40.	5.
ALUMINUM OXIDE	8740.	0.	N.	0.	13	0.	14.

RAW MATERIAL REQUIREMENTS FOR GA AS 1 XTL-500X FRESNEL

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50. ONE

FACTORS	RAW MATERIAL USAGE (1000MT)	WORLD PRODUCTN GROWTH RATE	MAX. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KW OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	7. %/YR	10.	400.	300.	60.	300.	200.	50.	50.
MATERIALS										
ANTIMONY ORE	12569.	5.	7.	1327 *	1230 *	22.	78.	67.	3.	55. *
ARSENIC TRIOXIDE	1.	0.	0.	128.	17.	34.	31.	35.	0.	96. *
ASBESTOS	5.	3.	0.	539 *	28.	34.	190.	129.	0.	90. *
BAUXITE	48011.	5.	2.	2310 *	308 *	29.	14.	9.	12.	89. *
BORATE	449.	5.	1.	11.	0.	50.	10.	0.	1.	3.
BUTANE	462.	1.	2.	20.	2.	10.	12.	1.	0.	5.
CHROMITE	677.	4.	2.	3414 *	432 *	27.	17.	4.	1.	86. *
CLAYS	616.	2.	0.	0.	0.	10.	0.	0.	0.	0.
COAL	46627.	1.	0.	6.	1.	6.	13.	1.	14.	10.
COAL BITUM/LIGHT	6.	1.	0.	6.	1.	6.	13.	1.	0.	10.
COPPER ORE	363871.	6.	1.	1003 *	440 *	12.	85.	25.	14.	37.
FELDSPAR	0.	3.	0.	5.	0.	10.	13.	0.	0.	5.
FLUORSPAR	724.	5.	0.	787 *	152.	22.	201.	120.	2.	50. *
GOLD ORE	880.	0.	0.	2275 *	95.	58.	109.	72.	0.	89. *
GYP SUM	109.	0.	0.	175.	0.	10.	11.	0.	0.	37.
IRON ORE	124766.	5.	0.	56.	7.	11.	15.	6.	5.	35.
LEAD ORE	169051.	3.	7.	87.	43.	11.	129.	14.	19.	33.
LIME	0.	3.	0.	0.	0.	31.	0.	0.	0.	2.
MANGANESE ORE	674.	3.	0.	100.	4.	24.	6.	11.	2.	100. *
MOLYBDENUM ORE	90.	5.	0.	44.	0.	16.	43.	13.	13.	4.
NATURAL GAS	1618.	5.	0.	245.	277.	30.	93.	9.	2.	5.
NICKEL ORE	8496.	3.	1.	4477 *	5373 *	37.	54.	23.	12.	75. *
NITROGEN FIXED	1.	4.	0.	0.	0.	5.	0.	0.	0.	10.
PETROLEUM	33147.	3.	0.	563 *	211.	22.	110.	36.	40.	40.
PROPANE	1722.	1.	0.	192.	23.	10.	136.	11.	1.	5.
RUTILE	0.	1.	0.	221.	81.	90. *	44.	17.	0.	100. *
SALT	37154.	6.	1.	0.	0.	5.	0.	0.	22.	9.
SAND/GRAVEL	7502.	4.	0.	0.	0.	0.	0.	0.	0.	0.
STONE	9201.	3.	0.	0.	0.	3.	0.	0.	0.	0.
SULFUR	3095.	3.	0.	94.	1.	15.	90.	0.	3.	28.
TIN ORE	214200.	0.	1.	4384 *	1315 *	29.	73.	20.	2.	65. *
ZINC ORE	534.	0.	0.	146.	33.	19.	154.	8.	0.	88. *
COTTON	1.	2.	0.	0.	0.	16.	0.	0.	0.	1.
FLAX SEED	20.	1.	0.	0.	0.	25.	0.	0.	0.	20.
MILK BYPRODUCTS	2.	3.	0.	0.	0.	20.	0.	0.	0.	1.
LUMBER	1018.	1.	0.	0.	0.	12.	0.	0.	0.	18.
SEA WATER	5214.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SOYBEAN	39.	3.	0.	0.	0.	12.	0.	0.	0.	0.
TUNG NUTS	41.	1.	5.	0.	0.	70. *	0.	0.	1.	80. *
WATER	74030.	3.	0.	17.	2.	0.	3.	0.	0.	0.
WHEAT	6.	3.	0.	0.	0.	10.	0.	0.	0.	0.
MISC.	752.	0.	0.	0.	0.	0.	0.	0.	0.	0.
STEAM	232096.	5.	1.	1.	0.	10.	0.	0.	0.	0.
LIMESTONE	42017.	3.	2.	0.	0.	5.	0.	0.	2.	2.
BAUXITE, BY PROD	22311.	0.	1.	2268 *	302 *	28.	14.	9.	0.	89. *
ZINC, BY PRODUCT	784.	0.	0.	146.	33.	19.	154.	8.	0.	88. *
COAL, BY PROD	1492876.	1.	4.	6.	1.	6.	13.	1.	0.	10.
ELECTRICITY	166627.	3.	0.	0.	0.	0.	0.	0.	0.	0.
ZINC 3 BYPRODUCT	0.	0.	0.	146.	33.	19.	154.	8.	0.	88. *
ZINC 2 BYPRODUCT	0.	0.	0.	146.	33.	19.	154.	8.	0.	88. *

BULK MATERIAL REQUIREMENTS FOR GALLIUM ARSENIDE MIS

SOLAR SCENARIO:
 INTRODUCTION YEAR - 1985
 CUMULATIVE CAPACITY 2000 - 50. GHW

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODN GROWTH RATE 1976-2000	SOL OR CONS	%S % WORLD OPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/KW	NET PERCENT IMPORTED
THRESHOLD LEVELS		50.	10. %/YR		10.	35.	50.	50.
MATERIALS								
ALUMINUM	17821626	0.	7.		4.	13.	350. *	14.
ANTIMONY	119700.	100. *	5.		7.	22.	9.	55. *
ARSENIC	1300.	100. *	0.		0.	31.	0.	37.
CEMENT	17853720.	0.	3.		0.	10.	12.	4.
COPPER	1379190.	1.	6.		1.	12.	36.	45.
GALLIUM	1200.	100. *	12. *		81. *	45. *	18.	75. *
GERMANIUM	66500.	100. *	23. *		99. *	29.	419. *	19.
GLASS, FIBER	1790000.	0.	7.		6.	0.	12.	2.
GLASS, SODA LIM	4001360.	0.	3.		4.	5.	20.	5.
GOLD	60.	40.	2.		0.	50. *	6.	50. *
IRON, STEEL	11231945.	1.	3.		0.	16.	77. *	10.
LEAD	5074514.	13.	5.		7.	11.	56. *	18.
MAGNESIUM	167470.	30.	6.		3.	20.	7.	0.
FERROMANGANESE	62915.	100. *	2.		0.	9.	0.	99. *
PORCELAIN	600.	0.	0.		0.	10.	0.	0.
SAND + GRAVEL	35335920.	0.	4.		0.	10.	1.	0.
STONE	69453360.	0.	3.		0.	3.	4.	0.
SILICON	125720.	0.	3.		0.	14.	2.	0.
SULFURIC ACID	1452000.	20.	5.		0.	15.	1.	0.
TANTALUM	100.	100. *	5.		1.	37. *	0.	60. *
TIN	32227.	25.	2.		1.	20.	0.	65. *
ZINC	1360.	25.	3.		0.	21.	0.	80. *
STAINLESS STEEL	1790740.	0.	3.		2.	10.	36.	15.
FERROCHROME	50610.	5.	0.		0.	10.	3.	50. *
LINSEED OIL	6000.	0.	1.		0.	5.	0.	1.
ACRYLIC	143000.	0.	1.		1.	5.	4.	1.
ALKYD RESIN	13600.	0.	1.		0.	5.	0.	1.
EPOXY RESIN	1814.	0.	1.		0.	5.	0.	5.
EPOXY - FIBERGL	400.	0.	1.		0.	5.	0.	5.
CALCIUM	06200.	0.	3.		0.	9.	0.	2.
GLUE, PHENOL, FOR	20120.	0.	1.		1.	5.	0.	5.
LUMBER, SOFTWOOD	905000.	0.	4.		0.	20.	1.	12.
PHENOLIC RESIN	31766.	0.	1.		0.	5.	1.	1.
PLASTIC, RESIN	10000.	0.	1.		0.	5.	0.	3.
POLYESTER RESIN	0160.	0.	1.		0.	5.	0.	0.
PVC PLASTIC	10700.	0.	1.		0.	5.	0.	0.
RUBBER, SAR	29900.	0.	0.		0.	5.	0.	4.
TEFLON	3900.	0.	1.		1.	5.	1.	1.
NYLON	600.	0.	1.		0.	5.	0.	1.
POLYPROPYLENE	414000.	0.	1.		1.	5.	5.	1.
COTTON FIBERS	641.	0.	3.		0.	10.	0.	1.
KRAFT FIBERS	275.	0.	3.		0.	10.	0.	15.
TUNG OIL	20400.	0.	0.		6.	40. *	1.	70. *
EVA	299200.	0.	1.		2.	5.	4.	5.

RAW MATERIAL REQUIREMENTS FOR GALLIUM ARSENIDE MIS

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50. GWE

FACTORS	RAW MATERIAL USAGE (1000MT)	WORLD PRODUCTN GROWTH RATE	MAX. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KW OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	7. %/YR	10	400.	300.	60.	300.	300.	50.	50.
MATERIALS										
ANTHONY ORE	12569.	5.	7.	1327.	*	1236.	*	73.	67.	3.
ARSENIC TRIOXIDE	2.	0.	0.	120.	*	17.	*	34.	31.	0.
ASBESTOS	6.	3.	0.	539.	*	28.	*	34.	190.	0.
BAUXITE	98987.	5.	5.	2433.	*	325.	*	28.	15.	27.
BORATE	449.	5.	1.	11.	0.	50.	10.	0.	0.	1.
BUTANE	34.	1.	0.	20.	2.	10.	12.	1.	0.	0.
CHROMITE	1326.	4.	4.	3476.	*	440.	*	27.	18.	4.
CLAYS	2714.	2.	0.	0.	0.	10.	0.	0.	0.	1.
COAL	66029.	1.	0.	0.	1.	0.	13.	1.	21.	10.
COPPER ORE	303422.	6.	1.	1000.	*	438.	*	12.	85.	25.
FELDSPAR	454.	3.	1.	5.	0.	10.	13.	0.	0.	0.
FLUORSPAR	1352.	0.	1.	711.	*	152.	22.	201.	120.	3.
GOLD ORE	6000.	0.	0.	2292.	*	96.	58.	109.	72.	2.
GYPHUM	819.	3.	0.	175.	0.	10.	11.	0.	0.	0.
IRON ORE	74128.	0.	0.	56.	7.	11.	15.	6.	0.	0.
LEAD ORE	168981.	3.	7.	87.	43.	11.	129.	14.	19.	13.
MANGANESE ORE	477.	3.	0.	100.	4.	24.	6.	11.	1.	100.
NATURAL GAS	2468.	0.	0.	245.	277.	30.	93.	9.	0.	5.
NICKEL ORE	14326.	3.	1.	4509.	*	5411.	*	37.	54.	23.
NITROGEN, FIXED	1.	4.	0.	0.	0.	5.	0.	0.	0.	0.
PETROLEUM	2257.	3.	0.	562.	*	210.	22.	110.	36.	3.
PROPANE	881.	1.	0.	192.	23.	10.	136.	11.	1.	5.
SALT	70693.	6.	2.	0.	0.	5.	0.	0.	42.	9.
SAND/GRAVEL	44126.	4.	0.	0.	0.	0.	0.	0.	2.	0.
STONE	69453.	3.	0.	0.	0.	3.	0.	0.	4.	0.
SULFUR	11706.	4.	2.	96.	2.	15.	91.	0.	11.	28.
TANTALUM ORE	67.	5.	1.	100.	1747.	*	37.	97.	0.	100.
TIN ORE	322268.	2.	1.	4410.	*	1323.	*	29.	73.	3.
ZINC ORE	543.	0.	0.	146.	33.	10.	154.	8.	0.	0.
COTTON	1.	2.	0.	0.	0.	16.	0.	0.	0.	0.
FLAX SEED	20.	1.	0.	0.	0.	25.	0.	0.	0.	0.
MILK BYPRODUCTS	2.	3.	0.	0.	0.	20.	0.	0.	0.	0.
LUMBER	1042.	1.	0.	0.	0.	12.	0.	0.	3.	18.
SEA WATER	125964.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SOYBEAN	39.	3.	0.	0.	0.	12.	0.	0.	0.	0.
TUNG NUTS	41.	1.	5.	0.	0.	70.	*	0.	0.	1.
WATER	46281.	3.	0.	17.	2.	0.	3.	0.	0.	0.
WHEAT	6.	3.	0.	0.	0.	10.	0.	0.	0.	0.
MISC.	1136.	0.	0.	0.	0.	0.	0.	0.	11.	0.
STEAM	467940.	5.	1.	1.	0.	10.	0.	0.	16.	0.
LIMESTONE	88138.	3.	3.	0.	0.	5.	0.	0.	4.	2.
BAUXITE, BY PROD	64000.	0.	4.	2370.	*	316.	*	28.	14.	9.
ZINC, BY PRODUCT	576356.	2.	32.	264.	60.	19.	174.	9.	0.	0.
COAL, BY PROD	189514.	1.	1.	6.	1.	6.	13.	1.	0.	0.
ZINC 3 BYPRODUCT	576356.	2.	32.	264.	60.	19.	174.	9.	0.	0.
ZINC 2 BYPRODUCT	576289.	2.	32.	264.	60.	19.	174.	9.	0.	0.

BULK MATERIAL REQUIREMENTS FOR INDIUM TIN OXIDE/P-SI

SOLAR SCENARIO:
INTRODUCTION YEAR - 1985
CUMULATIVE CAPACITY 2000 - 50 GWE

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODN GROWTH RATE 1976-2000	SOL OF WORLD CONS	% S % OPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/KW	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	50.	10. %/YR	10.	35.	50.	50.	
MATERIALS								
ALUMINUM	17828726.	0.	7.	4.	13.	351.	*	14
ANTIMONY	119700.	100.	*	5.	7.	22.	9.	50. *
BORON	0.	20.	5.	0.	47.	*	0.	0.
CEMENT	17058720.	0.	3.	0.	10.	12.	0.	4.
COPPER	1378670.	1.	6.	1.	12.	36.	45.	2.
GLASS, FIBER	1796000.	0.	7.	6.	5.	12.	0.	5.
GLASS, SODA LIM	1360.	0.	3.	0.	5.	0.	0.	75. *
INDIUM	1140.	100.	*	0.	63.	*	7.	10.
IRON, STEEL	12710370.	1.	5.	7.	11.	56.	*	18.
LEAD	5074514.	13.	6.	3.	26.	7.	0.	99. *
MAGNESIUM	167479.	30.	2.	0.	9.	0.	0.	0.
FERROMANGANESE	71891.	100.	*	0.	0.	10.	0.	0.
PORCELAIN	680.	0.	0.	0.	10.	0.	0.	0.
SAND ! GRAVEL	35335920.	0.	4.	0.	10.	1.	0.	0.
STONE	69453360.	0.	3.	0.	3.	4.	0.	0.
SILICON	183720.	0.	1.	1.	14.	3.	0.	0.
SULFURIC ACID	1452000.	20.	5.	0.	15.	1.	0.	65. *
TIN	17927.	25.	2.	1.	29.	5.	0.	80. *
ZINC	1360.	25.	4.	0.	21.	0.	15.	50. *
STAINLESS STEEL	1790740.	0.	3.	2.	10.	36.	0.	1.
FERROCHROME	58618.	5.	5.	0.	10.	3.	50.	1.
LINSEED OIL	6000.	0.	1.	0.	5.	0.	0.	1.
ACRYLIC	143800.	0.	7.	1.	5.	4.	1.	1.
ALKYD RESIN	13600.	0.	7.	0.	5.	0.	0.	1.
EPOXY RESIN	1814.	0.	7.	0.	5.	0.	0.	5.
EPOXY - FIBERGL	480.	0.	7.	0.	5.	0.	0.	5.
CALCIUM	86280.	0.	3.	0.	9.	0.	0.	2.
GLUE, PHENOL FOR	20120.	0.	7.	1.	5.	0.	0.	5.
LUMBER, SOFTWOOD	985880.	0.	4.	0.	20.	1.	12.	1.
PHENOLIC RESIN	31766.	0.	7.	0.	5.	1.	1.	2.
PLASTIC, RESIN	18800.	0.	7.	0.	5.	0.	0.	0.
POLYESTER RESIN	8160.	0.	7.	0.	5.	0.	0.	0.
PVC PLASTIC	18780.	0.	7.	0.	5.	0.	0.	4.
RUBBER, SBR	29980.	0.	6.	0.	5.	0.	1.	1.
TEFLON	3900.	0.	7.	1.	5.	1.	1.	1.
NYLON	600.	0.	7.	0.	5.	0.	0.	1.
POLYPROPYLENE	414000.	0.	7.	1.	5.	5.	1.	1.
COTTON FIBERS	641.	0.	3.	0.	10.	0.	1.	15.
KRAFT FIBERS	275.	0.	3.	0.	10.	0.	70.	*
TUNG OIL	20400.	0.	0.	6.	45.	*	1.	5.
EVA	299200.	0.	7.	2.	5.	4.		

RAW MATERIAL REQUIREMENTS FOR INDIUM TIN OXIDE/P-SI

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50. GWE

FACTORS	RAW MATERIAL USAGE (1000MT)	WORLD PRODUCTN GROWTH RATE	MAX. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KW OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS		7. %/YR	10	400	300	65	300	200	50	50
MATERIALS										
ANTIMONY ORE	12569.	5	7	1327 *	1230 *	22	78	27	3	55 *
ASBESTOS	5	3	0	539 *	28	34	190	129	0	90 *
BAUXITE	91638.	5	5	2438 *	325 *	28	15	9	27	83 *
BORATE	449.	5	1	11	0	50	10	0	1	3
BUTANE	34.	1	0	26	2	10	12	1	0	5
CHROMITE	1288.	4	3	3473 *	439 *	27	18	4	2	66 *
CLAYS	2727.	2	0	0	0	10	0	0	1	0
COAL	60050.	1	0	0	1	0	13	1	18	10
COAL BITUM/LIANT	1.	1	0	0	1	0	13	1	0	10
COPPER ORE	303175.	6	1	1000 *	438 *	12	85	25	12	37
FELDSPAR	0.	3	0	5	0	10	13	0	0	5
FLUORSPAR	1363.	5	1	711 *	152	22	201	120	3	50 *
GYPSUM	819.	3	0	175	0	10	11	0	0	37
IRON ORE	82109.	5	0	56	7	11	15	6	3	25
LEAD ORE	168981.	3	7	87	43	11	129	14	19	23
MANGANESE ORE	414.	3	0	100	4	24	6	11	1	100 *
NATURAL GAS	2370.	5	0	245	277	30	93	9	4	5
NICKEL ORE	14326.	3	1	4509 *	5411 *	37	54	23	5	75 *
NITROGEN, FIXED	1.	4	0	0	0	5	0	0	0	10
PETROLEUM	2307.	3	0	562 *	210	22	110	36	3	40
PROPANE	879.	1	0	192	23	10	136	11	1	5
SALT	62638.	6	1	0	0	5	0	0	38	9
SAND/GRAVEL	40136.	4	0	0	0	0	0	0	2	0
STONE	69453.	3	0	0	0	3	0	0	4	0
SULFUR	5065.	4	1	95	1	15	90	0	5	28
TIN ORE	179268.	2	1	4376 *	1313 *	29	73	20	2	65 *
ZINC ORE	532.	0	0	146	33	19	154	8	0	88 *
COTTON	1.	2	0	0	0	16	0	0	0	1
FLAX SEED	20.	1	0	0	0	25	0	0	0	20
MILK BYPRODUCTS	2.	3	0	0	0	20	0	0	0	1
LUMBER	1043.	1	0	0	0	12	0	0	3	10
SEA WATER	125964.	0	0	0	0	0	0	0	0	0
SOYBEAN	39.	3	0	0	0	12	0	0	0	0
TUNG NUTS	41.	1	5	0	0	70 *	0	0	1	80 *
WATER	37727.	3	0	17	2	0	3	0	0	0
WHEAT	6.	3	0	0	0	10	0	0	0	0
MISC.	641.	0	0	0	0	0	0	0	6	0
STEAM	463351.	5	1	1	0	10	0	0	16	0
LIMESTONE	83167.	3	3	0	0	5	0	0	2	2
ZINC, BY PRODUCT	6384.	0	1	148	34	19	154	8	0	88 *
COAL, BY PROD	189514.	1	1	6	1	6	13	1	0	10
ELECTRICITY	19.	3	0	0	0	0	0	0	0	0

BULK MATERIAL REQUIREMENTS FOR SILICON MIS

SOLAR SCENARIO:
 INTERPOLATION YEAR - 1985
 CUMULATIVE CAPACITY 2000 - 53. ONE

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY PRODUCT	WORLD PROD GROWTH RATE 1976-2000.	SOLAR'S % OF WORLD CONSUMPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/KW	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	50	10. %/YR	10	35	50	50
MATERIALS							
ALUMINUM	17828384.	0.	7.	4.	13.	351. *	14.
ANTIMONY	119788.	100. *	5.	7.	22.	9.	55. *
BORON	0.	20.	5.	0.	47. *	0.	0.
CEMENT	17058720.	0.	3.	0.	10.	12.	4.
CHROMIUM	20.	0.	0.	0.	31.	0.	100. *
COPPER	1379190.	1.	6.	1.	12.	36.	45.
GLASS, FIBER	1796000.	0.	7.	6.	5.	12.	2.
GLASS, SODA LIM	1360.	0.	3.	0.	5.	0.	5.
IRON, STEEL	12716970.	1.	3.	0.	16.	87. *	10.
LEAD	5074514.	13.	5.	7.	11.	56. *	18.
MAGNESIUM	167479.	30.	6.	3.	26.	7.	0.
MANGANESE	71891.	100. *	20.	0.	9.	0.	99. *
PORCELAIN	680.	0.	0.	0.	10.	0.	0.
SAND, GRAVEL	35330920.	0.	4.	0.	10.	1.	0.
STONE	69453360.	0.	3.	0.	3.	4.	0.
SILICON	183728.	0.	1.	1.	14.	3.	0.
SULFURIC ACID	1452000.	20.	5.	0.	15.	1.	0.
TIN	17867.	25.	3.	1.	29.	5.	65. *
ZINC	1360.	25.	3.	0.	21.	0.	88. *
STAINLESS STEEL	1790740.	0.	3.	2.	10.	36.	15.
FERROCHROME	58618.	5.	5.	0.	18.	3.	50. *
LINSEED OIL	6800.	0.	1.	0.	5.	0.	1.
ACRYLIC	143800.	0.	7.	1.	5.	4.	1.
ALKYD RESIN	13600.	0.	7.	0.	5.	0.	1.
EPOXY RESIN	1814.	0.	7.	0.	5.	0.	5.
EPOXY - FIBERGL	480.	0.	7.	0.	5.	0.	5.
CALCIUM	86280.	0.	3.	0.	9.	0.	0.
GLUE, PHENOL FOR	20120.	0.	7.	1.	5.	0.	0.
LUMBER, SOFTWOOD	985880.	0.	4.	0.	20.	1.	12.
PHENOLIC RESIN	31766.	0.	7.	0.	0.	1.	1.
PLASTIC, RESIN	18000.	0.	7.	0.	5.	0.	3.
POLYESTER RESIN	8160.	0.	7.	0.	5.	0.	0.
PVC PLASTIC	18780.	0.	7.	0.	5.	0.	0.
RUBBER, SBR	29980.	0.	6.	0.	5.	0.	4.
TEFLON	3900.	0.	7.	1.	5.	1.	1.
NYLON	600.	0.	7.	0.	5.	0.	1.
POLYPROPYLENE	414000.	0.	7.	1.	5.	5.	1.
COTTON FIBERS	641.	0.	3.	0.	16.	0.	1.
KRAFT FIBERS	275.	0.	3.	0.	10.	0.	15.
TUNG OIL	20400.	0.	0.	6.	45. *	1.	70. *
EVA	299200.	0.	7.	2.	0.	4.	5.

RAW MATERIAL REQUIREMENTS FOR SILICON ITS

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50 GWE

FACTORS	RAW MATERIAL USAGE (1000MT)	WORLD PRODUCTN GROWTH RATE	MAX. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KW OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS		7. %/YR	10	400	300	60	300	100	50	50
MATERIALS										
ANTHONY ORE	12569.	5.	7.	1327.	*	1230.	*	70.	3.	50. *
ASBESTOS	5.	3.	0.	539.	*	28.		190.	0.	90. *
BAUXITE	91025.	5.	5.	2438.	*	325.	*	15.	27.	89. *
BORATE	449.	5.	1.	11.	0.	50.	10.	0.	1.	3.
BUTANE	34.	1.	0.	20.	2.	10.	12.	1.	0.	0.
CHROMITE	1288.	4.	3.	3473.	*	439.	*	18.	4.	66. *
CLAYS	2727.	2.	0.	0.	0.	10.	0.	0.	1.	0.
COAL	68956.	1.	0.	0.	1.	6.	13.	1.	18.	13.
COPPER ORE	303422.	6.	1.	1000.	*	438.	*	85.	12.	37.
FELDSPAR	0.	2.	0.	5.	0.	10.	13.	0.	0.	9.
FLUORSPAR	1363.	5.	1.	711.	*	152.	201.	100.	3.	50. *
GYPSUM	819.	3.	0.	175.	0.	10.	11.	0.	0.	37.
IRON ORE	82112.	5.	0.	56.	7.	11.	15.	6.	3.	35.
LEAD ORE	168981.	3.	7.	87.	43.	11.	129.	14.	19.	33.
MANGANESE ORE	414.	3.	0.	100.	4.	24.	6.	11.	1.	100. *
NATURAL GAS	2378.	5.	0.	245.	277.	30.	93.	9.	4.	5.
NICKEL ORE	14326.	3.	1.	4509.	*	5411.	*	54.	23.	75. *
NITROGEN, FIXED	1.	4.	0.	0.	0.	5.	0.	0.	0.	10.
PETROLEUM	2307.	3.	0.	562.	*	210.	110.	36.	3.	40.
PROPANE	879.	1.	0.	192.	23.	10.	136.	11.	1.	5.
SALT	62634.	6.	1.	0.	0.	5.	0.	0.	38.	9.
SAND/GRAVEL	40136.	4.	0.	0.	0.	0.	0.	0.	2.	0.
STONE	69453.	1.	0.	0.	0.	3.	0.	0.	4.	0.
SULFUR	5057.	4.	1.	95.	1.	15.	90.	0.	5.	28.
TIN ORE	176608.	2.	1.	1375.	*	1313.	*	73.	2.	65. *
ZINC ORE	532.	0.	0.	146.	33.	19.	154.	8.	0.	88. *
COTTON	1.	2.	0.	0.	0.	16.	0.	0.	0.	1.
FLAX SEED	20.	1.	0.	0.	0.	25.	0.	0.	0.	20.
MILK BYPRODUCTS	2.	3.	0.	0.	0.	20.	0.	0.	0.	1.
LUMBER	1043.	1.	0.	0.	0.	12.	0.	0.	3.	18.
SEA WATER	125964.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SOYBEAN	39.	3.	0.	0.	0.	12.	0.	0.	0.	0.
TUNG NUTS	41.	1.	5.	0.	0.	70.	*	0.	1.	80. *
WATER	37732.	2.	0.	17.	2.	0.	3.	0.	0.	0.
WHEAT	6.	3.	0.	0.	0.	10.	0.	0.	0.	0.
MISC.	641.	0.	0.	0.	0.	0.	0.	0.	6.	0.
STEAM	463343.	5.	1.	1.	0.	10.	0.	0.	16.	0.
LIMESTONE	83166.	3.	3.	0.	0.	5.	0.	0.	3.	2.
COAL, BY PROD	189514.	1.	1.	6.	1.	6.	13.	1.	0.	10.

BULK MATERIAL REQUIREMENTS FOR ST 44P 1 X 14 PERCENT

DATE SUBMITTED
 PRODUCTION YEAR - 1983
 EXPENDITURE CATEGORY - 50 - 00

FABRIC	MATERIAL PRICE	PERCENT SUPPLIED BY PRODUCER	WORLD PRODN GROWTH RATE 1976-2000	SOURCE % OF WORLD CONE. ACTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/KH	NET PERCENT IMPORTED
RESERVED LEVELS		50	10.2%	10	0	50	50
MATERIALS							
ALUMINUM	12912513	0	7	3	13	252 *	14
ANTHRACITE	119700	100 *	5	7	23	9	50 *
BARREN	0	20	5	0	47 *	0	0
BORON	42217720	0	3	0	10	0	4
COBALT	1009436	1	6	1	12	29	45
COTTON FIBER	1700000	0	7	6	5	12	2
COTTON SEED LHM	1360	0	3	0	5	0	5
CRACKED STEEL	11745023	1	3	0	10	01 *	10
CRACK	5071121	11	0	7	11	05 *	10
MONOPOLYMER	119585	30	6	2	26	5	0
FLUOROPOLYMER	60018	100 *	2	0	9	0	90 *
PHENOL	4	100 *	3	0	30	0	90 *
PHENOLIC	0	0	6	0	13	0	0
PHENOLIC	0	0	0	0	10	0	0
CRACKED STEEL	000	0	0	0	10	0	0
CRACKED STEEL	20000000	0	4	0	10	1	0
STONE	40045300	0	3	0	3	3	0
STEEL	263191	0	3	1	14	5	8
SILVER	940	70 *	4	1	14	3	46
SILICIC ACID	1450000	20	5	0	15	1	0
TANTALUM	210	100 *	5	1	37 *	0	68 *
TIN	12726	25	2	0	29	3	65 *
TITANIUM	3	0	5	0	50 *	0	50 *
ZINC	1360	25	3	0	21	0	88 *
STAINLESS STEEL	1496120	0	3	2	10	30	15
PERFLUORINE	41805	5	5	0	18	2	50 *
REFINED OIL	6000	0	1	0	5	0	1
ROXYLIC	130000	0	7	1	5	3	1
HYDRO RESIN	13000	0	7	0	5	0	1
POWDER RESIN	1814	0	7	0	5	0	5
POWDER FIBERGL	400	0	7	0	5	0	5
GLASS	86200	0	2	0	9	0	2
GLASS FIBERGL FOR	10120	0	7	1	5	0	5
FLUOROPOLYMER	90000	0	4	0	20	1	12
FLUOROPOLYMER	11700	0	7	0	5	1	1
FLUOROPOLYMER	13000	0	7	0	5	0	3
POLYESTER RESIN	8160	0	7	0	5	0	0
PVC PLASTIC	13400	0	7	0	5	0	0
RUBBER SBR	21300	0	6	0	5	0	4
NYLON	2000	0	7	1	5	0	1
NYLON	420	0	7	0	5	0	1
POLYPROPYLENE	414000	0	7	1	5	5	1
COTTON FIBERS	641	0	3	0	10	0	1
ROXY FIBERS	270	0	3	0	10	0	15
TURB OIL	20100	0	0	6	45 *	1	70 *
LYN	214000	0	7	1	5	3	5

RAH MATERIAL REQUIREMENTS FOR SI N/T 1 XTL 14 PERCENT

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
COMPLIATIVE CAPACITY 2600 - 50. ONE

FACTORS	RAH MATERIAL USAGE (1000MT)	WORLD PRODUCTN GROWTH RATE	MAX % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KW OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS		% /YR	10	100	300	60	300	300	50	50
MATERIALS										
ANTHRACITE COAL	12569	5	2	1327 *	1230 *	22	70	67	3	50 *
BITUMINOUS	4	3	0	539 *	28	34	190	129	0	90 *
BRUNNIE	63692	5	4	2375 *	317 *	28	14	9	20	80 *
BUKITE	449	5	1	11	0	50	10	0	1	3
CHALK	24	1	0	20	2	10	12	1	0	5
CHALKITE	1050	4	3	3450 *	437 *	27	18	4	1	66 *
CLAYS	1997	2	0	0	0	10	0	0	1	0
COAL	47940	1	0	6	1	6	13	1	15	10
COALITE ORE	241804	6	1	506 *	427 *	12	85	24	9	37
FLUORITE	0	3	0	5	0	10	13	0	0	5
FLUORITE	1004	5	1	709 *	152	22	201	120	2	50 *
GYPSON	588	3	0	175	0	10	11	0	0	37
IRON ORE	74966	5	0	56	7	11	15	6	3	35
LEAD ORE	168881	3	7	87	43	11	129	14	19	33
MANGANESE ORE	382	3	0	100	4	24	6	11	1	100 *
NATURAL GAS	1009	5	0	245	277	30	93	9	3	5
NICKEL ORE	11969	3	1	4496 *	5396 *	37	54	23	4	75 *
NITROGEN FIXED	1	4	0	0	0	5	0	0	0	10
PETROLEUM	1762	3	0	562 *	210	22	110	36	3	40
PHOSPHATE ROCK	0	6	0	48	0	13	29	0	0	0
PROPANE	787	1	0	192	23	10	136	11	1	5
ROFILL	0	1	0	221	81	30 *	44	17	0	100 *
SALT	47654	6	1	0	0	5	0	0	29	9
SAND/GRAVEL	29734	4	0	0	0	0	0	0	1	0
SILVER ORE	6692	4	0	373	99	14	208	66	1	40
STONE	49845	3	0	0	0	3	0	0	3	0
SILFUR	3840	4	1	94	1	15	90	0	4	20
TITANIUM ORE	09	5	1	100	1751 *	37	97	22	0	100 *
TAI ORE	127200	2	0	4303 *	1309 *	29	73	20	1	60 *
ZINC ORE	535	0	0	146	33	19	154	8	0	80 *
COTTON	1	2	0	0	0	16	0	0	0	1
FLAX SPED	20	1	0	0	0	25	0	0	0	20
RAIK BYPRODUCTS	2	3	0	0	0	20	0	0	0	1
LUMBER	1033	1	0	0	0	12	0	0	3	10
SALT WATER	91430	0	0	0	0	0	0	0	0	0
SOYBEAN	39	3	0	0	0	12	0	0	0	0
TUNG NUTS	41	1	5	0	0	70 *	0	0	1	80 *
WATER	34640	3	0	17	2	0	3	0	0	0
WILLY	6	3	0	0	0	10	0	0	0	0
WISC	535	0	0	0	0	0	0	0	5	0
STEAM	341420	5	1	1	0	10	0	0	12	0
LIMESTONE	63481	3	2	0	0	5	0	0	3	2
CU OXIDE SLINES	1990	6	0	984 *	431 *	12	85	24	0	37
COAL BY PROD	107903	1	1	6	1	6	13	1	0	10

BULK MATERIAL REQUIREMENTS FOR SI 1 XTL-30X PARA TROUGH

SOURCE COUNTRY:
 INTERPRETATION YEAR: 1993
 CUMULATIVE CAPACITY 2000: CA. QM

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODN GROWTH RATE 1976-2000	SOLIDS % OF WORLD CONSUMPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT 1/TH	NET PERCENT IMPORTED
THRESHOLD LEVELS		50.	10. %/YR	10.	30.	50.	50.
MATERIALS							
ALUMINUM	8312901.	0.	7.	2.	13.	163. *	14.
ANTHRACITE	119700.	100. *	5.	7.	22.	9.	55. *
BARON	0.	20.	5.	0.	47. *	0.	0.
CEMENT	10042720.	0.	3.	0.	10.	11.	4.
COTTON	1819500.	1.	6.	1.	12.	48.	45.
GLASS FIBER	1700000.	0.	7.	6.	5.	12.	2.
GLASS, SOFT LIM	145300.	0.	3.	0.	5.	1.	5.
IRON, STEEL	15065223.	1.	3.	0.	10.	110. *	10.
LEAD	5572171.	13.	7.	7.	11.	50. *	18.
MANGANESE	91707.	100. *	2.	0.	9.	0.	99. *
NICKELUM	0.	100. *	3.	0.	30.	0.	96. *
NICKELUMOUS	0.	0.	6.	0.	13.	0.	0.
PORCELAIN	600.	0.	0.	0.	10.	0.	0.
GRAND GRAVEL	31177918.	0.	4.	0.	10.	1.	0.
STONE	61245364.	0.	3.	0.	3.	3.	0.
SILICON	40030.	0.	3.	0.	14.	1.	8.
SILVER	74.	70. *	4.	0.	14.	0.	46.
SULFURIC ACID	1452000.	20.	5.	0.	15.	1.	0.
TANTALUM	19.	100. *	5.	0.	37. *	0.	68. *
TIN	14755.	25.	2.	1.	29.	4.	65. *
TITANIUM	0.	0.	5.	0.	50. *	0.	50. *
ZINC	3060.	25.	3.	0.	21.	0.	88. *
STAINLESS STEEL	942000.	0.	3.	1.	10.	19.	15.
LINSEED OIL	6000.	0.	1.	0.	5.	0.	1.
ACRYLIC	105000.	0.	7.	1.	5.	3.	1.
ALKYD RESIN	13600.	0.	7.	0.	5.	0.	1.
EPOXY RESIN	1814.	0.	7.	0.	5.	0.	5.
EPOXY FIBERGL	400.	0.	7.	0.	5.	0.	5.
CHLORUM	86280.	0.	3.	0.	9.	0.	2.
GLASS FIBERGL FOR	20120.	0.	7.	1.	5.	0.	5.
LUMINOUS SOFTWOOD	900000.	0.	4.	0.	20.	1.	12.
PHENOLIC RESIN	37700.	0.	7.	0.	5.	1.	1.
PLASTIC RESIN	18400.	0.	7.	0.	5.	0.	3.
POLYESTER RESIN	8100.	0.	7.	0.	5.	0.	0.
PVC PLASTIC	651600.	0.	7.	1.	5.	11.	0.
RUBBER, SBR	41300.	0.	6.	0.	5.	1.	4.
SILICONES	23400.	0.	7.	1.	5.	2.	1.
NYLON	5400.	0.	7.	1.	5.	1.	1.
NYLON	420.	0.	7.	0.	5.	0.	1.
POLYPROPYLENE	425000.	0.	7.	1.	5.	6.	1.
COTTON FIBERS	641.	0.	3.	0.	16.	0.	1.
KNIT FIBERS	275.	0.	3.	0.	10.	0.	15.
TUNG OIL	20400.	0.	0.	6.	45. *	1.	70. *
NEOPRENE	100000.	0.	3.	2.	5.	3.	1.

RAW MATERIAL REQUIREMENTS FOR SI 1 XTL-BOX PARM TROUGH

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50, GWE

FACTORS	RAW MATERIAL USAGE (1000MT)	% WORLD PRODUCTN GROWTH RATE	RAW. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KW OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS		7. 2/4R	10.	400.	300.	60.	300.	200.	50.	50.
MATERIALS										
ANTHRACITE ORE	12580.	5.	7.	1327.	*	1230.	*	78.	67.	3.
BAUXITE	4.	3.	0.	539.	*	28.		190.	129.	0.
BORAX	42900.	5.	3.	2318.	*	309.	*	14.	9.	13.
BORON	449.	5.	1.	11.	0.	0.		10.	0.	1.
BRILLIANT	46.	1.	0.	20.	2.	10.		12.	1.	0.
CHROMITE	602.	4.	2.	3407.	*	431.	*	17.	4.	1.
CLAYS	2413.	2.	0.	0.	0.	10.		0.	0.	1.
COAL	44142.	1.	0.	6.	1.	6.		13.	1.	14.
COR. HYDROLYT	15000.	1.	0.	6.	1.	6.		13.	1.	5.
COPPER ORE	400491.	6.	1.	1005.	*	440.	*	85.	25.	16.
FLUORSPAR	14.	3.	0.	5.	0.	10.		13.	0.	0.
FLUORSPAR	730.	5.	0.	707.	*	152.		201.	120.	2.
GYPHUM	722.	3.	0.	175.	0.	10.		11.	0.	0.
IRON ORE	98470.	5.	0.	56.	7.	11.		15.	6.	4.
LEAD ORE	158903.	3.	7.	87.	43.	11.		129.	14.	19.
MANGANESE ORE	521.	3.	0.	100.	4.	24.		11.	11.	1.
NATURAL GAS	2225.	5.	0.	245.	277.	30.		93.	9.	4.
NICKEL ORE	7542.	3.	1.	4472.	*	5366.	*	54.	23.	2.
NITROGEN, FIXED	1.	4.	0.	0.	0.	5.		0.	0.	0.
PETROLEUM	1470.	3.	0.	562.	*	210.		110.	36.	2.
PHOSPHATE ROCK	0.	6.	0.	48.	0.	13.		29.	0.	0.
PROPANE	560.	1.	0.	192.	23.	10.		136.	11.	0.
RUYLE	0.	1.	0.	221.	81.	90.	*	44.	17.	0.
SALT	35240.	6.	1.	0.	0.	5.		0.	0.	21.
SAND/AGGREG.	34722.	4.	0.	0.	0.	0.		0.	0.	1.
SILVER ORE	526.	4.	0.	372.	90.	14.		207.	06.	0.
STONE	61245.	3.	0.	0.	0.	3.		0.	0.	2.
SULFUR	2001.	3.	0.	94.	1.	15.		90.	0.	2.
TANTALUM ORE	7.	5.	0.	100.	1737.	*		97.	22.	0.
TIN ORE	147660.	2.	1.	4368.	*	1310.	*	73.	20.	1.
ZINC ORE	562.	0.	0.	146.	33.	19.		154.	8.	0.
COTTON	1.	2.	0.	0.	0.	16.		0.	0.	0.
FLAX SEED	20.	1.	0.	0.	0.	25.		0.	0.	0.
HULK BYPRODUCTS	2.	3.	0.	0.	0.	20.		0.	0.	0.
LUMBER	1014.	1.	0.	0.	0.	12.		0.	0.	3.
SEA WATER	5209.	0.	0.	0.	0.	0.		0.	0.	0.
SOYBEAN	39.	3.	0.	0.	0.	12.		0.	0.	0.
TUNG NUTS	41.	1.	5.	0.	0.	70.	*	0.	0.	1.
WATER	36989.	3.	0.	17.	2.	0.		3.	0.	0.
WHEAT	6.	3.	0.	0.	0.	10.		0.	0.	0.
MISC.	759.	0.	0.	0.	0.	0.		0.	0.	0.
STEAM	237965.	5.	1.	1.	0.	10.		0.	0.	0.
LIMESTONE	60009.	3.	2.	0.	0.	5.		0.	0.	2.
CU ANODE SLIMES	156.	6.	0.	984.	*	431.	*	85.	24.	0.
COAL BY PROD	194769.	1.	1.	6.	1.	6.		13.	1.	0.

BULK MATERIAL REQUIREMENTS FOR TIN OXIDE/N-SILICON

SOLAR SCENARIO:
INTRODUCTION YEAR -- 1985
CUMULATIVE CAPACITY 2000 -- 50. GWT

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY-PRODUCT	WORLD PROD GROWTH RATE 1976-2000	SOLAR % OF WORLD CONSUMPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT 4/HR	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	50.	10. %/YR	10.	35.	50.	50.
MATERIALS							
ALUMINUM	17828726.	0.	7.	4.	13.	351.	14.
ANTIMONY	119700.	100. *	5.	7.	22.	9.	55. *
CEMENT	17058726.	0.	3.	0.	10.	12.	4.
COPPER	1372970.	1.	6.	1.	12.	36.	45.
GLASS, FIBER	1796000.	0.	7.	6.	5.	12.	2.
GLASS, SODA LIM	1360.	0.	3.	0.	5.	0.	5.
IRON, STEEL	10645485.	1.	3.	0.	16.	73.	10.
LEAD	5874814.	13.	5.	7.	11.	56.	18.
MANGANESE	167479.	30.	6.	3.	26.	7.	0.
FERRONMANGANESE	59375.	100. *	2.	0.	9.	0.	99. *
PHOSPHOROUS	0.	0.	6.	0.	13.	0.	0.
PORCELAIN	600.	0.	0.	0.	10.	0.	0.
SAND & GRAVEL	35335020.	0.	4.	0.	10.	1.	0.
STONE	69453360.	0.	3.	0.	3.	4.	0.
SILICON	183728.	0.	3.	1.	14.	3.	0.
SULFURIC ACID	1452000.	20.	5.	0.	15.	1.	0.
TIN	18687.	25.	2.	1.	29.	5.	65. *
ZINC	1360.	25.	3.	0.	21.	0.	88. *
STAINLESS STEEL	1790740.	0.	2.	2.	10.	36.	15.
FERROCHROME	58618.	5.	5.	0.	10.	3.	50. *
LINSEED OIL	6000.	0.	1.	0.	5.	0.	1.
ACRYLIC	143800.	0.	7.	1.	5.	4.	1.
ALKYD RESIN	13600.	0.	7.	0.	5.	0.	1.
EPOXY RESIN	1814.	0.	7.	0.	5.	0.	5.
EPOXY - FIBERGL	480.	0.	7.	0.	5.	0.	5.
CALCIUM	86280.	0.	3.	0.	5.	0.	2.
GLUE, PHENOL, FOR	20120.	0.	7.	1.	5.	0.	5.
LUMBER, SOFTWOOD	985880.	0.	4.	0.	20.	1.	12.
PHENOLIC RESIN	31766.	0.	7.	0.	5.	1.	1.
PLASTIC, RESIN	18000.	0.	7.	0.	5.	0.	3.
POLYESTER RESIN	8160.	0.	7.	0.	5.	0.	0.
PVC PLASTIC	18780.	0.	7.	0.	5.	0.	0.
RUBBER, SBR	29900.	0.	6.	0.	5.	0.	4.
TEFLON	3900.	0.	7.	1.	5.	1.	1.
NYLON	600.	0.	7.	0.	5.	0.	1.
POLYPROPYLENE	414000.	0.	7.	1.	5.	5.	1.
COTTON FIBERS	641.	0.	3.	0.	16.	0.	1.
KRAFT FIBERS	275.	0.	3.	0.	10.	0.	15.
TUNG OIL	20400.	0.	0.	6.	45. *	1.	70. *
EVA	299200.	0.	7.	2.	5.	4.	5.

RAW MATERIAL REQUIREMENTS FOR TIN OXIDE/N-SILICON

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50. GWE

FACTORS	RAW MATERIAL USAGE (1999MT)	WORLD PRODUCTN GROWTH RATE	MAX % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KW OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS		7. %/YR	10.	400.	300.	60.	300.	200.	50.	50.
MATERIALS										
ANTIMONY ORE	12560.	5.	7.	1327.	*	1230.	*	73.	3.	55. *
ASBESTOS	5.	3.	0.	539.	*	28.		190.	0.	90. *
BAUXITE	91021.	5.	5.	2438.	*	325.	*	15.	9.	89. *
BORATE	440.	5.	1.	11.		0.		10.	0.	3.
BUTANE	31.	1.	0.	20.		2.		12.	1.	5.
CHRONITE	1288.	4.	3.	3473.	*	439.	*	18.	4.	66. *
CLAYS	2785.	2.	0.	0.		0.		0.	0.	0.
COAL	57729.	1.	0.	6.		1.		13.	1.	10.
COPPER ORE	303170.	6.	1.	1600.	*	430.	*	80.	23.	37.
FELDSPAR	0.	3.	0.	5.		0.		13.	0.	5.
FLUORSPAR	1346.	50.	1.	711.	*	152.		201.	100.	50. *
GYPNUM	819.	3.	0.	175.		0.		11.	0.	27.
IRON ORE	70394.	50.	0.	55.		7.		15.	6.	35.
LEAD ORE	160981.	30.	7.	87.		43.		129.	14.	33.
MANGANESE ORE	346.	3.	0.	100.		4.		6.	11.	100. *
NATURAL GAS	2347.	5.	0.	245.		277.		93.	9.	5.
NICKEL ORE	14326.	3.	1.	4509.	*	5411.	*	54.	23.	75. *
NITROGEN, FIXED	1.	4.	0.	0.		0.		0.	0.	10.
PETROLEUM	2233.	3.	0.	562.	*	210.		110.	36.	40.
PHOSPHATE ROCK	0.	6.	0.	48.		0.		29.	0.	0.
PROPANE	879.	1.	0.	192.		23.		136.	11.	5.
SALT	62632.	6.	1.	0.		0.		0.	0.	38.
SAND/GRAVEL	40134.	4.	0.	0.		0.		0.	0.	0.
STONE	69453.	3.	0.	0.		0.		0.	0.	4.
SULFUR	5057.	4.	1.	95.		1.		90.	0.	20.
TIN ORE	186868.	2.	1.	4377.	*	1313.	*	73.	20.	65. *
ZINC ORE	532.	0.	0.	146.		33.		154.	0.	80. *
COTTON	1.	2.	0.	0.		0.		0.	0.	1.
FLAX SEED	20.	1.	0.	0.		0.		0.	0.	20.
MILK BYPRODUCTS	2.	3.	0.	0.		0.		0.	0.	1.
LUMBER	1042.	1.	0.	0.		0.		0.	0.	10.
SEA WATER	125964.	0.	0.	0.		0.		0.	0.	0.
SOYBEAN	39.	2.	0.	0.		0.		0.	0.	0.
TUNG NUTS	41.	1.	5.	0.		0.	*	0.	0.	80. *
WATER	37559.	3.	0.	17.		2.		3.	0.	0.
WHEAT	6.	0.	0.	0.		0.		0.	0.	0.
MISC.	622.	0.	0.	0.		0.		0.	0.	0.
STEAM	461012.	5.	1.	1.		0.		0.	16.	0.
LIMESTONE	82072.	3.	3.	0.		0.		0.	3.	2.
COAL, BY PROD	189514.	1.	1.	6.		1.		13.	1.	10.

MARKET MATERIAL SUMMARY REPORT

THIS REPORT IS A SUMMARY OF THE 15 FACTORS:
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Cumulative Capacity by the Year 2000 - 50 GWe,
Each System at 3.33 GWe.

FACTORS	MATERIAL UNIT	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODH GROWTH RATE 1976-2000	SOLAR'S % OF WORLD CAPACITY	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT	NET PERCENT IMPORTED
THRESHOLD LEVELS		50.	10 %/YR	10.	35.	50.	50.
MATERIALS							
ALUMINUM	10645196.	0.	7.	4.	13.	300. *	14.
ANTHRA	115000.	100. *	5.	7.	22.	9.	50. *
ARSENIC	6090.	100. *	1.	2.	31.	0.	37.
BORON	0.	20.	5.	0.	47. *	0.	0.
CAESIUM	3444.	100. *	4.	1.	15.	1.	57. *
CEMENT	10102004.	0.	3.	0.	18.	11.	4.
CHROMIUM	509.	0.	3.	0.	31.	0.	100. *
COBALT	1300037.	1.	0.	1.	12.	37.	43.
COBALT	6000.	100. *	10. *	90. *	40. *	120. *	70. *
COBALTUM	4429.	100. *	10. *	84. *	29.	42.	19.
GLASS FIBER	1794204.	0.	7.	6.	5.	12.	2.
GLASS, SODA LIN	1748157.	0.	3.	1.	5.	10.	5.
GOLD	713.	40.	2.	5.	58. *	101. *	50. *
INDIUM	332.	100. *	5.	33. *	10.	1.	70. *
IRON, STEEL	12052601.	1.	3.	0.	16.	88. *	10.
LEAD	5860049.	13.	5.	7.	11.	55. *	18.
BERKALIUM	136853.	30.	6.	2.	26.	7.	0.
FLUOROMANGANESE	70907.	100. *	22.	0.	9.	0.	99. *
MOLYBDENUM	8.	42.	5.	0.	16.	0.	4.
NICKEL	416.	7.	3.	0.	28.	0.	75. *
PALLADIUM	0.	100. *	2.	0.	30.	0.	96. *
PHOSPHOROUS	29.	0.	6.	0.	13.	0.	0.
PLATINUM	4.	100. *	3.	0.	45. *	7.	90. *
PORCELAIN	679.	0.	0.	0.	10.	0.	0.
SAND & GRAVEL	31202002.	0.	4.	0.	10.	1.	0.
STONE	61487060.	0.	3.	0.	3.	3.	0.
SELENIUM	91.	100. *	4.	0.	37. *	0.	59. *
SILICON	131253.	0.	3.	0.	14.	2.	0.
SILVER	68.	70. *	4.	0.	14.	0.	46.

SULFUR	1000.	31.	3.	0.	15.	0.	15.
SULFURIC ACID	1450548.	20.	5.	0.	15.	1.	0.
TANTALUM	29.	100.	0.	0.	37.	0.	60.
TELLURIUM	89.	100.	1.	4.	16.	0.	37.
TIN	18614.	25.	2.	1.	29.	5.	65.
TITANIUM	3.	0.	5.	0.	50.	0.	50.
ZINC	1612.	25.	3.	0.	21.	0.	88.
STAINLESS STEEL	1633814.	0.	3.	2.	10.	23.	15.
FLUOROCARBON	47099.	5.	5.	0.	18.	2.	50.
LINSEED OIL	6793.	0.	1.	0.	0.	0.	1.
ACRYLIC	226360.	0.	7.	1.	0.	6.	1.
ALKYD RESIN	13586.	0.	7.	0.	0.	0.	1.
EPOXY RESIN	1691.	0.	7.	0.	0.	0.	5.
EPOXY - FIBERGL.	600.	0.	7.	0.	0.	0.	0.
CALCIUM	86194.	0.	3.	0.	0.	0.	2.
GLUE, PHENOL FOR	20100.	0.	7.	1.	0.	0.	5.
LUMBER, SOFTWOOD	984894.	0.	4.	0.	20.	1.	12.
PHENOLIC RESIN	32533.	0.	7.	0.	0.	1.	1.
PLASTIC RESIN	18701.	0.	7.	0.	0.	0.	3.
POLYESTER RESIN	8152.	0.	7.	0.	0.	0.	0.
PVC PLASTIC	60280.	0.	7.	0.	0.	1.	0.
RUBBER, SBR	54953.	0.	6.	0.	0.	1.	4.
SILICONES	1891.	0.	7.	0.	0.	0.	1.
TEFLON	3861.	0.	7.	1.	0.	1.	1.
NYLON	566.	0.	7.	0.	0.	0.	1.
POLYPROPYLENE	414319.	0.	7.	1.	0.	5.	1.
COTTON FIBERS	641.	0.	3.	0.	16.	0.	1.
KRAFT FIBERS	275.	0.	3.	0.	10.	0.	15.
TUNG OIL	20380.	0.	0.	6.	45.	1.	70.
NEOPRENE	6660.	0.	3.	0.	5.	0.	1.
EVA	233446.	0.	7.	1.	0.	0.	5.
ABS	148118.	0.	7.	0.	0.	4.	5.
ALUMINUM OXIDE	582.	0.	7.	0.	13.	0.	14.

IRON RESERVE SUMMARY REPORT

THIS REPORT IS A SUMMARY OF THESE 15 DESIGNS:

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

DESIGN	RAW MATERIAL USAGE (1000MT)	WORLD PRODUCTION GROWTH RATE	MAX. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/TON OF SOLAR	NET PERCENT IMPORTED			
DESIGNED LEVELS		%/YR	10.	400.	300.	60.	300.	200.	50.	50.			
MATERIALS													
ANTHRACITE ORE	12306.	5.	7.	1377.	*	1230.	*	22.	70.	67.	3.	50.	*
ARSENIC TRIOXIDE	10.	1.	2.	121.		17.		34.	31.	35.	0.	95.	*
ASBESTOS	5.	3.	0.	539.	*	28.		34.	190.	129.	0.	98.	*
BARIUM	88881.	5.	5.	2410.	*	321.	*	28.	15.	9.	24.	89.	*
BORATE	449.	5.	1.	11.		0.		50.	10.	0.	1.	2.	
BUTANE	61.	1.	0.	20.		2.		10.	12.	1.	0.	5.	
CHROMITE	1165.	4.	3.	3461.	*	438.	*	27.	18.	4.	1.	66.	*
CLAYS	2432.	2.	0.	0.		0.		10.	0.	0.	1.	0.	
COAL	57180.	1.	0.	6.		1.		6.	13.	1.	18.	10.	
COAL, BITUMINOUS	1801.	1.	0.	6.		1.		6.	13.	1.	0.	10.	
COPPER ORE	304857.	6.	1.	1000.	*	438.	*	12.	85.	25.	12.	37.	
FELDSPAR	162.	0.	0.	5.		0.		10.	13.	0.	0.	5.	
FLUORSPAR	1210.	5.	1.	710.	*	152.		22.	201.	120.	3.	50.	*
GOLD ORE	71321.	2.	5.	2501.	*	104.		58.	111.	73.	51.	89.	*
GYPSUM	725.	0.	0.	175.		0.		10.	11.	0.	0.	37.	
IRON ORE	88881.	5.	0.	56.		7.		11.	15.	6.	3.	35.	
LEAD ORE	168816.	0.	7.	87.		43.		11.	129.	14.	19.	33.	
LIME	0.	0.	0.	0.		0.		31.	0.	0.	0.	2.	
MANGANESE ORE	417.	0.	0.	100.		4.		24.	6.	11.	1.	100.	*
MOLYBDENUM ORE	6.	0.	0.	44.		8.		16.	43.	13.	1.	4.	
NATURAL GAS	2277.	5.	0.	245.		277.		30.	93.	9.	4.	5.	
NICKEL ORE	13112.	3.	1.	4503.	*	5403.	*	37.	54.	23.	4.	75.	*
NITROGEN, FIXED	1.	4.	0.	0.		0.		5.	0.	0.	0.	10.	
PETROLEUM	4206.	3.	0.	563.	*	210.		22.	110.	36.	6.	40.	
PHOSPHATE ROCK	0.	6.	0.	10.		0.		13.	29.	0.	0.	0.	
PROPANE	885.	1.	0.	192.		23.		10.	136.	11.	1.	5.	
RUSSIA	0.	1.	0.	221.		81.	*	90.	44.	17.	0.	100.	*
SALT	50013.	6.	1.	0.		0.		5.	0.	0.	35.	9.	
SHALV/SHAL	36891.	4.	0.	0.		0.		0.	0.	0.	1.	0.	
SILICA ORE	401.	4.	0.	372.		93.		14.	207.	36.	0.	45.	
STONE	61487.	3.	0.	0.		0.		3.	0.	0.	3.	0.	
SULFUR	5011.	4.	1.	95.		1.		15.	90.	0.	5.	28.	
TANTALUM ORE	11.	5.	0.	100.		1737.	*	37.	97.	72.	0.	100.	*
TIN ORE	186136.	2.	1.	4377.	*	1313.	*	29.	73.	20.	2.	65.	*
ZINC ORE	1364.	0.	0.	146.		33.		19.	154.	8.	0.	88.	*
COTTON	1.	2.	0.	0.		0.		16.	0.	0.	0.	1.	
FLAX SEED	28.	1.	0.	0.		0.		25.	0.	0.	0.	20.	
MILK BYPRODUCTS	2.	3.	0.	0.		0.		20.	0.	0.	0.	1.	
LUMBER	1036.	1.	0.	0.		0.		12.	0.	0.	3.	18.	
SEA WATER	103878.	0.	0.	0.		0.		0.	0.	0.	0.	0.	
SOYBEAN	39.	3.	0.	0.		0.		12.	0.	0.	0.	0.	
TUNG NUTS	41.	1.	5.	0.		0.		70.	0.	0.	1.	80.	*
WATER	46771.	3.	0.	17.		2.		0.	3.	0.	0.	0.	
WHEAT	6.	3.	0.	0.		0.		10.	0.	0.	0.	0.	
WISC.	783.	0.	0.	0.		0.		0.	0.	0.	7.	0.	
STEAM	413717.	5.	1.	1.		0.		10.	0.	0.	14.	0.	
LIMESTONE	84260.	3.	3.	0.		0.		5.	0.	0.	3.	2.	
CU ANODE SLIMES	143.	6.	0.	984.	*	431.	*	12.	85.	24.	0.	37.	
BAUXITE, BY PROD	302252.	6.	16.	2966.	*	395.	*	28.	15.	9.	0.	89.	*
ZINC, BY PRODUCT	40244.	0.	3.	154.		35.		19.	156.	8.	0.	88.	*
COAL, BY PROD	275437.	1.	1.	6.		1.		6.	13.	1.	0.	10.	
ELECTRICITY	1772667.	3.	0.	0.		0.		0.	0.	0.	0.	0.	
CU BYPROD 1	884.	6.	0.	984.	*	431.	*	12.	85.	24.	0.	37.	
CU BYPROD 2	3956040.	6.	0.	1194.	*	523.	*	12.	89.	26.	0.	37.	
ZINC 3 BYPRODUCT	38366.	0.	3.	154.		35.		19.	156.	8.	0.	88.	*
ZINC 2 BYPRODUCT	38362.	0.	3.	154.		35.		19.	156.	8.	0.	88.	*

BULK MATERIAL SUMMARY REPORT

THIS REPORT IS A SUMMARY OF THESE 15 DESIGNS:
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Cummulative Capacity by the Year 2000 - 100 GWe,
Each System at 6.66 GWe.

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODN GROWTH RATE 1976-2000	SOLAR'S % OF WORLD CONSUMPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	50.	10. %/YR	10.	35.	50.	50.
MATERIALS							
ALUMINUM	31337378.	0.	7.	7.	13.	308. *	14.
ANTIMONY	239520.	100. *	6.	14. *	22.	9.	55. *
ARSENIC	13017.	100. *	1.	4.	34.	0.	37.
BORON	0.	20.	5.	0.	47. *	0.	0.
CADMIUM	6891.	100. *	4.	3.	15.	1.	57. *
CEMENT	30249518.	0.	3.	0.	18.	11.	4.
CHROMIUM	1019.	0.	3.	0.	31.	0.	100. *
COPPER	2775474.	1.	6.	2.	12.	37.	45.
CALLIUM	12100.	100. *	22. *	98. *	45. *	125. *	75. *
GERMANIUM	8871.	100. *	13. *	91. *	29.	42.	19.
GLASS, FIBER	3593797.	0.	0.	12. *	5.	12.	0.
GLASS, SODA LIM	3486140.	0.	0.	3.	5.	10.	0.
GOLD	1429.	40.	0.	10. *	58. *	151. *	58. *
INDIUM	664.	100. *	0.	50. *	19.	5.	75. *
IRON, STEEL	25143000.	1.	0.	0.	16.	86. *	10.
LEAD	10154322.	13.	5.	13. *	11.	56. *	18.
MAGNESIUM	274118.	30.	0.	5.	26.	7.	0.
FERROMANGANESE	142026.	100. *	2.	0.	9.	0.	99. *
MOLYBDENUM	16.	42.	5.	0.	16.	0.	4.
NICKEL	832.	7.	0.	0.	28.	0.	75. *
PALLADIUM	1.	100. *	0.	0.	30.	0.	96. *
PHOSPHOROUS	59.	0.	6.	0.	13.	0.	0.
PLATINUM	0.	100. *	3.	0.	45. *	7.	90. *
PORCELAIN	1361.	0.	0.	0.	10.	0.	0.
SAND & GRAVEL	62659712.	0.	4.	0.	10.	1.	0.
STONE	123158760.	0.	3.	0.	3.	3.	0.
SELENIUM	181.	100. *	4.	1.	37. *	0.	59. *
SILICON	262900.	0.	3.	1.	14.	2.	8.
SILVER	135.	70. *	4.	0.	14.	0.	46.

SULFUR	2020.	31.	W	0.	15.	0.	15.
SULFURIC ACID	2905452.	20.	W	0.	15.	1.	0.
TANTALUM	59.	100.	W	0.	27.	0.	68.
TELLURIUM	176.	100.	W	7.	16.	0.	37.
TIN	37203.	25.	W	1.	23.	5.	65.
TITANIUM	6.	0.	W	0.	50.	0.	50.
ZINC	3228.	25.	W	0.	21.	0.	88.
STAINLESS STEEL	3272535.	0.	W	4.	10.	33.	15.
FERROCHROME	95941.	5.	W	0.	10.	2.	50.
LINSEED OIL	13607.	0.	W	0.	5.	0.	1.
ACRYLIC	453400.	0.	W	3.	5.	6.	1.
ALKYD RESIN	27214.	0.	W	0.	5.	0.	1.
EPOXY RESIN	3388.	0.	W	0.	5.	0.	5.
EPOXY - FIBERGL	1202.	0.	W	0.	5.	0.	0.
CALCIUM	172646.	0.	W	0.	9.	0.	2.
GLUE, PHENOL, FOR	40260.	0.	W	1.	5.	0.	0.
LUMBER, SOFTWOOD	1972746.	0.	W	0.	20.	1.	12.
PHENOLIC RESIN	65165.	0.	W	0.	5.	1.	1.
PLASTIC RESIN	37459.	0.	W	0.	5.	0.	3.
POLYESTER RESIN	16328.	0.	W	0.	5.	0.	0.
PVC PLASTIC	120740.	0.	W	0.	5.	1.	0.
RUBBER, SBR	110071.	0.	W	0.	5.	1.	4.
SILICONES	3789.	0.	W	0.	5.	0.	1.
TEFLON	7735.	0.	W	2.	5.	1.	1.
NYLON	1134.	0.	W	0.	5.	0.	1.
POLYPROPYLENE	829882.	0.	W	1.	5.	5.	1.
COTTON FIBERS	1283.	0.	W	0.	16.	0.	1.
KRAFT FIBERS	550.	0.	W	0.	10.	0.	15.
TUNG OIL	40820.	0.	W	12.	45.	1.	70.
NEOPRENE	13340.	0.	W	0.	5.	0.	1.
EVA	467594.	0.	W	3.	5.	4.	5.
ABS	296682.	0.	W	1.	5.	4.	5.
ALUMINUM OXIDE	1166.	0.	W	0.	13.	0.	14.

RAW MATERIAL SUMMARY REPORT

THIS REPORT IS A SUMMARY OF THESE 15 DESIGNS:

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

FACTORS	RAW MATERIAL USAGE (1000MT)	WORLD PRODUCTN GROWTH RATE	MAX. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/OR OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	7. %/YR	10.	400.	300.	60.	300.	200.	50.	50.
MATERIALS										
ANTIMONY ORE	25159.	6.	14. *	1430. *	1332. *	22.	81.	39.	3.	95. *
ARSENIC TRIOXIDE	21.	1.	4.	122.	17.	34.	31.	36.	0.	95. *
ASBESTOS	10.	2.	0.	539. *	28.	34.	190.	29.	0.	90. *
BAUXITE	168241.	5.	9.	2611. *	343. *	20.	15.	9.	24.	89. *
BORATE	898.	3.	2.	11.	0.	50.	11.	0.	1.	3.
BUTANE	123.	1.	0.	20.	2.	10.	12.	1.	0.	5.
CHROMITE	2334.	4.	5.	3573. *	452. *	27.	18.	4.	1.	66. *
CLAYS	4870.	2.	0.	0.	0.	10.	0.	0.	1.	0.
COAL	114531.	1.	0.	6.	1.	6.	13.	1.	18.	10.
COAL BITUM./LIGHT	2004.	1.	0.	6.	1.	0.	13.	1.	0.	10.
COPPER ORE	610629.	6.	1.	1016. *	445. *	12.	86.	25.	12.	37.
FELDSPAR	325.	3.	1.	5.	0.	10.	13.	0.	0.	5.
FLUORSPAR	2423.	5.	1.	718. *	154.	22.	201.	120.	3.	50. *
GOLD ORE	142855.	3.	10. *	2730. *	114.	58.	113.	75.	51. *	89. *
GYPSUM	1452.	3.	0.	175.	0.	10.	11.	0.	0.	37.
IRON ORE	162085.	5.	0.	56.	7.	11.	15.	6.	3.	35.
LEAD ORE	338139.	4.	13. *	97.	47.	11.	133.	14.	19.	33.
LIME	0.	3.	0.	0.	0.	31.	0.	0.	0.	2.
MANGANESE ORE	835.	2.	0.	100.	4.	24.	6.	11.	1.	100. *
MOLYBDENUM ORE	12.	5.	0.	44.	8.	16.	43.	13.	1.	4.
NATURAL GAS	4561.	5.	0.	245.	277.	30.	93.	9.	4.	5.
NICKEL ORE	26254.	4.	2.	4576. *	5491. *	37.	54.	23.	4.	75. *
NITROGEN, FIXED	3.	4.	0.	0.	0.	5.	0.	0.	0.	10.
PETROLEUM	8424.	3.	0.	563. *	210.	22.	110.	36.	6.	40.

PHOSPHATE ROCK	1.	6.	0.	48.	0.	13.	29.	0.	0.	0.
PROPANE	1773.	1.	0.	192.	23.	10.	136.	11.	1.	5.
RUTILE	0.	1.	0.	221.	81.	90.	44.	17.	0.	100.
SALT	118282.	6.	3.	0.	0.	5.	0.	0.	20.	9.
SAND/GRAVEL	73892.	4.	0.	0.	0.	0.	0.	0.	1.	0.
SILVER ORE	904.	4.	0.	372.	98.	14.	207.	06.	0.	40.
STONE	123159.	3.	0.	0.	0.	3.	0.	0.	3.	0.
SULFUR	10038.	4.	1.	96.	0.	15.	91.	0.	5.	28.
TANTALUM ORE	22.	5.	0.	100.	1739.	37.	97.	22.	0.	100.
TIN ORE	372830.	2.	1.	4422.	1327.	29.	73.	20.	2.	65.
ZINC ORE	2732.	0.	0.	147.	33.	19.	154.	0.	0.	80.
COTTON	1.	2.	0.	0.	0.	15.	0.	0.	0.	1.
FLAX SEED	40.	1.	0.	0.	0.	25.	0.	0.	0.	20.
MILK BYPRODUCTS	4.	3.	0.	0.	0.	20.	0.	0.	0.	1.
LUMBER	2076.	1.	0.	0.	0.	12.	0.	0.	3.	10.
SEA WATER	200069.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SOYBEAN	79.	3.	0.	0.	0.	12.	0.	0.	0.	0.
TUNG NUTS	82.	1.	10.	0.	0.	70.	0.	0.	1.	80.
WATER	93683.	3.	0.	17.	0.	0.	3.	0.	0.	0.
WHEAT	11.	3.	0.	0.	0.	10.	0.	0.	0.	0.
MISC.	1407.	0.	0.	0.	0.	0.	0.	0.	0.	0.
STEAM	820576.	5.	2.	1.	0.	10.	0.	0.	14.	0.
LIMESTONE	168774.	3.	0.	0.	0.	5.	0.	0.	3.	2.
CU ANODE SLIMES	286.	6.	0.	984.	431.	12.	85.	24.	0.	37.
BAUXITE, BY PROD	605411.	6.	20.	3724.	497.	20.	17.	10.	0.	89.
ZINC, BY PRODUCT	88608.	1.	0.	163.	37.	19.	157.	0.	0.	80.
COAL, BY PROD	551700.	1.	2.	6.	1.	6.	13.	1.	0.	10.
ELECTRICITY	3550658.	3.	0.	0.	0.	0.	0.	0.	0.	0.
CU BYPROD 1	1772.	6.	0.	984.	431.	12.	85.	24.	0.	37.
ZINC 3 BYPRODUCT	76888.	1.	0.	162.	37.	19.	157.	0.	0.	80.
ZINC 2 BYPRODUCT	76879.	1.	0.	162.	37.	19.	157.	0.	0.	80.

BULK MATERIAL REQUIREMENTS FOR GAS 1 XTIL HETEROJUNCT.

SOLAR SCENARIO:
 INTRODUCTION YEAR - 1985
 CUMULATIVE CAPACITY 2000 - 50 GWE

Collector Only

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY-PRODUCT	WORLD PROD GROWTH RATE 1976-2000	SOLAR'S % OF WORLD CONSUMPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/KW	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	50.	10. %/YR	10.	35	50.	50.
<u>MATERIALS</u>							
ALUMINUM	9105641.	0.	7.	2.	13.	179. *	14.
ARSENIC	95720.	100. *	2.	22. *	34.	1.	37.
CEMENT	9363200.	0.	3.	0.	18.	7.	4.
COPPER	420010.	1.	6.	0.	13.	11.	45.
GALLIUM	89040.	100. *	33. *	100. *	45. *	1227. *	75. *
GERMANIUM	2.	100. *	2.	0.	29.	0.	19.
GLASS, SODA LIM	1588589.	0.	3.	1.	5.	9.	5.
GOLD	2140.	40.	3.	14. *	58. *	203. *	58. *
IRON, STEEL	1800320.	1.	6.	0.	10.	13.	18.
LEAD	5824.	13.	5.	0.	11.	0.	18.
MAGNESIUM	93000.	30.	6.	2.	26.	4.	0.
FERROMANGANESE	11441.	100. *	2.	0.	9.	0.	99. *
SAND & GRAVEL	19395200.	0.	4.	0.	18.	1.	0.
STONE	38121596.	0.	3.	0.	3.	2.	0.
SILICON	55800.	0.	2.	0.	14.	1.	8.
TIN	17916.	25.	2.	1.	29.	5.	65. *
TITANIUM	44.	0.	5.	0.	50. *	0.	50. *
ZINC	200.	25.	3.	0.	21.	0.	88. *
STAINLESS STEEL	571000.	0.	3.	1.	10.	11.	15.
FERROCHROME	32550.	5.	5.	0.	18.	1.	50. *
PVC PLASTIC	600.	0.	7.	0.	5.	0.	0.
RUBBER, SER	15000.	0.	0.	0.	5.	0.	4.
TEFLON	2100.	0.	7.	0.	5.	0.	1.
NYLON	340.	0.	7.	0.	5.	0.	1.

RAW MATERIAL REQUIREMENTS FOR GAS 1 XTL RETROJUNCT.

SOLAR SCENARIO:
 INTRODUCTION YEAR -1985
 COMBUSTIVE CAPACITY 2000 - 50 GWP

FACTORS	PERCENT MATERIAL USAGE (1000000)	WORLD PRODUCTN GROWTH RATE	PERCENT SOLAR IN ONE YEAR WORLD	PERCENT RESERVES CONSUMED BY 2000	PERCENT RESOURCES CONSUMED BY 2000	PERCENT LARGEST COUNTRY NON-US	PERCENT WORLD RESERVES CONSUMED BY 2000	PERCENT WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KWH OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS		2. WWR	10.	400	300.	60	200.	100.	50.	50.
MATERIALS										
ACETIC ACID/OLIVE	153.	2.	22 *	141.	20.	24.	33.	59.	1.	98. *
ASBESTOS	1.	3.	0.	539. *	28.	34.	190.	129.	0.	90. *
BAUXITE	45989.	5.	3.	2325. *	310. *	28.	14.	9.	14.	89. *
CHROMITE	445.	1.	1.	3392. *	429. *	27.	17.	4.	1.	98. *
COPPER ORE	94200.	0.	0.	989. *	433. *	12.	85.	24.	4.	37. *
FLUORSPAR	655.	0.	0.	706. *	151.	22.	201.	100.	2.	50. *
GOLD ORE	214000.	14. *	14. *	2958. *	123.	58.	115.	76.	68. *	89. *
MANGANESE ORE	67.	0.	0.	100.	4.	24.	6.	11.	0.	100. *
NICKEL ORE	4569.	3.	0.	4455. *	5346. *	37.	54.	23.	1.	75. *
PETROLEUM	1054.	2.	0.	562. *	210.	22.	110.	36.	2.	40. *
RUTILE	0.	1.	0.	221.	81.	90. *	44.	17.	0.	100. *
TIN ORE	173162.	2.	1.	4376. *	1313. *	29.	73.	30.	2.	65. *
ZINC ORE	424.	0.	0.	146.	33.	19.	154.	8.	0.	88. *
BAUXITE, BY PROD	4452001.	11. *	74. *	13340. *	1779. *	28.	33.	20.	0.	89. *
ZINC, BY PRODUCT	17.	0.	0.	146.	33.	19.	154.	8.	0.	88. *
ZINC 3 BYPRODUCT	17.	0.	0.	146.	33.	19.	154.	8.	0.	88. *
ZINC 2 BYPRODUCT	17.	0.	0.	146.	33.	19.	154.	8.	0.	88. *

BULK MATERIAL REQUIREMENTS FOR GAAS 1 XTL HETEROJUNCT.

SOLAR SCENARIO:
INTRODUCTION YEAR - 1985
CUMULATIVE CAPACITY 2000 - 50. GW

Energy Storage Deleted

FACTORS	MATERIAL USAGE MT	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODN GROWTH RATE 1976-2000	SOLAR'S % OF WORLD CONSUMPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/KW	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	50.	10. %/YR	10.	35.	50.	50.
MATERIALS							
ALUMINUM	10010001.	0.	7.	2.	13.	197. *	14.
ARSENIC	95720.	100. *	2.	22. *	34.	1.	37.
GALLIUM	89040.	100. *	33. *	100. *	45. *	1227. *	75. *
GERMANIUM	2.	100. *	2.	0.	29.	0.	19.
GOLD	2140.	40.	0.0001.	14. *	58. *	203. *	58. *
IRON , STEEL	8765752.	1.	3.	0.	16.	60. *	10.
FERROMANGANESE	48029.	100. *	2.	0.	9.	0.	99. *
TIN	17916.	25.	2.	1.	29.	5.	65. *
TITANIUM	44.	0.	0.	0.	50. *	0.	50. *
ZINC	1560.	25.	3.	0.	21.	0.	88. *
FERROCHROME	32550.	5.	5.	0.	18.	1.	50. *
TUNG OIL	20400.	0.	0.	6.	45. *	1.	70. *

RAN MATERIAL REQUIREMENTS FOR GAAS 1 VTL HETERODJUNCT.

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50 GWE

FACTORS	RAN MATERIAL USAGE (1990MT)	WORLD PRODUCTN GROWTH RATE	MAX. % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KWH OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS		% /YR	10	100	300	08	200	200	50	50
MATERIALS										
ARSENIC TRIOXIDE	153	2	22 *	141	20	34	33	39	1	26 *
ASBESTOS	1	3	0	539 *	28	34	190	129	0	99 *
BAUXITE	51031	5	3	2338 *	312 *	70	14	9	15	89 *
CHROMITE	541	2	1	3461 *	430 *	27	17	4	1	66 *
COPPER ORE	200809	6	0	991 *	436 *	12	85	24	8	27 *
FLUORSPAR	775	5	0	707 *	152	22	201	120	2	50 *
GOLD ORE	214000	3	14 *	2958 *	123	50	115	76	68 *	89 *
MANGANESE ORE	283	3	0	100	4	24	6	11	1	100 *
NICKEL ORE	5767	3	0	4462 *	5354 *	37	54	23	2	75 *
PETROLEUM	1413	3	0	562 *	210	22	110	36	2	40 *
RUYLE	0	1	0	221	81	90 *	44	17	0	100 *
TIN ORE	179162	2	1	4376 *	1313 *	29	73	20	2	65 *
ZINC ORE	448	0	0	146	33	19	154	8	0	88 *
TUNG NUTS	41	1	5	0	0	70 *	0	0	1	80 *
BAUXITE, BY PROD	4452001	11 *	74 *	13340 *	1779 *	28	33	20	0	89 *
ZINC, BY PRODUCT	17	0	0	146	33	19	154	8	0	88 *
ZINC 3 BYPRODUCT	17	0	0	146	33	19	154	8	0	88 *
ZINC 2 BYPRODUCT	17	0	0	146	33	19	154	8	0	88 *

BULK MATERIAL REQUIREMENTS FOR CAD SULFIDE/CAD TELLURIDE

Energy Storage Deleted

SOLAR SCENARIO:
INTRODUCTION YEAR - 1985
CUMULATIVE CAPACITY 2000 - 50. GWE

FACTORS	MATERIAL USAGE MT.	PERCENT SUPPLIED AS BY PRODUCT	WORLD PRODN GROWTH RATE 1970-2000	SOLAR'S % OF WORLD CONSUMPTION	% FROM LARGEST COUNTRY	COST PER UNIT OUTPUT \$/KW	NET PERCENT IMPORTED
THRESHOLD LEVELS	---	50.	10. %/YR	10.	35.	50.	50.
<u>MATERIALS</u>							
ALUMINUM	17821626.	0.	7.	4.	13.	350. *	14.
CADMIUM	4360.	100. *	4.	2.	15.	1.	57. *
CEMENT	16988160.	0.	3.	0.	18.	12.	4.
CHROMIUM	40.	0.	3.	0.	31.	0.	100. *
COPPER	1358710.	1.	6.	1.	12.	36.	45.
GLASS, FIBER	1888000.	0.	7.	4.	5.	7.	2.
GLASS, SODA LIM	4881360.	0.	3.	4.	5.	28.	5.
INDIUM	500.	100. *	0.	40. *	19.	4.	75. *
IRON, STEEL	8794677.	1.	3.	0.	16.	00. *	10.
LEAD	10493.	13.	5.	0.	11.	0.	18.
MAGNESIUM	167479.	30.	0.	3.	26.	7.	0.
FERROMANGANESE	48203.	100. *	2.	0.	9.	0.	99. *
NICKEL	2020.	7.	3.	0.	28.	0.	75. *
PORCELAIN	600.	0.	0.	0.	10.	0.	0.
SAND & GRAVEL	35189764.	0.	4.	0.	10.	1.	0.
STONE	69166000.	0.	0.	0.	3.	4.	0.
SILICON	125728.	0.	3.	0.	14.	2.	8.
SULFUR	920.	31.	0.	0.	15.	0.	15.
TELLURIUM	1320.	100. *	0.	37. *	16.	1.	37.
TIN	17897.	25.	0.	1.	29.	5.	65. *
ZINC	1360.	25.	0.	0.	21.	0.	88. *
STAINLESS STEEL	1178740.	0.	0.	1.	10.	24.	15.
FERROCHROME	58618.	5.	0.	0.	18.	3.	50. *
LINSEED OIL	6800.	0.	1.	0.	5.	0.	1.
ACRYLIC	37800.	0.	7.	0.	0.	1.	1.
ALKYD RESIN	13600.	0.	7.	0.	0.	0.	1.
EPOXY - FIBERGL	480.	0.	7.	0.	0.	0.	5.
GLUE, PHENOL FOR	12200.	0.	7.	0.	0.	0.	5.
LUMBER, SOFTWOOD	597800.	0.	4.	0.	20.	0.	12.
PHENOLIC RESIN	38760.	0.	7.	0.	0.	1.	1.
PLASTIC, RESIN	18800.	0.	7.	0.	0.	0.	3.
POLYESTER RESIN	8160.	0.	7.	0.	0.	0.	0.
PVC PLASTIC	18790.	0.	7.	0.	0.	0.	0.
RUBBER, SBR	29980.	0.	6.	0.	0.	0.	4.
TEFLON	3900.	0.	7.	1.	0.	1.	1.
NYLON	600.	0.	7.	0.	0.	0.	1.
TUNG OIL	20400.	0.	0.	6.	45. *	1.	70. *
EVA	299200.	0.	7.	2.	0.	4.	5.

RAW MATERIAL REQUIREMENTS FOR CAD SULFIDE/CD TELURIDE

SOLAR SCENARIO:
INTRODUCTION YEAR -1985
CUMULATIVE CAPACITY 2000 - 50 GWE

FACTORS	RAW MATERIAL USAGE (1980MT)	WORLD PRODUCTION GROWTH RATE	MAX % FOR SOLAR IN ONE YEAR WORLD	% U.S. RESERVES CONSUMED BY 2000	% U.S. RESOURCES CONSUMED BY 2000	% FROM LARGEST COUNTRY NON-US	% WORLD RESERVES CONSUMED BY 2000	% WORLD RESOURCES CONSUMED BY 2000	PRESENT COSTS IN \$/KWH OF SOLAR	NET PERCENT IMPORTED
THRESHOLD LEVELS		7.2%/yr	10.	400	300	60.	350.	250.	50.	50.
MATERIALS										
ADAMANTINE	1.	3.	0.	500 *	20.	31.	190.	10.	0.	50. *
BAUXITE	90400	5.	5.	2437 *	325. *	20.	15.	9.	27.	89. *
BORATE	272.	5.	1.	11.	0.	50.	10.	0.	1.	3.
BUTANE	34.	1.	0.	20.	2.	10.	12.	1.	0.	5.
CHROMITE	800.	4.	2.	3435 *	435. *	27.	18.	4.	1.	66. *
CLAYS	2641	2.	0.	0.	0.	10.	0.	0.	1.	0.
COAL	50093.	1.	0.	6.	1.	6.	13.	1.	16.	10.
COAL BITUM/LIGHT	2.	1.	0.	0.	1.	6.	13.	1.	0.	10.
COPPER ORE	298910.	6.	1.	1000 *	430. *	10.	85.	15.	12.	37.
FELDSPAR	454.	3.	1.	5.	0.	10.	13.	0.	0.	5.
FLUORSPAR	1322.	5.	1.	711. *	152.	22.	201.	120.	3.	50. *
GYPNUM	815.	3.	0.	175.	0.	10.	11.	0.	0.	37.
IRON ORE	56830.	5.	0.	55.	7.	11.	15.	6.	2.	35.
LEAD ORE	349.	3.	0.	77.	38.	11.	126.	13.	0.	33.
MANGANESE ORE	201.	2.	0.	100.	4.	24.	6.	11.	1.	100. *
NATURAL GAS	2299.	5.	0.	245.	277.	30.	93.	9.	4.	5.
NICKEL ORE	9632.	3.	1.	4483 *	5380. *	37.	54.	23.	3.	75. *
NITROGEN FIXED	0.	4.	0.	0.	0.	5.	0.	0.	0.	10.
PETROLEUM	2144.	3.	0.	562. *	210.	22.	110.	36.	3.	40.
PROPANE	332.	1.	0.	192.	23.	10.	136.	11.	0.	5.
SALT	57726.	6.	1.	0.	0.	5.	0.	0.	35.	9.
SAND/GRAVEL	41537.	4.	0.	0.	0.	0.	0.	0.	2.	0.
STONE	69166.	3.	0.	0.	0.	3.	0.	0.	4.	0.
SULFUR	4486.	4.	1.	94.	1.	15.	90.	0.	4.	28.
TIN ORE	170968.	2.	1.	4370 *	1313. *	20.	73.	10.	2.	60. *
ZINC ORE	897.	0.	0.	146.	33.	19.	154.	0.	0.	88. *
FLAX SEED	20.	1.	0.	0.	0.	25.	0.	0.	0.	20.
MILK BYPRODUCTS	2.	3.	0.	0.	0.	20.	0.	0.	0.	1.
LUMBER	637.	1.	0.	0.	0.	12.	0.	0.	2.	10.
SEA WATER	120763.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SOYBEAN	39.	3.	0.	0.	0.	12.	0.	0.	0.	0.
TUNG NUTS	41.	1.	5.	0.	0.	70. *	0.	0.	1.	80. *
WATER	26670.	3.	0.	17.	2.	0.	3.	0.	0.	0.
WHEAT	3.	3.	0.	0.	0.	10.	0.	0.	0.	0.
MISC	540.	0.	0.	0.	0.	0.	0.	0.	5.	0.
STEAM	445602.	5.	1.	1.	0.	10.	0.	0.	15.	0.
LIMESTONE	78250.	3.	3.	0.	0.	5.	0.	0.	3.	2.
ZINC, BY PRODUCT	3136.	0.	0.	147.	33.	19.	154.	0.	0.	80. *
COAL, BY PROD	186747.	1.	0.	6.	1.	6.	13.	1.	0.	10.
ELECTRICITY	2232330.	3.	0.	0.	0.	0.	0.	0.	0.	0.

APPENDIX B

CHARACTERIZATION OF PHOTOVOLTAIC CELLS

W. T. Pawlewicz

The objective of this characterization of photovoltaic devices or solar cells is to provide the numerical information necessary for computation of the material quantities required for large-scale, terrestrial deployment of each solar cell presently being researched in the DOE Solar Photovoltaic Program. Material supply problems can then be foreseen by comparison of the computed material requirements with known reserves and resources, and potential production capacity. The solar cells examined in this study were of five general types:

- CdS/Cu₂S Cells: Backwall and Frontwall
- CdS Heterojunctions with CdTe, InP, CuInSe₂
- Cu₂O Cells
- Si Cells: n/p, MIS, heterojunctions with In_{2-x}Sn_xO₃ and SnO₂, and amorphous devices
- GaAs Cells: Ga_{1-x}Al_xAs/GaAs, MIS.

Particular attention is directed to those cells containing elements potentially in short supply such as Cd, Ga, In, Se, and Te.

The information necessary for computation of the material required for use of a given photovoltaic device includes:

- a reference design for the construction and operation of the device
- an estimated efficiency for the device fabrication process.

A reference design considers the cell construction, the thickness and percent area coverage of each layer of the cell, the concentration of sunlight with which the cell is expected to be operated, and the conversion efficiency of the cells under the expected operating conditions. Fabrication process efficiency includes the utilization of material during either crystal growth or thin film deposition, the estimated efficiency of material recovery, and also the production yield of devices meeting electrical output specifications.

Given the above reference design and fabrication process efficiency, the quantity of each element used in each layer of a cell can be calculated per unit power output from the following expression:

$$\frac{\text{Element Quantity}}{1} = \frac{C (\text{layer thickness})(\text{area coverage})(\text{power output})}{(\text{solar insolation})(\text{conversion efficiency})(\text{concentration factor})(\text{process efficiency})} \quad (1)$$

where C is a constant which depends on the atomic number of the element, the density and molecular number of the compound containing the element, and the units chosen for the computation. The solar insolation value used for all calculations in this study is the Air Mass 1 (AM1) or peak insolation value of $1 \text{ kW}\cdot\text{m}^{-2}$. The material requirements calculated on the basis of a yearly average insolation are generally 4 to 7 times higher than the peak values, depending on geographic location and the prevailing atmospheric conditions. More specific information concerning the reference design parameters and the fabrication process efficiencies used in the above calculations is given in the following sections.

PARAMETERS AFFECTING MATERIAL REQUIREMENTS IN PHOTOVOLTAIC REFERENCE DESIGNS

The layer thickness of photovoltaic materials, the conversion efficiency of the photovoltaic devices, and the concentration of sunlight are three parameters that affect final materials requirements in the reference designs. These parameters are interrelated and must be considered together.

Layer Thickness

Consistent with the goal of a fair materials availability assessment, the layer thickness for each material was estimated from the literature data as the minimum layer thickness required to yield the maximum practical conversion efficiency in a given solar cell design. In some cases, particularly for the thin film constructions, the use of these minimum thickness values does represent an advance over state-of-the-art technology. However, fabrication of a solar cell with the maximum theoretical efficiency using these minimum

thickness values is probably technologically feasible, given continued research and development. Moreover, the minimum thickness values selected are, in all cases where estimates are available in the published literature, identical with the expectations of other researchers working with the individual devices.

The minimum thickness of the active semiconductor layer of each cell is estimated chiefly on the basis of AM1 absorption lengths reported in the literature. For the cells examined here, it is further required that the layer thickness be 2 to 3 times larger than the highest minority carrier diffusion length reported in the literature for a given material. A notable exception is the Si n/p device for which technological advances such as the COMSAT Company's Non-Reflecting front surface, the Back Surface Field, and optically-reflecting back contacts suggest consideration of only a 50- μm thickness for the active layer.⁽¹⁾

The minimum thickness of the semiconductor window layer of a heterojunction cell is estimated from reported transmission and conductivity data. For common window layers such as CdS, $\text{In}_{2-x}\text{Sn}_x\text{O}_3$, and SnO_2 , the thicknesses necessary for maximum optical transmission and minimum series resistance contribution are well defined by several independent measurements.

Metal grid thickness is selected on the basis of negligible series resistance contribution and 95% optical transmission.

Antireflection coatings used on some types of solar cells are presently all of the single-layer, quarter-wavelength variety. The layer thickness needed for minimum reflection near the 600-nm peak in the AM1 spectrum is easily calculated from standard optics equations and, for some of the cells, these theoretical values have been confirmed by measurements reported in the literature.

Conversion Efficiency

A narrow range of material requirements for each photovoltaic device is calculated using two different conversion efficiencies. A lower limit for materials usage is defined using maximum (practical) theoretical efficiency values published in the literature. The upper limit is calculated using

state-of-art efficiency for a given device if efficiencies greater than 10% have been demonstrated for that device. If these efficiencies have not been demonstrated, then 10% is used in the computations since it is generally agreed that this value is the minimum acceptable for economic viability of power-generating, photovoltaic systems. All efficiencies used are AM1 values.

Concentration Factors

The material requirements for all cells are calculated assuming unconcentrated AM1 solar insolation. The actual material quantities necessary for a given power production can be reduced by a factor equal to the ratio of the solar power concentrated on the cell to the AM1 power density; this applies only to those devices where operation under concentrated sunlight does not result in a significant drop in the cell's conversion efficiency or in a reduction of the cell's operating lifetime. To date, only two cells have been successfully used under concentrated sunlight. The $\text{Ga}_{1-x}\text{Al}_x\text{As}/\text{GaAs}$ cell has been operated at concentrations up to about 2000X with essentially no loss in conversion efficiency,⁽²⁾ and single-crystal Si n/p cells can be operated at concentrations of 50 to 100X with efficiencies only slightly lower (~12%) than under AM1 conditions.⁽³⁾ Barring significant technological advances, it appears that concentration systems will not be used with thin-film cells because of accelerated degradation at the higher operating temperatures.

SOLAR CELL FABRICATION PROCESSES

The material requirements for all cells are calculated assuming a fabrication process efficiency of 100%. The actual material quantities necessary for a given power production must be adjusted in accordance with equation (1) to account for loss of material during crystal growth or thin film deposition, recovery of lost material, and recycling of finished devices that fail to meet electrical output performance specifications. Preliminary analysis of all fabrication processes presently contemplated for large-scale solar cell production indicates that taking into account fabrication process efficiencies will not affect the calculated material requirements by more than a factor of two. Considerations leading to this conclusion are summarized below.

Physical Vapor Deposition (PVD)

Physical vapor deposition techniques include thermal evaporation and sputtering. The materials-usage efficiency for each of these processes varies widely, depending on hardware geometry and process details. The efficiency of material utilization is measured by the ratio of the material constituting the device to the total amount of material used in the process. As a proportion this ranges from 40 to 60%, depending on substrate size, for the case of thermal evaporation using long filaments or multiple electron beam sources.⁽⁴⁾ For the case of sputter deposition with a plane-parallel substrate-target arrangement, experimentally determined collection efficiencies range from 75% for 0.1-m² substrate area to 90% for a 1-m² substrate.⁽⁵⁾ Both for evaporation and sputtering the efficiencies of material use may be increased by recovering the uncollected material from strategically located shielding.

Chemical Vapor Deposition (CVD)

For the deposition of metals by hydrogen reduction of halides, collection efficiencies of 10 to 90% are quoted for chemical vapor deposition.⁽⁶⁾ In the case of Si deposition for certain applications, a collection efficiency of 50% may be projected.⁽⁷⁾ Similar efficiencies are expected for the Chemical Spray Method. Material recovery will increase the usage efficiency, as in the case of the PVD processes.

Crystal Growth

Crystal growth techniques such as the Czochralski, Float Zone, ribbon, and dendrite processes are presently used only for silicon (Si) solar cell material. For Si the question of process efficiency appears not as important because of its abundance. Moreover, if the EFG ribbon or the dendrite processes are successfully developed, use of Si during the cell fabrication process would approach 100%. For cells manufactured from Czochralski-grown Si, material usage is reduced to 50% due to kerf losses, oxidation losses, zone refining losses, and etching/polishing of cut wafers. Recycling of this wasted material may be possible, depending chiefly upon cost.

Liquid Phase Epitaxy

The LPE process is used for fabrication of GaAs devices. Deposition of material by LPE is particularly favorable to efficient use of material. An overall material use efficiency of 90 to 99% has been demonstrated for GaAs processes in the recovery of material from reactor plumbing and traps as well as in the recovery of kerf losses.⁽⁸⁾

MATERIAL REQUIREMENT SUMMARY

A summary of the total material requirements for each of 13 different photovoltaic devices is displayed in Table B-1. Material requirements are listed in metric tons per gigawatt peak electric output. The materials calculations for each cell are described more completely in the following sections, which characterize the five general types of photovoltaic devices. General descriptions of the devices are included with consideration of a reference design and a discussion of the fabrication process currently used for each of the 13 solar cells.

TABLE B-1. Summary of Material Requirements for Solar Cells^(a)

Solar Cell	Estimated Commodity Required, MT/GWe (pk)											
	Ag	Al	As	Au	B	Cd	Ga	Ge	In	P	S	Si
CdS/Cu ₂ S Backwall		5.10				57.7					26.0	
CdS/Cu ₂ S Frontwall						749					214	
CdS/CdTe						87.1			11.3		18.2	
CdS/InP				73.0		63.7			43.3	8.65	18.2	
CdS/CuInSe ₂		6.76		96.6		75.0			19.7		21.4	
Cu ₂ O MIS												
Si n/p Single Crystal	18.8	96.5			6.5x10 ⁻⁵					7.4x10 ⁻³		3330
Si MIS		135			9.0x10 ⁻⁶							1160
In _{2-x} Sn ₄ O ₃ /Si		141.8			9.0x10 ⁻⁶				22.6			1160
SnO ₂ /Si		141.8								2.6x10 ⁻⁵		1160
Amorphous Si										7.0x10 ⁻³		25.2
Ga _x Al _{1-x} /GaAs		1.32	1915	42.9			1781	4.21x10 ⁻²				
GaAs MIS			55.0	1.16			51.2	266				

Solar Cell	Estimated Commodity Required, MT/GWe (pk)													
	Se	Ta	Te	Ti	Cu	Pb	Pd	Pt	Sn	Ni	Cr	Fe	Zn	Glass
CdS/Cu ₂ S Backwall					135.6	192			16.4	2.24	0.64	0.32		78,000
CdS/Cu ₂ S Frontwall					932.1								35	
CdS/CdTe			26.5		196.6				0.61	40.0	0.64	0.32		78,000
CdS/InP					196.6				0.61	2.24	0.64	0.32	2.97	78,000
CdS/CuInSe ₂	27.1				189.9									78,000
Cu ₂ O MIS					914.8									
Si n/p Single Crystal		4.80		0.064			0.084							
Si MIS					22.3						0.36			
In _{2-x} Sn ₄ O ₃ /Si									1.22					
SnO ₂ /Si									16.4					
Amorphous Si					22.3			1.07		79.2	150	561		
Ga _x Al _{1-x} /GaAs				0.90					160				3.88	
GaAs MIS		3.42			22.3				287					78,000

(a) Based on currently reported state-of-art conversion efficiencies

THE CdS/Cu₂S SOLAR CELL

The CdS/Cu₂S device is the most extensively researched and most highly developed thin-film solar cell. Over a period of more than 20 years this cell has been fabricated in two operationally different configurations, each with a variety of substrate and contact materials. An excellent general description of the CdS/Cu₂S cell and its evolution was recently presented by Böer et al.,⁽¹⁾ the main features of which are summarized here.

The cross-section of the basic cell in its two configurations is illustrated in Figure B-1. The cell consists of a substrate covered with an ohmic electrode making contact to a thin film of n-type CdS, the upper fraction of which is converted into a p-type Cu₂S layer usually via an ion exchange reaction. The Cu₂S layer, in turn, is connected to another ohmic contact. The two cell configurations, frontwall and backwall, are distinguished by whether the light impinges through the Cu₂S or the CdS layer, respectively. Each configuration has specific requirements for the substrates and ohmic contacts.

A. Frontwall Configuration

B. Backwall Configuration

FIGURE B-1. General Configurations of the CdS/Cu₂S Solar Cells

TABLE B-2. Requirements for CdS/Cu₂S Substrates and Contacts

<u>Configuration</u>	<u>Substrate</u>	<u>CdS Contact</u>	<u>Cu₂S Contact</u>
Frontwall	Mo, Cu, Fe/Ni or Al foils, glass, plastic	Zn, Al, Ni, Mo, Pd/Ag/Ti, Ag, Sn	Cu, Au, Graphite
Backwall	Glass, plastic	In _{2-x} Sn _x O ₃ , Cd ₂ SnO ₄ , SnO ₂	Cu, Au, Graphite

Commonly used substrates for the frontwall cells are metal foils of Cu, Mo, Fe/Ni and Al, or metallized glass or plastics (e.g., Ag/kapton). For the backwall cells transparent substrates of glass or plastic are used. Zn is predominantly used as an ohmic contact to the CdS layer for the frontwall cells, but other metals such as Al, Ni, Pd/Ag/Ti, Mo, Ag, or Sn have also been successfully employed. In the backwall configuration the contacts are transparent films of SnO₂, In_{2-x}Sn_xO₃, or Cd₂SnO₄.

The CdS layer is usually made by physical vapor deposition. However, sintered powder and sprayed-on, thermally decomposed compounds are also used. The Cu₂S is commonly prepared by dipping the CdS layer into a hot solution containing cuprous ions. Evaporating, spraying, or sputtering of the copper compounds onto the CdS followed by heat treatment can also be used to prepare the Cu₂S.

Ohmic contact to the Cu₂S layer is frequently made with Au in the form of opaque metal layers for backwall cells and transparent grids for frontwall cells. Copper, graphite and Au-plated Cu are also employed.

Computation of the material requirements for large-scale deployment of CdS/Cu₂S solar cells will be made using reference designs based on only the most advanced cell structures and processes developed to date. The latter include the backwall cell being developed by Photon Power Co., El Paso, Texas, and the frontwall cells being developed at the Institute of Energy Conversion of the University of Delaware and at Westinghouse Research Laboratories, Pittsburgh, Pennsylvania.

BACKWALL CELL

In the Photon Power Co. process, the thin film cells are made by spraying suitable chemical solutions onto heated glass substrates as the glass sheet emerges from a "float glass" manufacturing process. The construction of the backwall cells⁽²⁾ is shown schematically in Figure B-2. The substrate for the cell is 3-mm-thick, double-strength window glass through which the solar insolation passes. A 0.3- μm -thick film of SnO_2 is sprayed onto the glass substrate to serve as a transparent electrode. Upon the SnO_2 film are deposited a 1- μm -thick film of CdS-Al (26 at.% Al), a 1- μm -thick film of undoped CdS, followed by a 1- μm -thick layer of Cu_2S . The desired CdS/ Cu_2S interface is produced by suitable heat treatment. Contact to the SnO_2 electrode is made at frequent intervals by means of a grid structure consisting of a 0.4- μm -thick grid of Inconel plus a 5- μm -thick grid of Cu, both of which are vacuum evaporated through a suitable mechanical mask. Contact to the Cu_2S layer is made with a 0.7- μm -thick evaporated Cu layer followed by 2 μm of evaporated Pb.

Backwall cells with average sunlight efficiency of 4.5% have been produced, with some cells exceeding 5% efficiency.⁽²⁾ These cells are 5 x 5 cm in area and are fabricated in a batch process. Efficiencies in excess of 10% are predicted based on expected improvement in the stoichiometry of the Cu_2S layer, increase of the Cu_2S thickness from 0.4 to 1 μm for improved long wavelength response, and reduction of insolation losses in the glass and tin oxide. On the basis of experimental data available to date for both configurations of CdS/ Cu_2S cells, maximum overall conversion efficiencies in excess of 15% are expected.⁽¹⁾

The fabrication process⁽³⁾ for the backwall cells begins with a float glass plant which produces a continuous ribbon of 3 m-width glass from raw materials continuously fed into a furnace and melted. The glass ribbon floats on a bath of molten metal and passes under three spray stations which deposit the tin oxide, CdS, and Cu_2S layers sequentially. After cooling and cutting, the glass sheets are fed through an automatic vacuum evaporating line where electrodes are deposited through appropriate masks.

Using the layer thicknesses of Figure B-2 and a conversion efficiency of 10%, the quantities of material required per peak power output can be calculated for the backwall cell. The results are shown in Table B-3.

FIGURE B-2. Reference Backwall CdS/Cu₂S Solar Cell

TABLE B-3. Material Requirements per Peak Power Output for CdS/Cu₂S Backwall Solar Cells

Layer	Function	Thickness, μm	Element	MT/10 ⁹ We (pk)(a)
CdS	Window Layer	1 ^(b)	Cd	31.8
			S	9.1
CdS-Al	Cu Diffusion Barrier	1 ^(b)	Cd	25.9
			S	7.35
			Al (26 at.%)	5.10
Cu ₂ S	Active Layer	1 ^(b)	Cu	38.0
			S	9.6
Cu	Back Contact	0.7 ^(b)	Cu	53.0
Pb	Positive Electrode	2 ^(b)	Pb	192
SnO ₂	Transparent Contact	0.3	Sn	16.4
Inconel	Negative Electrode	0.4 ^(c)	Ni(.7)	2.24
			Cr(.2)	0.640
			Fe(.1)	0.320
Cu	Negative Electrode	5 ^(c)	Cu	44.6
Glass	Substrate	3000	Glass	7.80 x 10 ⁴

(a) Based on 10% conversion efficiency and no loss of materials during the manufacturing process. At a maximum theoretical efficiency of 15%, the materials requirements would be 2/3 of these values.

(b) 85% coverage.

(c) 10% coverage.

FRONTWALL CELL

The frontwall cells under development at the University of Delaware and at Westinghouse Research Laboratories are very similar in construction and will be treated together. In both processes the cell is formed on the front surface of a thin metal foil by sequential vacuum deposition of the compounds in a large chamber to form the heterojunction and the electrodes. A cross-section of the frontwall cell is illustrated in Figure B-3. It consists of 0.5- μm -thick zinc coating on a 10- μm -thick copper foil, a CdS layer 20 μm in thickness, a 0.4- μm -thick Cu_2S layer, and a 5- μm copper grid contact.

Full-size cells (55 cm^2) were recently fabricated at the University of Delaware with an average sunlight (AM1) efficiency of 6.84% and a maximum achieved efficiency of 7.8%.⁽⁴⁾ Small cells have been made elsewhere⁽⁵⁾ with conversion efficiencies of approximately 8.5%, which is presently the project goal of the Delaware group for their large-area, polycrystalline-film cells. Efficiencies of 5 to 6.6% were recently reported by the Westinghouse group for standard process cells.⁽⁶⁾ Based on the experimental data available to date, maximum overall conversion efficiencies in the excess of 15% are predicted.⁽¹⁾

The relatively high efficiency cells described above are typically made with a CdS layer 20 to 40 μm thick, although it is generally agreed that only about 1 μm of CdS is needed for the active photovoltaic part of the frontwall cell. The unusually large thickness of the CdS layer has traditionally been necessary to prevent shorting paths between the Cu_2S layer and the substrate. However, much thinner frontwall cells (1 to 5 μm) have been made with efficiencies in excess of 6%,⁽⁷⁾ and backwall cells with a CdS thickness as little as 2 μm have exhibited conversion efficiencies near 5%.⁽³⁾ The CdS layer thickness on Figure B-3 has been set at 20 μm and this number is used to calculate the material requirements per unit output for the frontwall cells.

Using the layer thicknesses of Figure B-3, and a conversion efficiency of 10%, the material requirements per peak power output are calculated for the frontwall cell and are summarized in Table B-4.

FIGURE B-3. Reference Frontwall CdS/Cu₂S Solar Cell

TABLE B-4. Material Requirements per Peak Power Output for CdS/Cu₂S Frontwall Solar Cells

<u>Layer</u>	<u>Function</u>	<u>Thickness, μm</u>	<u>Element</u>	<u>MT/10⁹We (pk)^(a)</u>
CdS	Barrier Layer	20.	Cd S	749 214
Cu ₂ S	Active Layer	0.4	Cu S	17.8 4.52
Zn	Back Contact	0.5	Zn	35.0
Cu	Foil Substrate	10	Cu	892
Cu	Grid Collector	5 ^(b)	Cu	22.3

(a) Based on 10% conversion efficiency and no loss of materials during the manufacturing process. At a maximum theoretical efficiency of 15%, the materials requirements would be 2/3 of these values.

(b) 5% coverage.

CdS HETEROJUNCTIONS WITH CdTe, InP, and CuInSe₂

Three additional solar cells involving CdS have been developed much more recently than the Cu₂S cell, and all show promise as high-efficiency thin-film devices. These cells are the heterojunctions of n-CdS with p-CdTe, p-InP and p-CuInSe₂. All three are "backwall" or "window" type cells in which the incident radiation enters through the large-band-gap material (CdS) and most of the photo-generation takes place at or near the adjoining surface of the smaller-band-gap material. Two possible thin-film structures are discussed for each of the CdTe, InP and CuInSe₂ cells, based on substrates of a) metal foil and b) glass. The construction of each of the three cells is identical except, of course, for the active layer and its contact metal.

CdS/CdTe CELL

Development work on the CdS/CdTe heterojunction cell began less than a decade ago. Thin-film CdS/CdTe structures were fabricated at Battelle-Frankfurt Laboratories; they consisted of 10 to 20 μm of polycrystalline CdTe deposited onto a Mo foil, followed by a few microns of CdS and an evaporated contact of indium.⁽⁸⁾ The CdTe was deposited by a high-temperature gas transport method and the CdS by conventional evaporation. Cells with active areas of $\sim 10 \text{ mm}^2$ exhibited efficiencies between 5 and 6% under simulated solar insolation at room temperature, and efficiencies in excess of 8% were predicted for an optimized cell.

Epitaxial growth of CdS on single-crystal p-CdTe at Stanford University recently produced cells with efficiencies of up to 7.9% (solar simulation, 85 mW/cm^2).⁽⁹⁾ These cells employed a conducting layer of $\text{In}_{2-x}\text{Sn}_x\text{O}_3$ as a transparent front electrode on the CdS film which reduced the distributed series resistance loss. The back contact was Ni. Maximum theoretical efficiencies of 17% were predicted for the CdS/CdTe heterojunction.⁽¹⁰⁾ The minority carrier diffusion length in the p-CdTe crystal substrate of the 7.9% efficient cell was measured to be $\sim 0.4 \mu\text{m}$. High conversion efficiency with

such a small diffusion length implied a very large optical absorption coefficient, which indeed was found both from the Stanford data and from recent measurements made at Mobil-Tyco Solar Energy Corporation.⁽¹¹⁾ Based on this absorption coefficient data it appears that only a 1- μm thickness is necessary for the CdTe layer of a thin film CdTe/CdS solar cell.

Similar work on epitaxial vapor growth of CdS on CdTe substrate crystals conducted at Matsushita Electric Industrial Co. produced a cell with a conversion efficiency of 10.5% for the total area (0.57 cm^2) and 12.0% for the active area (0.50 cm^2), measured under sunlight of 68 mW/cm^2 insolation.⁽¹²⁾ This cell used a Ni contact to the CdTe and an In-Ga alloy contact to the CdS.

Based on the findings of these three major research efforts, the reference designs for thin-film CdS/CdTe solar cells shown in Figures B-4 and B-5 were established. In each case the CdTe and CdS semiconductor layer are 1 and 2 μm in thickness, respectively, and the contact metal to the CdTe layer is Ni. The cell illustrated in Figure B-4 employs a Mo metal foil substrate with an indium contact to the CdS and is quite similar to the Battelle-Frankfurt cell. The cell in Figure B-5 uses a glass substrate with a transparent, conducting front contact of $\text{In}_{1.9}\text{Sn}_{0.1}\text{O}_3$. The collector contact arrangement is based on the design of the Photon Power Co. $\text{Cu}_2\text{/CdS}$ backwall cell.⁽²⁾ Since the oxide-coated glass substrate of Figure B-5 is currently receiving much greater attention in DOE-sponsored research programs,⁽¹³⁾ this reference design was used for the material-requirement calculations summarized in Table B-5.

FIGURE B-4. CdS/CdTe Solar Cell (Foil Substrate)

FIGURE B-5. Reference CdS/CdTe Solar Cell (Glass Substrate)

TABLE B-5. Material Requirements per Peak Power Output for CdS/CdTe Solar Cells on Glass Substrates

Layer	Function	Thickness, μm	Element	MT/ 10^9We (pk) (a)
CdS	Window Layer	2 ^(b)	Cd	63.7
			S	18.2
CdTe	Active Layer	1 ^(b)	Cd	23.4
			Te	26.5
Ni	Back Contact	0.5 ^(b)	Ni	37.8
Cu	Positive Electrode	2 ^(b)	Cu	152
$\text{In}_{1.9}\text{Sn}_{0.1}\text{O}_3$	Transparent Contact	0.2	In	11.3
			Sn	0.612
Inconel	Negative Electrode	0.4 ^(c)	Ni (.7)	2.24
			Cr (.2)	0.640
			Fe (.1)	0.320
Cu	Negative Electrode	5 ^(c)	Cu	44.6
Glass	Substrate	3000	Glass	7.80×10^4

(a) Based on 10% conversion efficiency and no loss of materials during the manufacturing process. At a maximum theoretical efficiency of 17%, the materials requirements would be 10/17 of these values.

(b) 85% coverage.

(c) 10% coverage.

CdS/InP CELL

Fabrication of CdS/InP heterojunction cells was reported for the first time about 2 years ago by Bell Laboratories.⁽¹⁴⁾ The cells were prepared by epitaxial growth of 5 to 10- μ m thick CdS films on p-type InP single crystals. The back contact to the InP was applied by electrodeposition of Au, Au, and Au layers in succession.⁽¹⁵⁾ Contact to the CdS surface was made with a contact grid of In or eutectic Ga-In alloy. An antireflection coating was applied by evaporation of SiO₂. Cells with active areas of $\sim 0.23 \text{ cm}^2$ exhibited power conversion efficiencies of 12.5% measured under sunlight of 53 mW/cm^2 intensity. The ultimate efficiency achievable with state-of-the-art single-crystal InP substrates was calculated to be 17.2% for AM2 conditions and 14.0% for the AMO conditions.⁽¹⁶⁾

Thin film polycrystalline CdS/InP cells with 2.8% AM1 conversion efficiency for a 0.52 mm^2 illuminated area were recently reported by the Bell group.⁽¹⁷⁾ These cells were made on graphitized carbon substrates by chemical vapor deposition of the Zn- or Cd-doped InP, followed by two-source evaporation of the CdS layer. Because InP has a direct band gap, only $\sim 1\text{-}\mu\text{m}$ film thickness is needed for absorption of most of the solar insolation that can be used by the cell.⁽¹⁸⁾ The Bell group estimated, at that time, that thin-film cells with 8% conversion could be achieved by improvement of the Cd/InP back contact alone. In support of this contention, improved power conversion efficiencies of up to 5.2% under AM2 conditions were reported for thin-film cells at a very recent photovoltaic conference.⁽¹⁹⁾

Thin-film polycrystalline CdS/InP cells are also under development at Hughes Research Laboratories,⁽²⁰⁾ Malibu, California, and at Rockwell International,⁽²¹⁾ Anaheim, California. The Hughes process uses a reactive vapor deposition technique to deposit InP on soda-lime glass substrates which have been sequentially precoated with $\text{In}_{1.9}\text{Sn}_{0.1}\text{O}_3$ and CdS. The Rockwell approach uses a metal-organic-hydride chemical vapor deposition technique to deposit the InP. No cell performance results have been reported to date by either group.

Two possible thin-film cell constructions based on the Hughes approach and the Bell work are illustrated in Figures B-6 and B-7 for carbon substrates

and conductive-oxide-coated glass substrates, respectively. The cell in Figure B-7 was used for calculation of the material requirements per peak power output for the CdS/InP thin-film cell, the results of which are summarized in Table B-6.

According to column 5 of Table B-6, 63.7 MT of Cd and 18.2 MT of S are used in enough $\text{In}_{1.9}\text{Sn}_{0.1}\text{O}_3/\text{CdS}/\text{InP}$ thin-film solar cells to produce a peak power output of 10^9 W, assuming AM1 solar insolation and 10% conversion efficiency. Very recent results⁽¹⁸⁾ reported by Bell Labs, however, show that it may be possible to completely eliminate the CdS layer from the cell and still achieve high conversion efficiency. The Bell group prepared indium tin oxide/indium phosphide solar cells by ion beam deposition of indium tin oxide on InP single-crystal substrates, and these cells exhibited solar power conversion efficiencies of 14.4% under AM2 conditions for active areas of $\sim 20 \text{ mm}^2$. The cells employed a Au-2 wt% Zn contact to the InP layer similar to the one listed in Table B-4, but used an Al contact to the indium tin oxide layer in place of the Inconel. With these changes, columns 4 and 5 would have the following modified entries:

<u>Element</u>	<u>Mt/10^9We (pk)^(a)</u>
Cd	0
S	0
Ni,Cr,Fe	0
Al	0.108

FIGURE B-6. CdS/InP Thin-Film Cell (Carbon Substrate)

FIGURE B-7. Reference CdS/InP Solar Cell (Glass Substrate)

TABLE B-6. Material Requirements per Peak Power Output for CdS/InP Solar Cells on Glass Substrates

Layer	Function	Thickness, μm	Element	MT/10 ⁹ We (pk) ^(a)
CdS	Window Layer	2 ^(b)	Cd	63.7
			S	18.2
InP	Active Layer	1 ^(b)	In	32.0
			P	8.65
Au-Zn	Back Contact	0.5 ^(b)	Au (.9)	73.0
			Zn (.1)	2.97
Cu	Positive Electrode	2 ^(b)	Cu	152
In _{1.9} Sn _{0.1} O ₃	Transparent Contact	0.2	In	11.3
			Sn	0.613
Inconel	Negative Electrode	0.4 ^(c)	Ni (.7)	2.24
			Cr (.2)	0.640
			Fe (.1)	0.320
Cu	Negative Electrode	5 ^(c)	Cu	44.6
Glass	Substrate	3000	Glass	7.80 x 10 ⁴

(a) Based on 10% conversion efficiency and no loss of materials during the manufacturing process. At a maximum theoretical efficiency of 17%, the materials requirements would be 10/17 of these values.

(b) 85% coverage.

(c) 10% coverage.

CdS/CuInSe₂ CELL

The CdS/CuInSe₂ heterojunction cell, like the CdS/InP cell, is a recently developed structure that was reported for the first time 2 yr ago by Bell Laboratories.⁽²²⁾ The Bell Laboratories cells were fabricated by epitaxial growth of 5 to 10- μ m-thick CdS on single-crystal p-type CuInSe₂. Contact to the CuInSe₂ was made with Au from an aqueous AuCl solution. Indium or eutectic Ga-In alloy provided ohmic contact to the CdS, and an antireflection coating was applied by evaporation of SiO. Cells with an active area of $\sim 0.79 \text{ mm}^2$ exhibited power conversion efficiencies of 12% measured under sunlight of 92 mW/cm^2 intensity.⁽²³⁾ A maximum theoretical conversion efficiency for this heterojunction has not yet been reported but a value close to 20% can be expected based on the broad spectral response obtained with the large CdS-CuInSe₂ "window."

Thin-film versions of the CdS/CuInSe₂ cell have been recently fabricated at the University of Maine using evaporation techniques.⁽²⁴⁾ Both backwall and frontwall cells were made. Backwall cells consisted of 5 to 6 μ m of CuInSe₂ deposited onto a Au-metallized glass substrate, followed by $\sim 6 \mu$ m of CdS and an Al grid. Frontwall cells were made by depositing 6 to 8 μ m of CdS onto a metallized substrate, followed by 0.25 to 0.50 μ m of CuInSe₂ which was contacted with a grid of Au-Ag past. For devices with areas of 1.2 cm^2 , conversion efficiencies up to 4.4% for the frontwall cells and up to 5.7% for the backwall cells were observed under 100 mW/cm^2 tungsten-halogen illumination.

Based on the work done at the University of Maine, the reference designs of Figures B-8 (frontwall) and B-9 (backwall) were drawn for computation of the material requirements of the CdS/CuInSe₂ heterojunction cell. The thicknesses of the CdS and CuInSe₂ layers have been reduced to their minimum practical values, based mainly on achievable sheet resistances for the CdS and on expected absorption length and minority-carrier diffusion length for the CuInSe₂. The backwall cell in Figure B-9 was used as the model for the calculations since the highest cell efficiencies have been observed for the backwall device. The results of the computation are summarized in Table B-7. (The CuInSe₂ requirement for the cell construction of Figure B-8 is 40% of that shown in Table B-7.)

FIGURE B-8. CdS/CuInSe₂ Solar Cell (Frontwall)

FIGURE B-9. Reference CdS/CuInSe₂ Solar Cell (Backwall)

TABLE B-7. Material Requirements per Peak Power Output for CdS/CuInSe₂ Solar Cells on Glass Substrates

Layer	Function	Thickness, μm	Element	MT/10 ⁹ W _{pe} (pk) ^(a)
CdS	Window Layer	2	Cd	75.0
			S	21.4
CuInSe ₂	Active Layer	1	Cu	10.9
			In	19.7
			Se	27.1
Au	Back Contact	0.5	Au	96.6
Cu	Positive Electrode	2	Cu	179
Al	Grid Contact	5 ^(b)	Al	6.76
Glass	Substrate	3000	Glass	7.80 × 10 ⁴

(a) Based on 10% conversion efficiency and no loss of materials during the manufacturing process. At a maximum theoretical efficiency of 20%, the materials requirements would be 1/2 of these values.

(b) 5% coverage.

Cu₂O SOLAR CELLS

Large-area Cu₂O rectifiers produced in large quantities during the 1930s were among the first semiconductor devices ever fabricated. The Cu₂O was made by heating Cu sheet in air at temperatures of 1000 to 1083°C, followed by water quenching. Present-day investigations of cuprous oxide for solar cells use similar techniques for preparation of the active material. Both backwall and frontwall cells are fabricated. Backwall cells are made by partially oxidizing a copper sheet, so that the active junction is the interface between the oxide and the mother copper. The cells are completed by applying a metal grid to the top surface of the Cu₂O which allows light to approach the junction through the oxide. Frontwall cells are made by completely oxidizing the Cu sheet, followed by application of an ohmic metal contact to the back of the oxide and a transparent, rectifying metal contact to the front. Heterojunction cells are also contemplated in which the top metal contact of the frontwall cell is replaced by a large-band-gap semiconductor. To date practical conversion efficiencies have not been obtained with Cu₂O cells, but their potential for contributions to very low cost photovoltaic system warrants their further examination.

REFERENCE DESIGNS AND FABRICATION PROCESSES

Cu₂O solar cells are currently researched in DOE-funded programs at the Joint Center for Graduate Study (JCGS), Richland, Washington, and at Wayne State University, Detroit, Michigan, where backwall and frontwall cells are being investigated, respectively. The JCGS backwall cells⁽²⁵⁾ are made by partially oxidizing a Cu disc in a tube furnace with a N₂-O₂ gas flow to form a polycrystalline Cu₂O layer 2 to 10 μm in thickness, followed by sequential application of a thin, transparent ohmic contact and a metal grid to the surface of the oxide. The transparent ohmic contact can be prepared by evaporation of Cu, Ni, or In₂O₃, and also by dipping in a ZnCl₂/Na₂S solution. Evaporated Cu is used as the grid material. These backwall cells exhibit AM1 conversion efficiencies of about 0.3% for cells with areas of 2.85 cm². The Wayne State University frontwall cells⁽²⁶⁾ are made by completely oxidizing a Cu disc, evaporating a thin transparent rectifying contact of Cu or Al onto

the front face, and painting a silver paste contact onto the back face. Cells with AMI efficiencies of 1.2% have been prepared. Although the performance of Cu_2O devices has been poor to date, both the JCGS and Wayne State groups estimate that efficiencies in excess of 10% can be obtained. Improved efficiencies are expected from development of Metal/Insulator/Semiconductor (MIS) and heterojunction devices based on the frontwall construction.

The material requirements per peak power output for the Cu_2O cell have been estimated using the cell construction of Figure B-10 and assuming a conversion efficiency of 10%. The results are presented in Table B-8. This frontwall cell may be constructed by partial oxidation of a 10- μm thick Cu foil, or by deposition of several microns of Cu_2O onto a thin Cu foil. The construction represents a significant advance over state-of-the-art Cu_2O solar cell technology, but allows for a fairer comparison of the ultimate Cu_2O cell material requirements with those for cells which are presently more highly developed. Note that the back Cu/ Cu_2O interface in the cell of Figure B-10 must be made ohmic for proper operation of the cell.

FIGURE B-10. Reference Cu₂O MIS Solar Cell (Frontwall)

TABLE B-8. Material Requirements per Peak Power Output for Cu₂O MIS Solar Cells

Layer	Function	Thickness, μm	Element	MT/10 ⁹ We (pk) ^(a)
Cu/Cu ₂ O	Foil to be oxidized	10	Cu	892
Cu	Semi-transparent barrier layer	0.005	Cu	0.446
Cu	Collector Grid	5 @ 95% Trans.	Cu	22.3

(a) Based on 10% conversion efficiency and no loss of materials during the manufacturing process. At a maximum theoretical efficiency of 15%, the materials requirements would be 2/3 of these values.

SILICON SOLAR CELLS

Silicon is the prime candidate material for large-scale, terrestrial, photovoltaic power-generating systems because of an abundance in the earth's crust and the large amount that can be economically obtained. Several solar cell constructions based on silicon are presently under investigation. Homojunction or n/p solar cells, typically made using single-crystal wafers cut from Czochralski rods, were highly developed for use in the nation's space program and are now the most promising devices for near-term realization of low-cost photovoltaic arrays. These homojunction cells can be produced in volume having AM1 efficiencies of 14%, and laboratory cells with efficiencies of 18-20% have been reported.⁽⁷⁾ A theoretical limit of 20% has been calculated for terrestrial use without concentration.⁽²⁷⁾ The thrust of silicon solar cell research is now directed towards reducing the cost of photovoltaic collectors, which are presently about 50X too expensive to be economically competitive with nonsolar sources of energy. One approach to reduction of the cost of Si cells is development of low-cost techniques for the growth of large-area sheets of silicon such as ribbon growth or chemical vapor deposition (CVD). This approach is being investigated in the Low-Cost Silicon Solar Array Project coordinated for DOE by the Jet Propulsion Laboratory, Pasadena, California.⁽²⁸⁾ A second approach is the investigation of alternate cell constructions which are less costly to fabricate and/or which can be made with less expensive polycrystalline material. Alternate cell constructions include Metal/Insulator/Semiconductor (MIS) devices, heterojunctions of silicon with transparent conductive semiconductors such as $\text{In}_{2-x}\text{Sn}_x\text{O}_3$ or SnO_2 , and solar cells based on amorphous silicon.

HOMOJUNCTION (n/p) CELLS

The material requirements per peak power output for the homojunction cell shown in Figure B-11 are listed in Table B-9. The calculations are based on a silicon layer 200 μm in thickness. A 50- μm thickness is estimated to be minimum necessary for 15% conversion efficiency, assuming the use of technological innovations such as the COMSAT Company's nonreflecting top surface and/or a reflective back surface.⁽²⁹⁾ Saw-cut Czochralski-grown

wafers and ribbon Si presently have minimum thicknesses several times larger than 50 μm . However, a 50- μm thickness is certainly possible by CVD techniques, and advances in sawcutting and ribbon pulling could make 50- μm layers possible in the near future.

Conventional homojunction cells are fabricated from p-type wafers cut from rods pulled from a Si melt containing boron. After polishing and etching to prepare the water surface, the material is exposed to P_2O_5 in a diffusion furnace to produce a shallow n/p junction extending 0.2 to 0.5 μm below the surface. The diffused layer is then removed from the back surface and an Al contact is applied by evaporation. A Ti/Pd/Ag grid is evaporated layer by layer onto the front (n-type) surface, followed by a Ta_2O_5 antireflection coating which completes the cell. In recent high-efficiency cells other steps are included, such as etching the wafer to obtain a nonreflective top surface,⁽²⁹⁾ and the addition of p^+/p junction on the back of the cell by alloy-diffusion of the evaporated Al contact (Back Surface Field).⁽³⁰⁾

FIGURE B-11. Reference Homojunction (n/p) Si Solar Cell

TABLE B-9. Material Requirements per Peak Power Output for Si n/p Single-Crystal Solar Cells

Layer	Function	Thickness, μm	Element	$\text{MT}/10^9 \text{We (pk)}^{(a)}$
Si	Active Layers	200	Si	3330
P	n-Dopant	0.2 @ 10^{20} cm^{-3}	P	7.39×10^{-3}
B	p-Dopant	50 @ 10^{16} cm^{-3}	B	6.45×10^{-5}
Ti/Pd/Ag	Grid Contact	0.004/0.002/5 @ 95% Trans.	Ti Pd Ag	0.0645 0.0836 18.8
Al	Back Contact	5	Al	96.5
Ta ₂ O ₅	Anti-Reflection Coating	0.1	Ta	4.80

(a) Based on state-of-art conversion efficiency = 14% and no loss of materials during the manufacturing process. At a maximum theoretical efficiency of 20%, the materials requirements would be 7/10 of these values.

MIS CELLS

Metal/Insulator/Semiconductor devices are prepared by evaporation or sputtering of a thin metal layer onto a Czochralski-grown Si slice or onto a Si ribbon. Cells under investigation for DOE at Rutgers University⁽³¹⁾ are fabricated by thermal evaporation of 40 to 50 Å of Cr onto the front face of a <100> p-type silicon wafer to form the rectifying junction, followed by a second, thicker layer of Cu evaporated through a mask to form a current-carrying grid electrode. Evaporation of several microns of Al onto the back of the wafer to serve as an ohmic contact and application of an antireflection coating to the front surface completes the fabrication process. A very thin 10- to 20-Å-thick oxide layer between the Si and Cr makes this cell an MIS Device. Figure B-12 is a schematic of the cell construction. To date, cells have been fabricated with AM1 efficiencies of 8-9% for cell areas of 1-2 cm².⁽³¹⁾ Current research efforts in the program are directed toward achieving 12% conversion efficiency in 2-6 cm² cells. Theoretical calculations for MIS devices indicate that efficiencies higher than 15% are possible.⁽³²⁾

The calculated material requirements for the Cr-Si MIS solar cell are summarized in Table B-10. The cell construction of Figure B-12, modeled after the Rutgers' devices, was used for the computation along with an assumed conversion efficiency of 10%. Note that no allowance has been made for an antireflection coating in the tabulation since such coatings have not yet been developed for these devices.

FIGURE B-12. Reference MIS Si Solar Cell

TABLE B-10. Material Requirements per Peak Power Output for Si MIS Solar Cells

Layer	Function	Thickness, μm	Element	MT/ $10^9 W_e$ (pk) ^(a)
Si	Active Layer	50	Si	1160
B	p-Dopant	10^{15} cm^{-3}	B	9.03×10^{-6}
Cr	Semi-Transparent Barrier Layer	0.005	Cr	0.360
Cu	Negative Electrode	5 @ 95% Trans.	Cu	22.3
Al	Back Contact	5	Al	135

(a) Based on 10% conversion efficiency and no loss of materials during the manufacturing process. At a maximum theoretical efficiency of 15%, the materials requirements would be 2/3 of these values.

HETEROJUNCTION CELLS

A second recently-introduced, potentially low-cost alternative to the conventional silicon homojunction device is the heterojunction of silicon with transparent conductive semiconductors such as $\text{In}_{2-x}\text{Sn}_x\text{O}_3$ or SnO_2 . Two basic structures are under investigation: $\text{In}_{2-x}\text{Sn}_x\text{O}_3/\text{p-Si}$ and $\text{SnO}_2/\text{n-Si}$. The $\text{In}_{2-x}\text{Sn}_x\text{O}_3/\text{p-Si}$ device has already been fabricated in 0.07-cm^2 size with an AM1 conversion efficiency of 12%.⁽³³⁾ These devices were prepared by ion beam sputtering $0.4\text{ }\mu\text{m}$ of $\text{In}_{1.9}\text{Sn}_{0.1}\text{O}_3$ onto a $2\text{ }\Omega\cdot\text{cm}$ single-crystal p-type Si wafer, followed by evaporation of an Al ohmic contact onto the back of the Si and an Al, Au or In contact onto the oxide surface. Present efforts are directed at the fabrication of larger devices. The $\text{SnO}_2/\text{n-Si}$ device has similarly exhibited efficiencies as high as 10%.⁽³⁴⁾ These devices were fabricated by electron beam evaporation of $\sim 0.3\text{ }\mu\text{m}$ SnO_2 onto n-type single-crystal Si wafers. Evaporated Al can be used both as a back contact to the Si and as a grid contact on the front surface of the device. Some degradation of these cells with time has been observed and present research is concentrated on understanding the degradation mechanism.

The material requirements per peak power output have been calculated for both the $\text{In}_{1.9}\text{Sn}_{0.1}\text{O}_3/\text{Si}$ and SnO_2/Si devices using data shown in the cell constructions of Figures B-10 and B-11, respectively. A conversion efficiency of 10% was assumed. The results are tabulated in Tables B-11 and B-12.

FIGURE B-13. Reference Heterojunction Si/In_{1.9}Sn_{0.1}O₃ Solar Cell

TABLE B-11. Material Requirements per Peak Power Output for In_{2-x}Sn_xO₃/Si Heterojunction Solar Cells

Layer	Function	Thickness, μm	Element	MT/10 ⁹ We (pk) ^(a)
Si	Active Layer	50	Si	1160
B	p-Dopant	@ 10 ¹⁵ cm ⁻³	B	9.03 x 10 ⁻⁶
In _{1.9} Sn _{0.1} O ₃	Window Layer	0.4	In Sn	22.6 1.22
Al	Back Contact	5	Al	135
Al	Front Contact	5 @ 95% Trans.	Al	6.75

(a) Based on 10% conversion efficiency and no loss of materials during the manufacturing process. At a maximum theoretical efficiency of 15%, the materials requirements would be 2/3 of these values.

FIGURE B-14. Reference Heterojunction SnO₂/Si Solar Cell

TABLE B-12. Material Requirements per Peak Power Output for SnO₂/Si Heterojunction Solar Cells

Layer	Function	Thickness, μm	Element	MT/10 ⁹ We (pk) ^(a)
Si	Active Layer	50	Si	1160
P	n-Dopant	@ 10 ¹⁵ cm ⁻³	P	2.59 x 10 ⁻⁵
SnO ₂	Window Layer	0.3	Sn	16.4
Al	Back Contact	5	Al	135
Al	Front Contact	5 @ 95% Trans.	Al	6.75

(a) Based on 10% conversion efficiency and no loss of materials during the manufacturing process. At a maximum theoretical efficiency of 15%, the materials requirements would be 2/3 of these values.

AMORPHOUS Si CELLS

Amorphous Si (a-Si) solar cells have been under development at RCA Laboratories, Princeton, New Jersey since 1974, and to date the RCA devices have the highest reported conversion efficiencies.^(35,36) Several device types have been made: p-n or p-i-n junctions, and Schottky barrier junctions. All of the devices use $\sim 1 \mu\text{m}$ of amorphous silicon deposited from a dc glow discharge in silane (SiH_4). The need for only $1\text{-}\mu\text{m}$ thickness, as compared to single-crystal solar cells, results from the very high absorption coefficient of a-Si in the visible range. Two device configurations have produced promising results to date.

The p-i-n devices of Figure B-15 configurations have demonstrated conversion efficiencies up to 2.4% (AM1) for small area cells ($\sim 5 \times 10^{-3} \text{ cm}^2$) and up to 1.1% for larger-area cells ($\sim 3.5 \text{ cm}^2$).⁽³⁵⁾ These cells are fabricated by depositing discharge-produced a-Si on substrates on indium-tin-oxide coated glass. A typical solar cell structure of the p-i-n type involves first depositing a few hundred angstroms of boron-doped a-Si from an atmosphere containing SiH_4 and $\sim 1\%$ B_2H_6 , followed by an undoped layer $\sim 1 \mu\text{m}$ in thickness, and finally several hundred angstroms of phosphorus-doped a-Si using SiH_4 containing $\sim 1\%$ PH_3 . An Al electrode completes the structure. A theoretical limit of 14-15% has been estimated for the conversion efficiency of thin-film amorphous-silicon solar cells.⁽³⁵⁾

The Schottky barrier device of Figure B-16 has exhibited conversion efficiencies up to 5.5% (AM1) for $\sim 1\text{-mm}^2$ cells using Pt as a barrier contact to the a-Si.⁽³⁷⁾ These Schottky barrier cells are made by depositing $1 \mu\text{m}$ of Si onto a stainless steel or Al sheet, followed by a semitransparent evaporated film of Pt about $45 \text{ \AA}$ thick, and a Si_3N_4 or TiO_2 antireflection coating about $0.1 \mu\text{m}$ thick. To ensure ohmic contact to the stainless steel substrate, the first $\sim 300 \text{ \AA}$ of silicon deposited is n-doped by the introduction of $\sim 1\%$ PH_3 into the silane gas.

Table B-13 summarizes the material requirements per peak power output for thin-film a-Si solar cells computed using the dimensions of Figure B-16, and a conversion efficiency of 10%.

FIGURE B-15. Amorphous Si Solar Cell (p-i-n junction)

FIGURE B-16. Reference Amorphous Si Solar Cell (Schottky Barrier Junction)

TABLE B-13. Material Requirements per Peak Power Output
for Amorphous Si Solar Cells

<u>Layer</u>	<u>Function</u>	<u>Thickness,</u> <u>μm</u>	<u>Element</u>	<u>MT/10⁹We (pk)^(a)</u>
Si	Active Layer	1	Si	23.3
p-Si	Doped Layer	0.03 @ 1 wt%	P	6.98×10^{-3}
Pt	Barrier Layer	0.005	Pt	1.07
Cu	Grid Electrode	5 ^(b)	Cu	22.3
Si ₃ N ₄	Anti-Reflection Coating	0.1 ^(c)	Si	1.96
Stainless Steel	Substrate/ Back Contact	10	Fe (.71) Cr (.19) Ni (.10)	561 150 79.2

- (a) Based on 10% conversion efficiency and no loss of materials during the manufacturing process. At a maximum theoretical efficiency of 15%, the materials requirements would be 2/3 of these values.
- (b) 5% coverage.
- (c) 95% coverage.

GaAs SOLAR CELLS

Theoretical estimates⁽³⁸⁾ indicate that efficiencies in excess of 25% may be achieved with GaAs cells because its energy gap is the optimum value for utilization of the solar spectrum. GaAs can be used in several different device configurations. To date the most promising results have been obtained with a single crystal heterostructure of $p\text{-Ga}_x\text{Al}_{1-x}\text{As}/p\text{-GaAs}/n\text{-GaAs}$. Under AM 1.4 sunlight a 0.5 in. diameter heterostructure was built and operated at Varian Associates, Palo Alto, California, with a conversion efficiency of 23%.⁽³⁹⁾ Heterostructure cells were also fabricated and tested at IBM Watson Research Center, Yorktown Heights, New York, with AM1 efficiencies of 21.9% for cells with areas around 0.1 cm^2 .⁽⁴⁰⁾ In addition, the Varian cells were operated at a solar concentration of 1735 suns with an efficiency near 19%.⁽⁴¹⁾ Operation of these cells with large factors of solar concentration reduces the projected cell cost per watt to an economically feasible level and lessens the potential impact of photovoltaic technology on the world's supply of Ga. An important alternative to the heterostructure device is the semitransparent metal Schottky barrier cell⁽⁴²⁾ now more generally known as an MIS device. These devices are simple to fabricate and may operate efficiently with less expensive polycrystalline material. Cells using gold on n-GaAs single crystals have been made in small areas (0.17 cm^2) with conversion efficiencies of 15% in terrestrial sunlight.^(43,44) Other GaAs device structures have been or are presently being studied, but the results to date are not as promising as the heterostructure and MIS solar cells. These cells include the p/n homojunction, the performance of which is limited by high surface recombination velocity and small minority-carrier diffusion lengths, and the drift cell, an improved version of the p/n junction that to date has met with only limited success.⁽⁴⁵⁾

HETEROSTRUCTURE CELL

The starting material for the $\text{Ga}_x\text{Al}_{1-x}\text{As}/p\text{-GaAs}/n\text{-GaAs}$ cell is a wafer of bulk $n^+\text{-GaAs}$. Onto this wafer an epitaxial layer of n-type material is grown by liquid phase epitaxy (LPE). Next deposited is a $\text{Ga}_{0.2}\text{Al}_{0.8}\text{As}$ layer doped with a p-type dopant such as Zn which diffuses a small distance into the

n-type GaAs layer during the $\text{Ga}_{0.2}\text{Al}_{0.8}\text{As}$ growth to produce a p/n junction in the GaAs across which the photovoltage appears. Au-Zn is used for the front-surface contact in the Varian cells, in the form of a grid or mesh covering 10% of the Cell area.⁽³⁹⁾ The IBM cells employed a contact consisting of 500 Å of evaporated Pd followed by 5000 Å of evaporated Al in the form of a grid covering 4% of the surface.⁽⁴⁰⁾ An antireflection coating of TiO_2 about 600 Å in thickness was used by IBM to successfully reduce losses from the $\text{Ga}_{1-x}\text{Al}_x\text{As}$ surface.⁽⁴⁰⁾ Sn is commonly used for the back contact. Figure B-17 is a schematic of the heterostructure cell showing the dimensions of the various layers. Table B-14 summarizes the material requirements per ea. power output calculated for this cell assuming a state-of-art conversion efficiency of 18% for production cells.

Recently, high-efficiency (12.8% AMO) heterostructure solar cells were reported which were fabricated by a metalorganic chemical vapor deposition technique (MO-CVD).⁽⁴⁶⁾ This process is capable of producing thin epitaxial layers over a much larger area than is possible by the LPE process described above.⁽⁴⁶⁾ As in the LPE cells, the starting material for a cell is a wafer of bulk n^+ -GaAs. Onto this substrate are sequentially deposited by MO-CVD a 4-6 μm thick layer of GaAs:Se, a 1-2 μm thick layer of GaAs:Zn and an ~500 Å layer of $\text{Ga}_{0.2}\text{Al}_{0.8}\text{As:Zn}$. The Se concentration in the GaAs is 7×10^{17} to $1 \times 10^{18} \text{ cm}^{-3}$, while the Zn content of the GaAs and GaAlAs layers is $2 \times 10^{18} \text{ cm}^{-3}$. A top-contrast grid of Au (2000 Å)/Zn (1600 Å)/Au (200 Å) is then evaporated on the GaAlAs side and a 2000 Å thick Au-12% Ge contact is evaporated on the substrate side, for cells with active areas of 0.2 to 0.4 cm^2 . For larger cells, thicker contacts are necessary. Except for the trace amounts of the dopant impurities Zn and Se, the material requirements per power output for the LPE and the MO-CVD cells are basically the same, because most of each cell is the thick GaAs substrate. Hence Table B-14 accurately describes the material requirements for both cell constructions.

FIGURE B-17. Reference Homojunction GaAs Solar Cell

TABLE B-14. Material Requirements per Peak Power Output for $\text{Ga}_x\text{Al}_{1-x}\text{As}/\text{GaAs}$ Heterojunction Solar Cells

Layer	Function	Thickness, μm	Element	MT/10 ⁹ We (pk)(a)
$\text{Ga}_x\text{Al}_{1-x}\text{As}$ ($x = 0.2$)	Window Layer	0.3	Ga Al As	0.854 1.32 4.59
GaAs	Active Layers + Substrate	125	Ga As	1780 1910
Ge	n-Dopant	125 @ $5 \times 10^{17} \text{ cm}^{-3}$	Ge	4.21×10^{-2}
Zn	p-Dopant	0.5 @ 10^{19} cm^{-3}	Zn	3.03×10^{-3}
Au/Zn	Front Contact	5 @ 90% Trans.	Au(0.8) Zn(0.2)	42.9 3.88
Sn	Back Contact	5	Sn	160
TiO ₂	Anti- reflection Coating	0.06	Ti	0.899

(a) Based on state-of-art conversion efficiency = 18% and no loss of materials during the manufacturing process. At a maximum theoretical efficiency of 25%, the materials requirements would be 18/25 of these values.

MIS CELLS

High efficiency (15%) Metal/Insulator/Semiconductor solar cells have been fabricated from Te-doped GaAs material with carrier concentrations from 2 to $20 \times 10^{15} \text{ cm}^{-3}$, epitaxially grown by vapor phase deposition on $\langle 100 \rangle$ GaAs substrates that are n-doped with Ge to carrier densities $5 \times 10^{17} \text{ cm}^{-3}$.⁽⁴⁴⁾ The ohmic back contact was evaporated Ge-doped gold. The semitransparent gold film which formed the front rectifying junctions was evaporated to a thickness of 60 Å, following an oxidation step which produced a thin oxide layer on the GaAs surface. A thicker gold or gold/silver grid contact was then applied to reduce the series resistance of the cells. Finally a Ta_2O_5 antireflection coating was evaporated to complete the cell. Low-cost versions of these devices are presently being researched.⁽⁴³⁾ The inexpensive cells use a glass or metal substrate onto which is vapor deposited a 5-μm thick layer of Sn, followed by a 5-μm thick layer of Ge. This Ge layer is then recrystallized using a laser heat-treating process to form a large-grained substrate suitable for epitaxial deposition of the GaAs layer by CVD techniques. The remainder of the fabrication process is identical to that of the laboratory cells, except that inexpensive metals such as Sn and Cu will probably replace the gold back contact and gold/silver grid, respectively. A schematic of one possible version of the low-cost cell is shown in Figure B-18, which was used for computation of the material requirements of the low-cost GaAs MIS device summarized in Table B-15.

FIGURE B-18. Reference MIS GaAs Solar Cell

TABLE B-15. Material Requirements per Peak Power Output for GaAs MIS Solar Cells

Layer	Function	Thickness (μm)	Element	MT/10 ⁹ We (pk)(a)
GaAs	Active Layer	1-2	Ga As	25.6-51.2 27.5-55.0
Ge	n-Dopant	@ $5 \times 10^{15} \text{ cm}^{-3}$	Ge	1.605×10^{-5}
Au	Barrier Layer	0.006	Au	1.16
Cu	Positive Electrode	5 @ 95% Trans.	Cu	22.3
Sn	Back Contact	5	Sn	287
Ta ₂ O ₅	Anti-Reflection Coating	0.051	Ta	3.42
Ge	Recrystallized Epitaxy Layer	5-25	Ge	266-1330
Glass	Substrate	3000	Glass	7.80×10^4

(a) Based on 10% conversion efficiency and no loss of materials during the manufacturing process. At a maximum theoretical efficiency of 15%, the materials requirements would be 2/3 of these values.

REFERENCES

1. K. W. Böer, H. C. Hadley, Jr., J. E. Phillips and A. Rothwarf, "CdS/Cu₂S Solar Cells, Their Potential and Limitations." Record of the Tenth Intersociety Energy Conversion Engineering Conference, University of Delaware, p. 387, August 1975.
2. J. F. Jordan and G. A. Samara, "Low Cost Thin Film CdS-Cu₂S Solar Cell Development Using Chemical Spraying." Proceedings of ERDA Semiannual Solar Photovoltaic Program Review Meeting, Orono, ME, I:260, August 1976.
3. J. F. Jordan, "Low Cost CdS-Cu₂S Solar Cells by the Chemical Spray Method." Record of 11th IEEE Photovoltaic Specialists Conference, Scottsdale, AZ, p. 508, May 1975.
4. J. D. Meakin, "Research Directed to Stable High Efficiency CdS Solar Cells." Proceedings of ERDA Semiannual Solar Photovoltaic Program Review Meeting, Orono, ME, I:285, August 1976.
5. T. S. teVelde and J. Dieleman, "Photovoltaic Efficiencies of Copper Sulfide Phases in the Topotaxial Heterojunction Copper Sulfide-Cadmium Sulfide," Phillips Research Reports. 28(6):573, 1973.
6. F. A. Shirland, "The Feasibility of Cu₂S/CdS Thin Film Solar Cells for Large Scale Power Generation." Proceedings of ERDA Semiannual Solar Photovoltaic Program Review Meeting, Orono, ME, I:305, 1976.
7. K. W. Böer and A. Rothwarf, "Materials for Solar Photovoltaic Energy Conversion." Annual Review of Materials Science. 6:303, 1976.
8. D. Bonnet and H. Rabenhorst, "New Results on the Development of Thin Film p-CdTe/n-CdS Heterojunction Solar Cells." Proc. Intl. Conf. Chem. Semicond. Heterojunctions, G. Szigeti, ed. I:119, Hungarian Academy of Sciences, Budapest, 1970.
9. A. L. Fahrenbruch, "Applied Research on II-VI Compound Materials for Heterojunction Solar Cells." Proceedings of ERDA Semiannual Solar Photovoltaic Program Review Meeting, Orono, ME, I:331, August 1976.
10. A. L. Fahrenbruch, V. Vasilchenko, F. Buch, K. Mitchell and R. H. Bube, "II-VI Photovoltaic Heterojunctions for Solar Energy Conversion." App. Phys. Letters. 25:605, 1974.
11. R. O. Bell, "Review of Optical Applications of CdTe," and F. V. Wald, "General Review of the Applications of CdTe." Proc. 2nd Intl. Symposium on Cadmium Telluride, Strasbourg, France, June 1976, and in Revue de Physique Appliquée, 192(2), February 1977.

12. K. Yamaguchi, H. Matsumoto, N. Nakayama, and S. Ikegami, "Photovoltaic Effect in CdTe-CdS Junctions Prepared by Vapor Phase Epitaxy." Japan. J. Appl. Phys. 15(8), 1975.
13. Proc. of ERDA Semiannual Solar Photovoltaic Program Review Meeting, Orono, ME, Volumes I and II, August 1976.
14. S. Wagner, J. L. Shay, K. J. Bachmann and E. Buehler, "p-InP/n-CdS Solar Cells and Photovoltaic Detectors." Appl. Phys. Letters. 26:229, 1975.
15. L. M. Schiavone and A. A. Pritchard, "Ohmic Contacts for Moderately Resistive p-Type InP." J. Appl. Phys., 46:452, 1975.
16. J. L. Shay, S. Wagner, K. J. Bachmann and E. Buehler, "Preparation and Properties of InP/Cds Solar Cells." J. Appl. Phys. 47:614, 1976.
17. K. J. Bachman, E. Buehler, J. L. Shay and S. Wagner, "Polycrystalline Thin-Film InP/CdS Solar Cell." Appl. Phys. Letters. 29:121, 1976.
18. K. S. Sree Harsha, K. J. Bachman, P. H. Schmidt, E. G. Spencer, and F. A. Thiel, "n-Indium Tin Oxide/p-Indium Phosphide Solar Cells." Appl. Phys. Letters. 30:645, 1977.
19. J. L. Shay, M. Bettini, S. Wagner, K. J. Bachman, and E. Buehler, Conf. Record 12th Photovoltaic Specialists Conference (IEEE, Baton Rouge, LA; 1976) 9.
20. K. Zanio and L. Fraas, "InP/Cds Thin Film Growth by Planar Reactive Deposition for Terrestrial Solar Cells." Proceedings of ERDA Semiannual Solar Photovoltaic Program Review Meeting, Orono, ME, II:921, August 1976.
21. R. Ruth, "Thin Polycrystalline Films of Indium Phosphide on Low-Cost Substrates." Proceedings of ERDA Semiannual Solar Photovoltaic Program Review Meeting, Orono, ME, II:933, August 1976.
22. S. Wagner, J. L. Shay, P. Migliorato and H. M. Kasper, "CuInSe₂/CdS Heterojunction Photovoltaic Detectors." App. Phys. Letters. 25:434, 1974.
23. J. L. Shay, S. Wagner and H. M. Kasper, "Efficient CuInSe₂/CdS Solar Cells." Appl. Phys. Letters. 27:89, 1975.
24. L. L. Kazmerski, F. R. White and G. K. Morgan, "Thin-Film CuInSe₂/CdS Heterojunction Solar Cells." Appl. Phys. Letters. 29:268, 1976.
25. L. C. Olsen, R. C. Bohara and H. L. Hampton, "Investigation of Low Cost Solar Cells Based on Cu₂O." Proceedings of ERDA Semiannual Solar Photovoltaic Program Review Meeting, Orono, ME, II:834, August 1976.

26. D. Trivich, E. Y. Wang and R. J. Komp, "Cuprous Oxide Photovoltaic Cells." Proceedings of ERDA Semiannual Solar Photovoltaic Program Review Meeting, Orono, ME, II:812, August 1976.
27. E. S. Rittner, "Improved Theory of the Silicon p-n Junction Solar Cell." J. Energy. I:9, January 1977.
28. R. G. Forney, "Low-Cost Silicon Solar Array Project." Proceedings of ERDA Semiannual Solar Photovoltaic Program Review Meeting, Orono, ME, I:416, August 1976.
29. R. A. Arndt, J. F. Allison, J. G. Haynos and A. Meulenber, Jr., "Optical Properties of the COMSAT Non-Reflecting Cell." Record of 11th IEEE Photovoltaic Specialists Conference, Scottsdale, AZ, p. 40, May 1975.
30. H. J. Hovel, Semiconductors and Semimetals. Academic Press, New York, NY, II:209, 1975.
31. W. Anderson, "Silicon Schottky Photovoltaic Diodes for Solar Energy Conversion." Proceedings of ERDA Semiannual Solar Photovoltaic Program Review Meeting, Orono, ME, II:738, August 1976.
32. D. L. Pulfrey and R. F. McQuat, "Schottky-Barrier Solar-Cell Calculations." Appl. Phys. Letters. 24:167, 1974.
33. J. B. DuBow and D. E. Burk, "Efficient Photovoltaic Heterojunctions of Indium Tin Oxides on Silicon." Appl. Phys. Letters. 29:494, 1976.
34. R. L. Anderson, "Heterojunction Solar Cells." Proceedings of ERDA Semiannual Solar Photovoltaic Program Review Meeting, Orono, ME, II:759, August 1976.
35. D. E. Carlson and C. R. Wronski, "Amorphous Silicon Solar Cell." Appl. Phys. Letters. 28:11, 1976.
36. C. R. Wronski, D. E. Carlson and R. E. Daniel, "Schottky Barrier Characteristics of Metal/Amorphous Silicon Diodes." Appl. Phys. Letters. 29(9), 1976.
37. D. E. Carlson and C. R. Wronski, 18th Annual Electronic Materials Conference, Salt Lake City, Utah, June 23-25, 1976; and D. E. Carlson, C. R. Wronski, A. R. Triano, and R. E. Daniel, Conf. Record 12th Photovoltaic Specialists Conference (IEEE, Baton Rouge, LA, 1976).
38. J. J. Loferski, "Possibilities Afforded by Materials Other Than Silicon in the Fabrication of Photovoltaic Cells." Acta Electronica. 5:350, 1961.
39. L. W. James and R. L. Moon, "GaAs Concentrator Solar Cell." Appl. Phys. Letters. 26:467, 1975.

40. J. M. Woodall and H. J. Hovel, "An Isothermal Etchback-Regrowth Method for High-Efficiency $\text{Ga}_{1-x}\text{Al}_x\text{As}$ -GaAs Solar Cells, Appl. Phys. Letters. 30:492, 1977.
41. L. W. James and R. L. Moon, "GaAs Concentrator Solar Cells." Record of 11th IEEE Photovoltaic Specialists Conference, Scottsdale, AZ, I:402, August 1976.
42. P. Vohl, D. M. Perkins, S. G. Ellis, R. R. Addiss, W. Hui and G. Noll. "GaAs Thin-Film Solar Cells." IEEE Transactions on Electron Devices. ED-14:26, 1967.
43. R. J. Stirn and Y-C. M. Yeh, "The AMOS Cell-An Improved Metal-Semiconductor Solar Cell." Record of 11th IEEE Photovoltaic Specialists Conference, Scottsdale, AZ, p. 437, May 1975.
44. R. J. Stirn and Y-C. M. Yeh, "A 15% Efficient Antireflection-Coated Metal-Oxide-Semiconductor Solar Cell." Appl. Physics Letters. 27:95, 1975.
45. J. M. Woodall and H. J. Hovel, "Outlooks for GaAs Terrestrial Photovoltaics." J. Vac. Sci. Technol. 12(5), 1975.
46. R. D. Dupuis, P. D. Dapkus, R. D. Tingling, and L. A. Moudy, "High-Efficiency GaAlAs/GaAs Heterostructure Solar Cells Grown by Metalorganic Chemical Vapor Deposition," Appl. Physics Letters 31:201, 1977.

APPENDIX C

PHOTOVOLTAIC SYSTEMS DESIGN CHARACTERIZATION
AND MATERIAL REQUIREMENTS*

*Materials Requirements in Kilograms.

This appendix contains the system design characterizations and material requirements for the 15 photovoltaic systems studied in this report. These systems are based on the existing design (25 kW peak capacity) at Mead Nebraska. Preceding the material requirements is a brief description of each system including solar efficiency, panel area and cell area. These items can change from system to system.

In order to study the impact on the number and type of critical materials caused by deleting various components, two systems were run without energy storage and one system was run with only the photovoltaic array. Note that "zeros" were entered for the material requirements when components were deleted. In the case of energy storage deleted, zeros were entered for the material requirements in category 15.0 Energy Storage.

The assumptions used in deriving the material requirements are listed under footnotes following each photovoltaic design.

APPENDIX C

PHOTOVOLTAIC SYSTEMS DESIGN CHARACTERIZATION AND MATERIAL REQUIREMENTS*

PHOTOVOLTAIC SYSTEM IDENTIFICATIONS	.	.	.	.	.	.	.	.	.	C-1
1. AMORPHOUS SILICON	.	.	.	.	.	.	.	.	.	C-5
2. CAD SULFIDE/CAD TELLURID	.	.	.	.	.	.	.	.	.	C-9
2. CAD SULFIDE/CAD TELLURID ENERGY STORAGE DELETED	.	.	.	.	.	.	.	.	.	C-13
3. CADMIUM SULFIDE/CU-IN-SE	.	.	.	.	.	.	.	.	.	C-17
4. CAD/CU SULFIDE BACKWALL	.	.	.	.	.	.	.	.	.	C-21
5. CAD/CU SULFIDE FRONTWALL	.	.	.	.	.	.	.	.	.	C-25
6. CAD SULFIDE/INDIUM PHOS	.	.	.	.	.	.	.	.	.	C-29
7. COPPER OXIDE MIS	.	.	.	.	.	.	.	.	.	C-33
8. GA AS 1 XTL HETEROJUNCT	.	.	.	.	.	.	.	.	.	C-37
8. GA AS 1 XTL HETEROJUNCT ENERGY STORAGE DELETED	.	.	.	.	.	.	.	.	.	C-41
8. GA AS 1 XTL HETEROJUNCT PHOTOVOLTAIC ARRAY ONLY	.	.	.	.	.	.	.	.	.	C-45
9. GA AS 1 XTL-500X FRESNEL	.	.	.	.	.	.	.	.	.	C-49
10. GALLIUM ARSENIDE MIS	.	.	.	.	.	.	.	.	.	C-53
11. INDIUM TIN OXIDE/P-SI	.	.	.	.	.	.	.	.	.	C-57
12. SILICON MIS	.	.	.	.	.	.	.	.	.	C-61
13. SI N/P 1 XTL 14 PERCENT	.	.	.	.	.	.	.	.	.	C-65
14. SI 1 XTL-30X PARA TROUGH	.	.	.	.	.	.	.	.	.	C-69
16. TIN OXIDE/N-SILICON	.	.	.	.	.	.	.	.	.	C-73

* Material Requirements are in Kilograms.

MIT-LL AND UNL PHOTOVOLTAIC SYSTEM

AT MEAD, NEBRASKA
MODIFIED WITH 1985 TECHNOLOGY
AMORPHOUS SI CELLS

A GEOMETRIC PACKING FACTOR OF 0.8 IS
ASSUMED FOR THIS CELL, WHICH REDUCES THE
TOTAL NUMBER OF 8-FOOT BY 25-FOOT PANELS
FROM 28 TO 17. THE UNITS' PEAK POWER OF
25 KW IS DERIVED FROM 250 SQUARE METERS
OF AMORPHOUS SI CELLS AT 18% EFFICIENCY.

THE ARRAY OUTPUT (6.2 AMPS AT 150 VOLTS
PER PANEL) IS FED TO TWO BUILDINGS. ONE
HOUSES SYSTEM CONTROL EQUIPMENT AND
THREE 7.5 KW INVERTERS. THE OTHER BUILDING
HOUSES 38 LARGE LEAD-ACID STORAGE BAT-
TERIES CAPABLE OF STORING 85 KW-HR.

THIS SYSTEM WAS BUILT BY THE MASSACHUSETTS
INSTITUTE OF TECHNOLOGY'S LINCOLN LABORATORY.
THE POWER PRODUCED IS USED TO PUMP WATER TO IRRIGATE 80 ACRES
OF CORN AND SOYBEANS AT THE UNIVERSITY
OF NEBRASKA FIELD LABORATORY NEAR MEAD.
PHOTOVOLTAICS
25 KW PEAK
CROP IRRIG + DRYING
MEAD, NEBRASKA
2,000 KW/HR/M2/YR

LINE POWER
10'
312 M2
250 M2
AMBIENT
ELECTRICAL
LEAD-ACID BATTERIES
85 KW/HR
MATERIAL REQUIREMENTS
BY

FUNCTIONAL COMPONENTS

Kilograms

12.	ENERGY COLLECTOR	EVA	0.53
12.02	ENCAPSULANT	ACRYLIC	14.00
12.03	ABSORBER - AMORPHOUS SI AT 18% EFFICIENCY ACTIVE LAYER	AMORPHOUS SI	0.00
		SILICON	2.75
		IRON	1.50
	BACK CONTACT	CHROMIUM	0.03
		NICKEL	0.03
	BARRIER LAYER	PLATINUM	0.03
	ANTI - REFLECTIVE COATING	SILICON	0.03
	GRID ELECTRODE	COPPER	0.56
	DOPED LAYER	PHOSPHORUS	0.00
12.04	ENERGY TRANSPORT PANEL INTERCONNECTS	COPPER	21.03
		TEFLON	1.93
	ELECTRICAL BOXES WIREWAYS, INSULATORS ETC.	CARBON STEEL	792.94
		STAINLESS STEEL	102.55
		COPPER	503.54
		PLASTICS, LAMINATES	0.00
		NYLON	0.00
		ALUMINUM	0.00
		RUBBER	14.13
		60-40 SOLDER	14.13
12.07	FRAME SOLAR CELL MODULE BACKING PANELS	CARBON STEEL	748.00

12.	09	SUPPORTS		
		UPRIGHTS		
			6061 ALUMINUM	1345.60
			STAINLESS STEEL	124.00
			CONCRETE	58200.00
		FRAMEWORKS		
			6061 ALUMINUM	7028.36
			STAINLESS STEEL	267.92
			CARBON STEEL	173.01
13.	ENERGY	TRANSPORT		
13.02		ELECTRICAL WIRE		
			COPPER	103.00
			PVC	9.39
13.05		SUPPORTS		
		CONDUIT	ALUMINUM	551.09
			CARBON STEEL	4.10
		CONDUIT SEALS		0.00
			RUBBER	1.41
15.	ENERGY	STORAGE		
15.01		MISCELLANEOUS		
		BATTERY BUILDING		
		10 FT X 20 FT		
			CARBON STEEL	1043.00
			CONCRETE	252.00
			FIBERGLASS WOOL	354.00
			PLYWOOD-SOFTWOOD	198.00
		BATTERY COVERS	ACRYLIC	53.00
		BATTERY INTERCONNECTS		
			COPPER	14.60
			PHENOLIC	0.05
			MICARTA	0.92
			EPOXY	0.91
15.02		PRIMARY STORAGE		
		30 BATTERIES 375	AMP-HR	
			5 PERCENT ANTIMONY LEAD	1197.00
			.3 PERCENT CALCIUM LEAD	1438.00
			SULFURIC ACID	726.00
			POLYPROPYLENE	207.00
15.04		SUPPORT		
			STAINLESS STEEL	306.00
			CARBON STEEL	103.00
16.	ENERGY	CONDITIONING		
16.02		INVERTER		
		ENCLOSURE		
			CARBON STEEL	106.00
		CORE CLAMPS		
			CARBON STEEL	34.00
		CORES AND WINDINGS		
			COPPER	150.00
			SILICON STEEL	417.00
			VARNISH	6.00
		INSULATION		
			POLYESTER	4.00
		INSTRUMENTATION		
			PHENOLIC	4.00
			COPPER	1.36
			ZINC	0.60
			SODA-LIME GLASS	0.60
-		SILICON CONTROLLED		
		RECTIFIERS		
			COPPER	5.00
			SILICON	0.11
			ELECTRICAL PORCELAIN	0.34
17.	ENERGY	SYSTEM CONTROLLER		
17.01		MISCELLANEOUS		
		BUILDING 15 FT X 25 FT		
			CARBON STEEL	1497.00
			CONCRETE	472.00
			FIBERGLASS WOOL	544.00
			PLYWOOD-SOFTWOOD	205.00
17.02		METERS, SWITCHES, RELAYS,		
		TERMINAL BOARDS, ETC.		
			COPPER	29.50
			CARBON STEEL	50.00
			PHENOLIC	11.30
			STAINLESS STEEL	64.40
			PLASTICS	8.85

17.03 SUPPORTS - CABINETS ETC.

ALUMINUM
STAINLESS STEEL
CARBON STEEL
EPOXY/GLASS LAMINATE

160.00
10.50
1350.00
0.24

FOOTNOTES

10. A geometric packing factor of 0.8 is assumed for this modification. Required number of 8-foot by 25-foot panels is 17. Actual Mead installation required 28 panels.
- 12.02 - Encapsulant assumed to be .020 inch EVA with .002 inch acrylic UV barrier.
- 12.03 - Assumed thicknesses in microns:
Active Layer	Si	1
Back Contact	Stainless Steel	10
Barrier Layer	Pt	.005
A/R Coating	Si_3N_4	1 at 95% coverage
Grid Electrode	Cu	5 at 5% coverage
Doped Layer	P.Si	.03 at 1 wt%
- 12.04 - Scaled at 17/28 of actual Mead installation.
- 12.07 - Carbon steel backing panel assumed .012 inches thick. It was also assumed that the supports (12.09) would be designed more efficiently to incorporate the additional support required for the thin steel backing.
- 12.09 - Same as note 12.04.
- 13.02 - Assumed one 8-panel row and one 9-panel row, and 25 feet to control house from row ends. Therefore, electrical wire scales by 0.39.
- 13.05 - Same as note 12.04.
- 15.01 - Steel buildings assumed on concrete pads with R-11 insulation and plywood interior paneling.
- 15.02 - Battery case is high density, high impact, structural foam. Polypropylene.
- 16.02 - Weights estimated from total weight of the solid state inverter.
- 17.01 - Same as note 15.01.

MIT-LI AND UNL PHOTOVOLTAIC SYSTEM
 AT NEAD, NEBRASKA
 MODIFIED WITH 1985 TECHNOLOGY
 CADMIUM SULFIDE/CADMIUM TELLURIDE CELLS
 A GEOMETRIC PACKING FACTOR OF 0.8 IS
 ASSUMED FOR THIS CELL, WHICH REDUCES THE
 TOTAL NUMBER OF 8-FOOT BY 25-FOOT PANELS
 FROM 29 TO 17. THE UNITS' PEAK POWER OF
 25 KW IS DERIVED FROM 250 SQUARE METERS
 OF CADMIUM SULFIDE/CADMIUM TELLURIDE CELLS AT 13 PERCENT EFFICIENCY
 THE ARRAY OUTPUT (6.2 AMPS AT 150 VOLTS
 PER PANEL) IS FED TO TWO BUILDINGS. ONE
 HOUSES SYSTEM CONTROL EQUIPMENT AND
 THREE 7.5 KVA INVERTERS. THE OTHER BUILDING
 HOUSES 38 LARGE LEAD-ACID STORAGE BAT-
 TERIES CAPABLE OF STORING 85 KW-HR.

THIS SYSTEM WAS BUILT BY THE MASSA-
 CHUSETTS INSTITUTE OF TECHNOLOGY'S
 LINCOLN LABORATORY. THE POWER PRODUCED
 IS USED TO PUMP WATER TO IRRIGATE 80 ACRES
 OF CORN AND SOYBEANS AT THE UNIVERSITY
 OF NEBRASKA FIELD LABORATORY NEAR NEAD,
 NEBRASKA.

CAPACITY	PHOTOVOLTAICS
APPLICATION	25 KW PEAK
LOCATION	CROP IRRIG. + DRYING
INSULATION	NEAD, NEBRASKA
SOLAR CONTRIBUTION	2,000 KW/HR/M2/YR
SUPPLEMENT	LINE POWER
SOLAR EFFICIENCY	13%
PANEL AREA	313 M2
CELL AREA	250 M2
OPERATING TEMPERATURE	AMBIENT
ENERGY TRANSPORT MEDIUM	ELECTRICAL
STORAGE TYPE	LEAD-ACID BATTERIES
STORAGE CAPACITY	85 KW/HR
	MATERIAL REQUIREMENTS
	BY
	FUNCTIONAL COMPONENTS

12.	ENERGY COLLECTOR		
12.02	ENCAPSULANT	EVA	149.00
		ACRYLIC	18.90
12.03	ABSORBER - CAD SULFIDE/CAD TELLURIDE		
	AT 13% EFFICIENCY		
	ACTIVE LAYER	CADMIUM	0.59
		TELLURIUM	0.66
	BACK CONTACT	NICKEL	0.25
	WINDOW LAYER	CADMIUM	1.59
		SULPHUR	0.48
	POSITIVE ELECTRODE	COPPER	3.00
	NEGATIVE ELECTRODE	NICKEL	0.06
		CHROMIUM	0.02
		IRON	0.01
		COPPER	1.12
	TRANSPARENT CONTACT	INDIUM	0.28
		TIN	0.01
	SUBSTRATE - GLAZING	SODA LIME GLASS	2440.00
12.04	ENERGY TRANSPORT		
	PANEL INTERCONNECTS	COPPER	21.00
		TEFLON	1.90

		ELECTRICAL BOXES WIREWAYS, INSULATORS ETC.		
		CARBON STEEL	792.94	
		STAINLESS STEEL	122.55	
		COPPER	343.61	
		PLASTICS, LAMINATES	0.55	
		NYLON	0.30	
		ALUMINUM	9.19	
		RUBBER	13.58	
		60-40 SOLDER	14.18	
12.09	SUPPORTS UPRIGHTS			
		6061 ALUMINUM	1345.60	
		STAINLESS STEEL	124.00	
		CONCRETE	50200.00	
	FRAMEWORK			
		6061 ALUMINUM	7029.36	
		STAINLESS STEEL	267.92	
		CARBON STEEL	173.01	
13.	ENERGY TRANSPORT			
13.02	ELECTRICAL WIRE			
		COPPER	103.00	
		PVC	9.39	
13.05	SUPPORTS CONDUIT			
		ALUMINUM	551.09	
		CARBON STEEL	4.19	
	CONDUIT SEALS			
		RUBBER	1.41	
15.	ENERGY STORAGE			
15.01	MISCELLANEOUS BATTERY BUILDING 10 FT X 20 FT			
		CARBON STEEL	1043.00	
		CONCRETE	252.00	
		FIBERGLASS WOOL	354.00	
		PLYWOOD-SOFTWOOD	190.00	
		ACRYLIC	52.00	
	BATTERY COVERS			
	BATTERY INTERCONNECTS			
		COPPER	14.60	
		PHENOLIC	0.05	
		MICA-STA	0.92	
		EPOXY	0.91	
15.02	PRIMARY STORAGE 30 BATTERIES 375 AMP-HR			
		3 PERCENT CALCIUM LEAD	1438.00	
		5 PERCENT ANTIMONY LEAD	1197.00	
		SULFURIC ACID	726.00	
		POLYPROPYLENE	237.00	
15.04	SUPPORT			
		STAINLESS STEEL	306.00	
		CARBON STEEL	183.00	
16.	ENERGY CONDITIONING			
16.02	INVERTER ENCLOSURE			
		CARBON STEEL	106.00	
	CORE CLAMPS			
		CARBON STEEL	34.00	
	CORES AND WINDINGS			
		COPPER	150.00	
		SILICON STEEL	417.00	
		VARNISH	6.00	
	INSULATION			
		POLYESTER	4.00	
	INSTRUMENTATION			
		PHENOLIC	4.00	
		COPPER	1.36	
		ZINC	0.60	
		SODA-LIME GLASS	0.60	
	SILICON CONTROLLED RECTIFIERS			
		COPPER	5.00	
		SILICON	0.11	
		ELECTRICAL PORCELAIN	0.11	

17.	ENERGY SYSTEM CONTROLLER		
17.01	MISCELLANEOUS		
	BUILDING 15 FT X 25 FT		
	CARBON STEEL	1497.00	
	CONCRETE	472.00	
	FIBERGLASS WOOL	544.00	
	PLYWOOD-SOFTWOOD	380.00	
17.02	METERS, SWITCHES, RELAYS,		
	TERMINAL BOARDS, ETC.		
	COPPER	29.50	
	CARBON STEEL	50.00	
	PHENOLIC	11.30	
	STAINLESS STEEL	64.40	
	PLASTICS	8.00	
17.03	SUPPORTS - CABINETS ETC.		
	ALUMINUM	160.00	
	STAINLESS STEEL	10.50	
	CARBON STEEL	1359.00	
	EPOXY/GLASS LAMINATE	0.24	

FOOTNOTES

10. A geometric packing factor of 0.8 is assumed for this modification. Required number of 8-foot by 25-foot panels is 17. Actual Mead installation required 28 panels.
- 12.02 - Encapsulant assumed to be .020 inch EVA with .002 inch acrylic UV barrier.
- 12.03 - Assumed thicknesses in microns:

Active Layer	CdTe	1.0 at 85% coverage
Back Contact	Ni	0.5 at 85% coverage
Window Layer	CdS	2.0 at 85% coverage
Positive Electrode	Cu	2.0 at 85% coverage
Negative Electrode	Cu	5.0 at 10% coverage
	Inconel	0.4 at 10% coverage
Transparent Contact	$\text{In}_{1.9}\text{Sn}_{0.1}\text{O}_3$	0.2
Substrate	Glass	3000
- 12.04 - Scaled at 17/28 of actual Mead installation.
- 12.09 - Same as note 12.04.
- 13.02 - Assumed one 8-panel row and one 9-panel row and 25 feet to control house from row ends. Therefore, electrical wire scales by 0.39.
- 13.05 - Same as note 12.04.
- 15.01 - Steel buildings assumed on concrete pads with R-11 insulation and plywood interior paneling.
- 15.02 - Battery case is high density, high impact, structural foam. Polypropylene assumed.
- 16.02 - Weights estimated from total weight of the solid state inverter.
- 17.01 - Same as note 15.01.

Energy Storage Deleted

MIT-LL AND UNL PHOTOVOLTAIC SYSTEM
 AT HEARD, NEBRASKA
 MODIFIED WITH 1985 TECHNOLOGY
 CADMIUM SULFIDE/CADMIUM TELLURIDE CELLS
 A GEOMETRIC PACKING FACTOR OF 0.8 IS
 ASSUMED FOR THIS CELL, WHICH REDUCES THE
 TOTAL NUMBER OF 8-FOOT BY 25-FOOT PANELS
 FROM 28 TO 17. THE UNITS PEAK POWER OF
 25 KW IS DERIVED FROM 250 SQUARE METERS
 OF CADMIUM SULFIDE/CADMIUM TELLURIDE CELLS AT 13 PERCENT EFFICIENCY
 THE ARRAY OUTPUT (6.2 AMPS AT 150 VOLTS
 PER PANEL) IS FED TO TWO BUILDINGS. ONE
 HOUSES SYSTEM CONTROL EQUIPMENT AND
 THREE 7.5 KVA INVERTERS. THE OTHER BUILDING
 HOUSES 38 LARGE LEAD-ACID STORAGE BAT-
 TERIES CAPABLE OF STORING 85 KW-HR.

THIS SYSTEM WAS BUILT BY THE MASSA-
 CHUSETTS INSTITUTE OF TECHNOLOGY'S
 LINCOLN LABORATORY. THE POWER PRODUCED
 IS USED TO PUMP WATER TO IRRIGATE 80 ACRES
 OF CORN AND SOYBEANS AT THE UNIVERSITY
 OF NEBRASKA FIELD LABORATORY NEAR HEARD.
 TECHNOLOGY_ PHOTOVOLTAICS
 CAPACITY_ 25 KW PEAK
 APPLICATION_ CROP IRRIG. + DRYING
 LOCATION_ HEARD, NEBRASKA
 INSOLATION_ 2,000 KW/HR/M2/YR
 SOLAR CONTRIBUTION_
 SUPPLEMENT_ LINE POWER
 SOLAR EFFICIENCY_ 13%
 PANEL AREA_ 313 M2
 CELL AREA_ 250 M2
 OPERATING TEMPERATURE_ AMBIENT
 ENERGY TRANSPORT MEDIUM_ ELECTRICAL
 STORAGE TYPE_ LEAD-ACID BATTERIES
 STORAGE CAPACITY_ 85 KW/HR

MATERIAL REQUIREMENTS BY FUNCTIONAL COMPONENTS

12.	ENERGY COLLECTOR		
12.02	ENCAPSULANT	EVA	149.00
		ACRYLIC	18.90
12.03	ABSORBER - CAD SULFIDE/CAD TELLURIDE AT 13% EFFICIENCY ACTIVE LAYER		
		CADMIUM	0.50
		TELLURIUM	0.66
	BACK CONTACT	NICKEL	0.80
	WINDOW LAYER		0.95
		CADMIUM	1.50
		SULPHUR	0.46
	POSITIVE ELECTRODE	COPPER	3.80
	NEGATIVE ELECTRODE		
		NICKEL	0.06
		CHROMIUM	0.02
		IRON	0.01
		COPPER	1.12
	TRANSPARENT CONTACT		
		INDIUM	0.28
		TIN	0.01
	SUBSTRATE - GLAZING	SODA LIME GLASS	2440.00
12.04	ENERGY TRANSPORT PANEL INTERCONNECTS		
		COPPER	21.03
		TEFLON	1.05
	ELECTRICAL BOXES WIREWAYS, INSULATORS ETC.		

			CARBON STEEL	792.94
			STAINLESS STEEL	122.55
			COPPER	343.61
			PLASTICS, LAMINATES	0.55
			NYLON	0.30
			ALUMINUM	9.19
			RUBBER	13.58
			60-40 SOLDER	14.18
12.09	SUPPORTS			
	UPRIGHTS			
			6061 ALUMINUM	1345.60
			STAINLESS STEEL	124.00
			CONCRETE	60200.00
	FRAMEWORK			
			6061 ALUMINUM	7028.36
			STAINLESS STEEL	267.92
			CARBON STEEL	173.01
13.	ENERGY TRANSPORT			
13.02	ELECTRICAL WIRE			
			COPPER	103.00
			PVC	9.39
13.05	SUPPORTS			
	CONDUIT			
			ALUMINUM	551.89
			CARBON STEEL	4.19
	CONDUIT SEALS			
			RUBBER	1.41
15.	ENERGY STORAGE			
15.01	MISCELLANEOUS			
	BATTERY BUILDING			
	10 FT X 20 FT			
			CARBON STEEL	0.00
			CONCRETE	0.00
			FIBERGLASS WOOL	0.00
			PLYWOOD-SOFTWOOD	0.00
	BATTERY COVERS		ACRYLIC	0.00
	BATTERY INTERCONNECTS			
			COPPER	0.00
			PHENOLIC	0.00
			MICARTA	0.00
			EPOXY	0.00
15.02	PRIMARY STORAGE			
	38 BATTERIES 375		AMP-HR	
			.3 PERCENT CALCIUM LEAD	0.00
			5 PERCENT ANTIMONY LEAD	0.00
			SULFURIC ACID	0.00
			POLYPROPYLENE	0.00
15.04	SUPPORT			
			STAINLESS STEEL	0.00
			CARBON STEEL	0.00
16.	ENERGY CONDITIONING			
16.02	INVERTER			
	ENCLOSURE			
			CARBON STEEL	106.00
	CORE CLAMPS			
			CARBON STEEL	34.00
	CORES AND WINDINGS			
			COPPER	150.00
			SILICON STEEL	417.00
			VARNISH	6.00
	INSULATION			
			POLYESTER	4.00
	INSTRUMENTATION			
			PHENOLIC	4.00
			COPPER	1.36
			ZINC	0.60
			SODA-LIME GLASS	0.60
	SILICON CONTROLLED			
	RECTIFIERS			
			COPPER	5.00
			SILICON	0.11
			ELECTRICAL PORCELAIN	0.34

17.	ENERGY SYSTEM CONTROLLER		
17.01	MISCELLANEOUS		
	BUILDING 15 FT X 25 FT		
	CARBON STEEL	1497.00	
	CONCRETE	472.00	
	FIBERGLASS WOOL	544.00	
	PLYWOOD-SOFTWOOD	305.00	
17.02	METERS, SWITCHES, RELAYS,		
	TERMINAL BOARDS, ETC.		
	COPPER	29.50	
	CARBON STEEL	50.00	
	PHENOLIC	11.30	
	STAINLESS STEEL	64.40	
	PLASTICS	8.85	
17.03	SUPPORTS - CABINETS ETC.		
	ALUMINUM	160.00	
	STAINLESS STEEL	10.50	
	CARBON STEEL	1359.00	
	EPOXY/GLASS LAMINATE	0.24	

2000

06-07-2008 10:00 AM

[illegible]

100-443886-100

10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846

FO
FO
FO
FO
FO
FO
FO
FO
FO
FO

三三三

100-443887-100

2014年12月

STOCK CONFIDENT

Figure 1. The structure of the proposed model.

SUBSTRATE - GLAZING

70
71
72
73
74
75
76
77
78
79
80

275

0
0
1
0
0
0
0
0
0
0

12.09	SUPPORTS UPRIGHTS		
		6061 ALUMINUM	1345.00
		STAINLESS STEEL	124.00
		CONCRETE	68200.00
	FRAMEWORK		
		6061 ALUMINUM	7828.36
		STAINLESS STEEL	267.92
		CARBON STEEL	173.01
13.	ENERGY TRANSPORT		
13.02	ELECTRICAL WIRE		
		COPPER	103.00
		PVC	9.39
13.05	SUPPORTS CONDUIT		
		ALUMINUM	551.89
		CARBON STEEL	4.19
	CONDUIT SEALS		
		RUBBER	1.41
15.	ENERGY STORAGE		
15.01	MISCELLANEOUS BATTERY BUILDING 10 FT X 20 FT		
		CARBON STEEL	1043.00
		CONCRETE	252.00
		FIBERGLASS WOOL	354.00
		PLYWOOD-SOFTWOOD	198.00
	BATTERY COVERS	ACRYLIC	53.00
	BATTERY INTERCONNECTS		
		COPPER	14.50
		PHENOLIC	0.05
		MICARTA	0.92
		EPOXY	0.91
15.02	PRIMARY STORAGE 38 BATTERIES 375	AMP-HR	
		5 PERCENT ANTIMONY LEAD	1197.00
		.3 PERCENT CALCIUM LEAD	1138.00
		SULFURIC ACID	726.00
		POLYPROPYLENE	207.00
15.04	SUPPORT		
		STAINLESS STEEL	306.00
		CARBON STEEL	183.00
16.	ENERGY CONDITIONING		
16.02	INVERTER ENCLOSURE		
		CARBON STEEL	106.00
	CORE CLAMPS		
		CARBON STEEL	34.00
	CORES AND WINDINGS		
		COPPER	150.00
		SILICON STEEL	417.00
		VARNISH	6.00
	INSULATION		
		POLYESTER	4.00
	INSTRUMENTATION		
		PHENOLIC	4.00
		COPPER	1.36
		ZINC	0.68
		SODA-LIME GLASS	0.60
	SILICON CONTROLLED RECTIFIERS		
		COPPER	5.00
		SILICON	0.11
		ELECTRICAL PORCELAIN	0.34
17.	ENERGY SYSTEM CONTROLLER		
17.01	MISCELLANEOUS BUILDING 15 FT X 25 FT		
		CARBON STEEL	1497.00
		CONCRETE	472.00
		FIBERGLASS WOOL	544.00
		PLYWOOD-SOFTWOOD	305.00
17.02	METERS, SWITCHES, TERMINAL BOARDS, ETC.		
		COPPER	29.50
		CARBON STEEL	50.00
		PHENOLIC	11.30
		STAINLESS STEEL	64.40
		PLASTICS	8.00

17.03 SUPPORTS - CABINETS ETC.

ALUMINUM
STAINLESS STEEL
CARBON STEEL
EPOXY/GLASS LAMINATE

150.00
10.50
1359.00
0.24

FOOTNOTES

10. Geometric packing factor of 0.8 is assumed for this modification. Required number of 8-foot by 25-foot panels is 17. Actual Mead installation required 28 panels.

12.02 - Encapsulant assumed to be .020 inch EVA with .002 inch acrylic UV barrier.

12.03 - Assumed thickness in microns:

Active Layer	CuInSe ₂	1
Back Contact	Au	0.5
Window Layer	CdS	2
Positive Electrode	Cu	2
Grid Contact	Al	5 at 5% coverage
Substrate	Glass	3000

12.04 - Scaled at 17/28 of actual Mead installation.

12.09 - Same as note 12.04.

13.02 - Assumed one 9-panel row and one 8-panel row, and 25 feet to control house from row ends. Therefore, electrical wire scales by 0.39.

13.05 - Same as note 12.04.

15.01 - Steel buildings assumed on concrete pads with R-11 insulation and plywood interior paneling.

15.02 - Battery case is high density, high impact, structural foam. Polypropylene assumed.

16.02 - Weights estimated from total weight of the solid state inverter.

17.01 - Same as note 15.01.

HIT-LL AND UNL PHOTOVOLTAIC SYSTEM

AT MEMO, NEBRASKA
CADIUM SULFIDE/COPPER SULFIDE BACKWALL CELLS

A GEOMETRIC PACKING FACTOR OF 0.8 IS ASSUMED FOR THIS CELL, WHICH REDUCES THE TOTAL NUMBER OF 8-FOOT BY 25-FOOT PANELS FROM 26 TO 17. THE UNITS PEAK POWER OF 25 KW IS DERIVED FROM 250 SQUARE METERS OF CHROMIUM SULFIDE/COPPER SULFIDE BACKWALL CELLS AT 10% EFFICIENCY.

THE ARRAY OUTPUT (6.2 MW) AT 150 VOLTS PER PANEL) IS FED TO TWO BUILDINGS. ONE HOUSES SYSTEM CONTROL EQUIPMENT AND THREE 7.5 KVA INVERTERS. THE OTHER BUILDING HOUSES 28 LARGE LEAD-ACID STORAGE BATTERY CAPABLE OF STORING 85 KW-HR. TERIES 00--72P STORING 85 KW-HR. TERIE: 00--72P STORING 85 KW-HR.

THIS SYSTEM WAS BUILT BY THE MESSA-CHUSETTS INSTITUTE OF TECHNOLOGY'S LINCOLN LABORATORY. THE POWER PRODUCED IS USED TO PUMP WATER TO IRRIGATE 30 ACRES OF CORN AND SOYBEANS AT THE UNIVERSITY OF NEBRASKA FIELD LABORATORY NEAR MEMO. PHOTOVOLTAICS 25 KW PEAK CROP IRRIG. + DRYING MEMO, NEBRASKA 2,000 KW/HR/M2/YR

APPLICATION-
LOCATION-
INSULATION-
SOLAR CONTRIBUTION-
SUPPLEMENT-
SOLAR EFFICIENCY-
PANEL AREA-
CELL AREA-
OPERATING TEMPERATURE-
ENERGY TRANSPORT MEDIUM-
STORAGE TYPE-
STORAGE CAPACITY-

LINE POWER
19'
113 M2
250 M2
AMBIENT
ELECTRICAL
LEAD-ACID BATTERIES
85 KW/HR
MATERIAL REQUIREMENTS
BY

FUNCTIONAL COMPONENTS

12	ENERGY COLLECTOR	149.50
12.02	ENCAPSULANT	18.50
12.03	ABSORBER - CHROMIUM SULFIDE BACKWALL AT 10% EFFICIENCY	
	ACTIVE LAYER	0.24
	BACK CONTACT	0.35
	WINDOW LAYER	1.33
	POSITIVE ELECTRODE	0.00
	NEGATIVE ELECTRODE	4.00
	LEAD	0.05
	NICKEL	0.00
	CHROMIUM	0.01
	IRON	1.12
	COPPER	
	SUBSTRATE - GLAZING	2440.00
	CU DIFFUSION	
	BARRIER	
	CADIUM SULFIDE	0.10
	ALUMINUM	0.10
12.04	TRANSPARENT CONTACT	0.41
	ENERGY TRANSPORT	
	PANEL INTERCONNECTS	
	COPPER	21.03
	TEFLON	1.50

ELECTRICAL BOXES, WIREMAPS, INSULATORS ETC.			
	CARBON STEEL		792 00
	STAINLESS STEEL		422 00
	COPPER		343 00
	PLASTICS, LAMINATES		80 00
	NYLON		80 00
	ALUMINUM		13 00
	RUBBER		13 00
	60-40 SOLDER		14 00
12. 09	SUPPORTS		
	UPRIGHTS		
	6061 ALUMINUM		1345 00
	STAINLESS STEEL		124 00
	CONCRETE		60200 00
	FRAMEWORK		
	6061 ALUMINUM		7020 00
	STAINLESS STEEL		267 00
	CARBON STEEL		172 00
13. ENERGY TRANSPORT			
13. 02	ELECTRICAL WIRE		
	COPPER		103 00
	PVC		103 00
13. 05	SUPPORTS		
	CONDUIT		
	ALUMINUM		554 00
	CARBON STEEL		4 00
	RUBBER		1 00
15. ENERGY STORAGE			
15. 01	MISCELLANEOUS		
	BATTERY BUILDING		
	10 FT X 20 FT		
	CARBON STEEL		1043 00
	CONCRETE		252 00
	FIBERGLASS MOD.		304 00
	PLYWOOD-SOFTWOOD		100 00
	ACRYLIC		30 00
	BATTERY COVERS		14 00
	BATTERY INTERCONNECTS		14 00
	COPPER		8 00
	PHENOLIC		8 00
	MICRITH		8 00
	EPOXY		8 00
15. 02	PRIMARY STORAGE		
	30 BATTERIES 375		
	AMP-HR		1497 00
	5 PERCENT ANTIMONY LEAD		1439 00
	3 PERCENT CALCIUM LEAD		720 00
	SULFURIC ACID		207 00
	POLYPROPYLENE		8 00
15. 04	SUPPORT		
	STAINLESS STEEL		202 00
	CARBON STEEL		182 00
16. ENERGY CONDITIONING			
16. 02	INVERTER		
	ENCLOSURE		
	CARBON STEEL		106 00
	CORE CLAMPS		
	CARBON STEEL		34 00
	CORES AND WINDINGS		
	COPPER		452 00
	SILICON STEEL		417 00
	VARNISH		6 00
	INSULATION		
	POLYESTER		4 00
	INSTRUMENTATION		
	PHENOLIC		4 00
	COPPER		1 00
	ZINC		0 00
	SODI-LIME GLASS		0 00
	SILICON CONTROLLED		
	RECTIFIERS		
	COPPER		5 00
	SILICON		0 00
	ELECTRICAL PORCELAIN		0 00

17.	ENERGY SYSTEM CONTROLLER		
17.01	MISCELLANEOUS		
	BUILDING 15 FT X 25 FT		
	CARBON STEEL	1497.00	
	CONCRETE	472.00	
	FIBERGLASS WOOL	544.00	
	PLYWOOD-SOFTWOOD	305.00	
17.02	METERS, SWITCHES, RELAYS,		
	TERMINAL BOARDS, ETC.		
	COPPER	29.50	
	CARBON STEEL	50.00	
	PHENOLIC	11.30	
	STAINLESS STEEL	64.40	
	PLASTICS	8.85	
17.03	SUPPORTS - CABINETS ETC.		
	ALUMINUM	160.00	
	STAINLESS STEEL	10.50	
	CARBON STEEL	1359.00	
	EPOXY/GLASS LAMINATE	0.24	

FOOTNOTES

10. A geometric packing factor of 0.8 is assumed for this modification. Required number of 8-foot by 25-foot panels is 17. Actual Mead installation required 28 panels.
- 12.02 - Encapsulant assumed to be .020 inch EVA with .002 inch acrylic UV barrier.
- 12.03 - Assumed thicknesses in microns:
Window Layer	CdS	1 at 85% coverage
Active Layer	Cu ₂ S	1 at 85% coverage
Back Contact	Cu ²	0.7 at 85% coverage
Positive Electrode	Pb	2 at 85% coverage
Negative Electrode	Inconel	0.4 at 10% coverage
	Cu	5 at 10% coverage
Cu Diffusion Barrier	CdS-Al	1 at 85% coverage
Transp. contact	SnO ₂	0.3
Glass Substrate		3000
- 12.04 - Scaled at 17/28 of actual Mead installation.
- 12.09 - Same as note 12.04.
- 13.02 - Assumed one 8-panel row and one-9 panel row, and 25 feet to control house from row ends. Therefore, electrical wire scales by 0.39.
- 13.05 - Same as note 12.04.
- 15.01 - Steel buildings assumed on concrete pads with R-11 insulation and plywood interior paneling.
- 15.02 - Battery case is high density, high impact structural foam. Polypropylene assumed.
- 16.02 - Weights estimated from total weight of the solid state inverter.
- 17.01 - Same as note 15.01.

HIT-LL AND UNL PHOTOVOLTAIC SYSTEM
 AT NERD, NEBRASKA
 MODIFIED WITH 1985 TECHNOLOGY
 CHROMIUM SULFIDE/COPPER SULFIDE FRONTMILL CELLS
 A GEOMETRIC PACKING FACTOR OF 0.015
 ASSUMED FOR THIS CELL, WHICH REDUCES THE
 TOTAL NUMBER OF 8-FOOT BY 25-FOOT PANELS
 FROM 26 TO 17. THE UNITS PERK POWER OF
 25 KW IS DERIVED FROM 250 SQUARE METERS
 CHROMIUM SULFIDE/COPPER SULFIDE FRONTMILL CELLS AT .10 EFFICIENCY.
 THE PERK OUTPUT (6.2 MW) AT 150 VOLTS
 PER PANEL IS FED TO TWO BUILDINGS. ONE
 HOUSES SYSTEM CONTROL EQUIPMENT AND
 THREE 7.5 KVA INVERTERS. THE OTHER BUILDING
 HOUSES 38 LARGE LEAD-ACID STORAGE BATT-
 TERIES CAPABLE OF STORING 85 KW-HR.

THIS SYSTEM WAS BUILT BY THE NERD-
 CHASEETS INSTITUTE OF TECHNOLOGIES
 LINCOLN LABORATORY. THE POWER PRODUCED
 IS USED TO PUMP WATER TO IRRIGATE 80 ACRES
 OF CORN AND SOYBEANS AT THE UNIVERSITY
 OF NEBRASKA FIELD LABORATORY NEAR NERD.
 TECHNOLOGY - PHOTOVOLTAICS
 CAPACITY - 25 KW PERK
 APPLICATION - DROP IRRIG. + DRYING
 LOCATION - NERD, NEBRASKA
 INSULATION - 2,000 KW-HR/M2/YR
 SUPER CONTRIBUTION -
 SUPPLEMENT -
 SOLAR EFFICIENCY -
 PANEL AREA -
 CELL AREA -
 OPERATING TEMPERATURE -
 ENERGY TRANSPORT MEDIUM -
 STORAGE TYPE -
 STORAGE CAPACITY -
 LINE POWER
 18'
 312 M2
 250 M2
 AMBIENT
 ELECTRICAL
 LEAD-ACID BATTERIES
 85 KW-HR
 MATERIAL REQUIREMENTS
 BY

12

ENERGY COLLECTOR
 12.02 ENCHSULPANT

FUNCTIONAL COMPONENTS

EVA
 POLYIC

12.03 ABSORBER -- CND/OU SULFIDE FRONTMILL
 AT .10 EFFICIENCY

ACTIVE LAYER

COPPER
 SULPHUR

BACK CONTACT

ZINC

ENERGIER LAYER

CADMIUM
 SULPHUR

GRID COLLECTOR

COPPER

FOIL SUBSTRATE

COPPER

12.04

ENERGY TRANSPORT
 PANEL INTERCONNECTS

COPPER
 TEFLON

ELECTRICAL BOXES
 WIREBAYS, INSULATORS
 ETC.

OREGON STEEL
 STAINLESS STEEL
 COPPER
 PLASTICS, LAMINATES
 NYLON
 ALUMINUM
 RUBBER
 60-40 SOLDER.

790554
 100055
 144054
 000050
 000050
 111500
 111500

12.09	SUPPORTS UPRIGHTS		
		6061 ALUMINUM	1245.60
		STAINLESS STEEL	124.00
		CONCRETE	60200.00
	FRAMEWORK		
		6061 ALUMINUM	7028.36
		STAINLESS STEEL	267.92
		CARBON STEEL	173.01
13.	ENERGY TRANSPORT		
13.02	ELECTRICAL WIRE		
		COPPER	103.00
		PVC	9.39
13.05	SUPPORTS CONDUIT		
		ALUMINUM	551.09
		CARBON STEEL	4.19
	CONDUIT SEALS		
		RUBBER	1.41
15.	ENERGY STORAGE		
15.01	MISCELLANEOUS BATTERY BUILDING 10 FT X 20 FT		
		CARBON STEEL	1043.00
		CONCRETE	252.00
		FIBERGLASS WOOL	354.00
		PLYWOOD-SOFTWOOD	199.00
	BATTERY COVERS	ACRYLIC	52.00
	BATTERY INTERCONNECTS		
		COPPER	14.60
		PHENOLIC	0.05
		MICARTA	0.92
		EPOXY	0.91
15.02	PRIMARY STORAGE 38 BATTERIES 375	AMP-HR	
		5 PERCENT ANTIMONY LEAD	1197.00
		3 PERCENT CALCIUM LEAD	1438.00
		SULFURIC ACID	726.00
		POLYPROPYLENE	207.00
15.04	SUPPORT		
		STAINLESS STEEL	306.00
		CARBON STEEL	183.00
16.	ENERGY CONDITIONING		
16.02	INVERTER ENCLOSURE		
		CARBON STEEL	106.00
	CORE CLAMPS		
		CARBON STEEL	34.00
	CORES AND WINDINGS		
		COPPER	150.00
		SILICON STEEL	417.00
		VARNISH	6.00
	INSULATION		
		POLYESTER	4.00
	INSTRUMENTATION		
		PHENOLIC	4.00
		COPPER	1.36
		ZINC	0.60
		SODA-LIME GLASS	0.60
	SILICON CONTROLLED RECTIFIERS		
		COPPER	5.00
		SILICON	0.11
		ELECTRICAL PORCELAIN	0.34
17.	ENERGY SYSTEM CONTROLLER		
17.01	MISCELLANEOUS BUILDING 15 FT X 25 FT		
		CARBON STEEL	1497.00
		CONCRETE	472.00
		FIBERGLASS WOOL	544.00
		PLYWOOD-SOFTWOOD	305.00
17.02	METERS, SWITCHES, RELAYS, TERMINAL BOARDS, ETC.		
		COPPER	29.50
		CARBON STEEL	50.00
		PHENOLIC	11.30
		STAINLESS STEEL	64.40
		PLASTICS	9.00

17.03	SUPPORTS - CABINETS ETC.	
	ALUMINUM	160.00
	STAINLESS STEEL	10.50
	CARBON STEEL	1350.00
	EPOXY/GLASS LAMINATE	0.24

10. A geometric packing factor of 0.8 is assumed for this modification. Required number of 8-foot by 25-foot panels is 17. Actual Mead installation required 28 panels.
- 12.02 - Encapsulant assumed to be .020 inch EVA with .002 inch acrylic UV barrier.
- 12.03 - Assumed thicknesses in microns:
Active Layer	Cu ₂ S	0.4
Back Contact	Zinc	0.5
Barrier Layer	CdS	20.
Grid Collector	Cu	5.0 at 5% coverage
Foil Substrate	Cu	10.0
- 12.04 - Scaled at 17/28 of actual Mead installation.
- 12.09 - Same as note 12.04.
- 13.02 Assumed one 8-panel row and one 9-panel row, and 25 feet to control house from row ends. Therefore, electrical wire scales by 0.39.
- 13.05 - Same as note 12.04.
- 15.01 - Steel buildings assumed on concrete pads with R-11 insulation and plywood interior paneling.
- 15.02 - Battery case is high density, high impact, structural foam. Polypropylene assumed.
- 16.02 - Weights estimated from total weight of the solid state inverter.
- 17.01 - Same as note 15.01.

MIT-LL AND UNL PHOTOVOLTAIC SYSTEM

AT MEAD, NEBRASKA

MODIFIED WITH 1985 TECHNOLOGY

CADMIUM SULFIDE/INDIUM PHOSPHIDE CELLS

A GEOMETRIC PACKING FACTOR OF 0.8 IS ASSUMED FOR THIS CELL, WHICH REDUCES THE TOTAL NUMBER OF 8-FOOT BY 25-FOOT PANELS FROM 28 TO 17. THE UNIT'S PEAK POWER OF 25 KW IS DERIVED FROM 250 SQUARE METERS OF CADMIUM SULFIDE/INDIUM PHOSPHIDE THIN FILM CELLS AT 10% EFFICIENCY.

THE ARRAY OUTPUT (6.2 AMPS AT 150 VOLTS PER PANEL) IS FED TO TWO BUILDINGS. ONE HOUSES SYSTEM CONTROL EQUIPMENT AND THREE 7.5 KVA INVERTERS. THE OTHER BUILDING HOUSES 38 LARGE LEAD-ACID STORAGE BATTERIES CAPABLE OF STORING 85 KW-HR.

THIS SYSTEM WAS BUILT BY THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY'S LINCOLN LABORATORY. THE POWER PRODUCED IS USED TO PUMP WATER TO IRRIGATE 80 ACRES OF CORN AND SOYBEANS AT THE UNIVERSITY OF NEBRASKA FIELD LABORATORY NEAR MEAD.

TECHNOLOGY	PHOTOVOLTAICS
CAPACITY	25 KW PEAK
APPLICATION	CROP IRRIG. + DRYING
LOCATION	MEAD, NEBRASKA
INSOLATION	2,000 KW/HR/M2/YR
SOLAR CONTRIBUTION	
SUPPLEMENT	LINE POWER
SOLAR EFFICIENCY	10%
PANEL AREA	313 M2
CELL AREA	250 M2
OPERATING TEMPERATURE	AMBIENT
ENERGY TRANSPORT MEDIUM	ELECTRICAL
STORAGE TYPE	LEAD-ACID BATTERIES
STORAGE CAPACITY	85 KW/HR

MATERIAL REQUIREMENTS BY FUNCTIONAL COMPONENTS

12.	ENERGY COLLECTOR		
12.02	ENCAPSULANT	EVA	149.60
		ACRYLIC	18.90
12.03	ABSORBER - CAD SULFIDE/INDIUM PHOSPHIDE AT 10% EFFICIENCY		
	ACTIVE LAYER	INDIUM	0.80
		PHOSPHORUS	0.22
	BACK CONTACT	GOLD	1.83
		ZINC	0.87
	WINDOW LAYER	CADMIUM	0.80
		SULPHUR	1.59
	POSITIVE ELECTRODE		0.46
	NEGATIVE ELECTRODE	COPPER	3.08
		NICKEL	0.06
		CHROMIUM	0.02
		IRON	0.01
		COPPER	1.12
	TRANSPARENT CONTACT	INDIUM	0.28
		TIN	0.01
	SUBSTRATE - GLAZING	SODA LIME GLASS	2440.00
12.04	ENERGY TRANSPORT		
	PANEL INTERCONNECTS	COPPER	21.32
		TEFLON	4.95

		ELECTRICAL BOXES		
		WIREWAYS, INSULATORS		
		ETC.		
		CARBON STEEL	792.94	
		STAINLESS STEEL	122.65	
		COPPER	343.61	
		PLASTICS, LAMINATES	0.00	
		NYLON	0.30	
		ALUMINUM	0.10	
		RUBBER	13.98	
		60-40 SOLDER	14.10	
12.09	SUPPORTS			
	UPRIGHTS			
		6061 ALUMINUM	1345.00	
		STAINLESS STEEL	124.00	
		CONCRETE	60200.00	
	FRAMEWORKS			
		6061 ALUMINUM	7028.36	
		STAINLESS STEEL	267.92	
		CARBON STEEL	173.01	
13.	ENERGY TRANSPORT			
13.02	ELECTRICAL WIRE			
		COPPER	103.00	
		PVC	9.39	
13.05	SUPPORTS			
	CONDUIT			
		ALUMINUM	551.09	
		CARBON STEEL	4.19	
	CONDUIT SEALS			
		RUBBER	0.00	
			1.41	
15.	ENERGY STORAGE			
15.01	MISCELLANEOUS			
	BATTERY BUILDING			
	10 FT X 20 FT			
		CARBON STEEL	1043.00	
		CONCRETE	252.00	
		FIBERGLASS WOOL	254.00	
		PLYWOOD-SOFTWOOD	190.00	
	BATTERY COVERS	ACRYLIC	53.00	
	BATTERY INTERCONNECTS		0.00	
		COPPER	14.00	
		PHENOLIC	0.00	
		MICARTA	0.00	
	30 BATTERIES 375	AMP-HR	0.00	
		EPOXY	0.91	
15.02	PRIMARY STORAGE			
		.3 PERCENT CALCIUM LEAD	1438.00	
		5 PERCENT ANTIMONY LEAD	1197.00	
		SULFURIC ACID	726.00	
		POLYPROPYLENE	207.00	
15.04	SUPPORT			
		STAINLESS STEEL	306.00	
		CARBON STEEL	183.00	
16.	ENERGY CONDITIONING			
16.02	INVERTER			
	ENCLOSURE			
		CARBON STEEL	106.00	
	CORE CLAMPS			
		CARBON STEEL	34.00	
	CORES AND WINDINGS			
		COPPER	150.00	
		SILICON STEEL	417.00	
		VARNISH	6.00	
	INSULATION			
		POLYESTER	4.00	
	INSTRUMENTATION			
		PHENOLIC	4.00	
		COPPER	1.36	
		ZINC	0.00	
		SODA-LIME GLASS	0.00	
	SILICON CONTROLLED			
	RECTIFIERS			
		COPPER	5.00	
		SILICON	0.11	
		ELECTRICAL PORCELAIN	0.34	

17.	ENERGY SYSTEM CONTROLLER		
17.01	MISCELLANEOUS		
	BUILDING 15 FT X 25 FT		
	CARBON STEEL	1497.00	
	CONCRETE	472.00	
	FIBERGLASS WOOL	544.00	
	PLYWOOD-SOFTWOOD	265.00	
17.02	METERS, SWITCHES, RELAYS,		
	TERMINAL BOARDS, ETC.		
	COPPER	29.50	
	CARBON STEEL	50.00	
	PHENOLIC	11.30	
	STAINLESS STEEL	64.40	
	PLASTICS	8.85	
17.03	SUPPORTS - CABINETS ETC.		
	ALUMINUM	150.00	
	STAINLESS STEEL	10.50	
	CARBON STEEL	1359.00	
	EPOXY/GLASS LAMINATE	0.24	

10. A geometric packing factor of 0.8 is assumed for this modification. Required number of 8-foot by 25-foot panels is 17. Actual Mead installation required 28 panels.

12.02 - Encapsulation assumed to be .020 inch EVA with .002 inch acrylic UV barrier.

12.03 - Assumed thicknesses in microns:

Active Layer	InP	1.0 at 85% coverage
Back Contact	Au-Zn	0.5 at 85% coverage
Window Layer	CdS	2.0 at 85% coverage
Positive Electrode	Cu	2.0 at 85% coverage
Negative Electrode	Inconel	0.4 at 10% coverage
	Cu	5.0 at 10% coverage
Transparent Contact	$\text{In}_{1.9}\text{Sn}_{0.1}\text{O}_3$	0.2
Substrate	Glass	3000

12.04 - Scaled at 17/28 of actual Mead installation.

12.09 - Same as note 12.04.

13.02 - Assumed one 8-panel row and one 9-panel row, and 25 feet to control house from row ends. Therefore, electrical wire scales by 0.39.

13.05 - Same as note 12.04.

15.01 - Steel buildings assumed on concrete pads with R-11 insulation and plywood interior paneling.

15.02 - Battery case is high density, high impact, structural foam. Polypropylene assumed.

16.02 - Weights estimated from total weight of the solid state inverter.

17.01 - Same as note 15.01.

MIT-LL AND UML PHOTOVOLTAIC SYSTEM

AT MEAD, NEBRASKA

MODIFIED WITH 1985 TECHNOLOGY

COPPER OXIDE MIS TYPE CELLS

A GEOMETRIC PACKING FACTOR OF 0.8 IS ASSUMED FOR THIS CELL, WHICH REDUCES THE TOTAL NUMBER OF 8-FOOT BY 25-FOOT PANELS FROM 28 TO 17. THE UNITS PEAK POWER OF 25 KW IS DERIVED FROM 250 SQUARE METERS OF COPPER OXIDE MIS TYPE CELLS AT 10% EFFICIENCY.

THE ARRAY OUTPUT (6.2 AMPS AT 150 VOLTS PER PANEL) IS FED TO TWO BUILDINGS. ONE HOUSES SYSTEM CONTROL EQUIPMENT AND THREE 7.5 KVA INVERTERS. THE OTHER BUILDING HOUSES 38 LARGE LEAD-ACID STORAGE BATTERIES CAPABLE OF STORING 85 KW-HR.

THIS SYSTEM WAS BUILT BY THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY'S LINCOLN LABORATORY. THE POWER PRODUCED IS USED TO PUMP WATER TO IRRIGATE 80 ACRES OF CORN AND SOYBEANS AT THE UNIVERSITY OF NEBRASKA FIELD LABORATORY NEAR MEAD.

TECHNOLOGY_ PHOTOVOLTAICS
CAPACITY_ 25 KW PEAK
APPLICATION_ CROP IRRIG. + DRYING
LOCATION_ MEAD, NEBRASKA
INSOLATION_ 2,000 KW/HR/M2/YR
SOLAR CONTRIBUTION_
SUPPLEMENT_ LINE POWER
SOLAR EFFICIENCY_ 10%
PANEL AREA_ 313 M2
CELL AREA_ 250 M2
OPERATING TEMPERATURE_ AMBIENT
ENERGY TRANSPORT MEDIUM_ ELECTRICAL
STORAGE TYPE_ LEAD-ACID BATTERIES
STORAGE CAPACITY_ 85 KW/HR

MATERIAL REQUIREMENTS
BY

FUNCTIONAL COMPONENTS

12.	ENERGY COLLECTOR		
12.02	ENCAPSULANT	EVA	149.00
		ACRYLIC	18.00
12.03	ABSORBER - COPPER OXIDE MIS		
	AT 10% EFFICIENCY		
	BARRIER LAYER		
		COPPER	0.01
	COLLECTOR GRID		
		COPPER	0.56
	FOIL		
		COPPER	22.30
12.04	ENERGY TRANSPORT		
	PANEL INTERCONNECTS		
		COPPER	21.03
		TEFLON	1.95
	ELECTRICAL BOXES		
	WIREWAYS, INSULATORS		
	ETC.		
		CARBON STEEL	792.94
		STAINLESS STEEL	122.55
		COPPER	343.61
		PLASTICS, LAMINATES	0.50
		NYLON	0.30
		ALUMINUM	10.40
		RUBBER	12.00
		60-40 SOLDER	14.18
12.07	FRAME		
	SOLAR CELL MODULE		
	BACKING PANELS		
		CARBON STEEL	748.00

12.	09	SUPPORTS UPRIGHTS	6061 ALUMINUM	1345.00
			STAINLESS STEEL	124.00
13.	02	ELECTRICAL WIRE	CONCRETE	60200.00
			6061 ALUMINUM	7028.36
			STAINLESS STEEL	267.92
			CARBON STEEL	173.01
13.	05	SUPPORTS CONDUIT	COPPER	103.00
			PVC	9.39
13.	05	CONDUIT SEALS	ALUMINUM	551.00
			CARBON STEEL	4.19
15.	01	STORAGE MISCELLANEOUS BATTERY BUILDING 10 FT X 20 FT	RUBBER	1.41
			CARBON STEEL	1043.00
15.	01	BATTERY COVERS	CONCRETE	252.00
			FIBERGLASS WOOL	354.00
15.	01	BATTERY INTERCONNECTS	PLYWOOD-SOFTWOOD	190.00
			ACRYLIC	53.00
15.	02	PRIMARY STORAGE 38 BATTERIES 375	COPPER	14.50
			PHENOLIC	0.05
15.	02	SUPPORT	MICARTA	0.92
			EPOXY	0.91
15.	04	SUPPORT	ANP-HR	1438.00
			3 PERCENT CALCIUM LEAD	1197.00
15.	04	SUPPORT	5 PERCENT ANTIMONY LEAD	726.00
			SULFURIC ACID	307.00
15.	04	SUPPORT	POLYPROPYLENE	307.00
			STAINLESS STEEL	305.00
16.	02	CONDITIONING INVERTER ENCLOSURE	CARBON STEEL	103.00
			CARBON STEEL	34.00
16.	02	CORE CLAMPS	COPPER	150.00
			SILICON STEEL	417.00
16.	02	CORES AND WINDINGS	VARNISH	6.00
			INSULATION	4.00
16.	02	INSTRUMENTATION	POLYESTER	4.00
			PHENOLIC	4.00
16.	02	INSTRUMENTATION	COPPER	1.36
			ZINC	0.60
16.	02	INSTRUMENTATION	SODA-LIME GLASS	0.60
			SILICON CONTROLLED RECTIFIERS	5.00
16.	02	INSTRUMENTATION	COPPER	0.11
			SILICON	0.74
17.	01	SYSTEM CONTROLLER MISCELLANEOUS BUILDING 15 FT X 25 FT	ELECTRICAL PORCELAIN	1497.00
			CARBON STEEL	472.00
17.	01	SYSTEM CONTROLLER MISCELLANEOUS BUILDING 15 FT X 25 FT	CONCRETE	544.00
			FIBERGLASS WOOL	305.00
17.	01	SYSTEM CONTROLLER MISCELLANEOUS BUILDING 15 FT X 25 FT	PLYWOOD-SOFTWOOD	305.00
			CONCRETE	472.00
17.	01	SYSTEM CONTROLLER MISCELLANEOUS BUILDING 15 FT X 25 FT	FIBERGLASS WOOL	544.00
			PLYWOOD-SOFTWOOD	305.00

17.02	METERS, SWITCHES, RELAYS, TERMINAL BOARDS, ETC.	29.58
	COPPER	58.00
	CARBON STEEL	11.30
	PHENOLIC	64.49
	STAINLESS STEEL	8.05
	PLASTICS	
17.03	SUPPORTS - CABINETS ETC.	160.00
	ALUMINUM	10.50
	STAINLESS STEEL	1359.00
	CARBON STEEL	8.24
	EPOXY/GLASS LAMINATE	

FOOTNOTES

10. A geometric packing factor of 0.8 is assumed for this modification. Required number of 8-foot by 25-foot panels is 17. Actual Mead installation required 28 panels.
- 12.02 - Encapsulant assumed to be .020 inch EVA with .002 inch acrylic UV barrier.
- 12.03 - Assumed thicknesses in microns:

Barrier Layer	Cu	.005
Collector Grid	Cu	5 at 95% trans
Foil	Cu/Cu ₂ O	10
- 12.04 - Scaled at 17/28 of actual Mead installation.
- 12.07 - Carbon steel backing panel assumed .012 inches thick. It was also assumed that the supports (12.09) would be designed more efficiently to incorporate the additional support required for the thin cell backing.
- 12.09 - Same as note 12.04..
- 13.02 - Assumed one 8-panel row and one 9-panel row, and 25 feet to control house from row ends. Therefore, electrical wire scales by 0.39.
- 13.05 - Same as note 12.04.
- 15.01 - Steel buildings assumed on concrete pads with R-11 insulation and plywood interior paneling.
- 15.02 - Battery case is high density, high impact, structural foam. Polypropylene assumed.
- 16.02 - Weights estimated from total weight of the solid state inverter.
- 17.01 - Same as note 15.01.

MIT-LL AND UNL PHOTOVOLTAIC SYSTEM
 AT NEAD, NEBRASKA
 MODIFIED WITH 1985 TECHNOLOGY
 GALLIUM ARSENIDE HETEROJUNCTION CELLS
 A GEOMETRIC PACKING FACTOR OF 0.8 IS
 ASSUMED FOR THIS CELL, WHICH REDUCES THE
 TOTAL NUMBER OF 8-FOOT BY 25-FOOT PANELS
 FROM 28 TO 9. THE UNIT'S PEAK POWER OF
 25 KW IS DERIVED FROM 139 SQUARE METERS
 OF GALLIUM ARSENIDE HETEROJUNCTION CELLS
 AT 18% EFFICIENCY.
 THE ARRAY OUTPUT (6.2 AMPS AT 150 VOLTS
 PER PANEL) IS FED TO TWO BUILDINGS. ONE
 HOUSE'S SYSTEM CONTROL EQUIPMENT AND
 THREE 7.5 KVA INVERTERS. THE OTHER BUILDING
 HOUSES 38 LARGE LEAD-ACID STORAGE BAT-
 TERIES CAPABLE OF STORING 95 KW-HR.

THIS SYSTEM WAS BUILT BY THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY'S
 LINCOLN LABORATORY. THE POWER PRODUCED
 IS USED TO PUMP WATER TO IRRIGATE 80 ACRES
 OF CORN AND SOYBEANS AT THE UNIVERSITY
 OF NEBRASKA FIELD LABORATORY NEAR NEAD
 TECHNOLOGY. PHOTOVOLTAICS
 CAPACITY. 25 KW PEAK
 APPLICATION. CROP IRRIG. + DRYING
 LOCATION. NEAD, NEBRASKA
 INSOLATION. 2000 KWH/M²/YR
 SOLAR CONTRIBUTION.
 SUPPLEMENT. LINE POWER
 SOLAR EFFICIENCY. 18%
 PANEL AREA. 174M²
 CELL AREA. 139M²
 OPERATING TEMPERATURE. AMBIENT
 ENERGY TRANSPORT MEDIUM. ELECTRICAL
 STORAGE TYPE. LEAD-ACID BATTERIES
 STORAGE CAPACITY. 95 KW-HR
 MATERIAL REQUIREMENTS
 BY
 FUNCTIONAL COMPONENTS

12.	ENERGY COLLECTOR		
12.02	ENCAPSULANT	SODA LIME GLASS	734.29
12.03	ABSORBER - GMS 1 XTL HETEROJUNCTION AT 18% EFFICIENCY ACTIVE LAYERS		
		GALLIUM	0.00
		ARSENIC	44.50
	BACK CONTACT		17.75
	WINDOW LAYER	TIN	4.00
		GALLIUM	0.02
		ALUMINUM	0.02
		ARSENIC	0.11
	N. DOPANT		
		CERNIUM	0.00
	P. DOPANT		
		ZINC	0.00
	ANTI-REFLECTIVE COATING		
	FRONT CONTACT	TITANIUM	0.02
		GOLD	1.07
		ZINC	0.10
12.04	ENERGY TRANSPORT PANEL INTERCONNECTS		0.00
		COPPER	0.00
		TEFLON	11.00
			1.00

		ELECTRICAL BOXES, WIREWAYS, INSULATORS ETC.		
		CARBON STEEL	448.31	
		STAINLESS STEEL	68.05	
		COPPER	190.00	
		PLASTICS, LAMINATES	0.30	
		NYLON	0.17	
		ALUMINUM	5.10	
		RUBBER	7.54	
		60-40 SOLDER	7.87	
12.07	FRAME			
	SOLAR CELL MODULE			
	BACKING PANELS			
		CARBON STEEL	417.00	
12.09	SUPPORTS			
	UPRIGHTS			
		6061 ALUMINUM	747.20	
		STAINLESS STEEL	68.72	
		CONCRETE	33449.00	
	FRAMEWORK			
		6061 ALUMINUM	3902.79	
		STAINLESS STEEL	148.77	
		CARBON STEEL	95.07	
13.	ENERGY TRANSPORT			
13.02	ELECTRICAL WIRE			
		COPPER	55.60	
		PVC	3.04	
13.05	SUPPORTS			
	CONDUIT			
		ALUMINUM	292.18	
		CARBON STEEL	2.22	
	CONDUIT SEALS			
		RUBBER	0.75	
15.	ENERGY STORAGE			
15.01	MISCELLANEOUS			
	BATTERY BUILDING			
	10 FT X 20 FT			
		CARBON STEEL	1043.00	
		CONCRETE	252.00	
		FIBERGLASS WOOL	354.00	
		PLYWOOD-SOFTWOOD	198.00	
	BATTERY COVERS	ACRYLIC	52.00	
	BATTERY INTERCONNECTS			
		COPPER	14.00	
		PHENOLIC	0.05	
		MICARTA	0.32	
		EPOXY	0.91	
15.02	PRIMARY STORAGE			
	39 BATTERIES 375 AMP-HR			
		1.3 PERCENT CALCIUM LEAD	1438.00	
		5 PERCENT ANTIMONY LEAD	1137.00	
		SULFURIC ACID	725.00	
		POLYPROPYLENE	297.00	
15.04	SUPPORT			
		STAINLESS STEEL	385.00	
		CARBON STEEL	183.00	
16.	ENERGY CONDITIONING			
16.02	INVERTER			
	ENCLOSURE			
		CARBON STEEL	185.00	
	CORE CLAMPS			
		CARBON STEEL	0.00	
	CORES AND WINDINGS			
		COPPER	150.00	
		SILICON STEEL	417.00	
		VARNISH	5.00	
	INSULATION			
		POLYESTER	4.00	
	INSTRUMENTATION			
		PHENOLIC	4.00	
		COPPER	1.36	
		ZINC	0.60	
		SODA-LIME GLASS	0.60	
	SILICON CONTROLLED			
	RECTIFIERS			
		COPPER	5.00	
		SILICON	0.11	
		ELECTRICAL PORCELAIN	0.34	

17.	ENERGY SYSTEM CONTROLLER		
17.01	MISCELLANEOUS		
	BUILDING 15 FT X 25 FT		
	CARBON STEEL	1497.00	
	CONCRETE	472.00	
	FIBERGLASS WOOL	544.00	
	PLYWOOD-SOFTWOOD	205.00	
17.02	METERS, SWITCHES, RELAYS,		
	TERMINAL BOARDS, ETC.	0.00	
	COPPER	29.50	
	CARBON STEEL	50.00	
	PHENOLIC	11.30	
	STAINLESS STEEL	64.40	
	PLASTICS	8.85	
17.03	SUPPORTS - CABINETS ETC.	0.00	
	ALUMINUM	160.00	
	STAINLESS STEEL	10.50	
	CARBON STEEL	1359.00	
	EPONY/GLASS LAMINATE	0.24	

FOOTNOTES

10. A geometric packing factor of 0.8 is assumed for this modification. Required number of 8-foot by 25-foot panels is 9. Actual Mead installation required 28 panels.
- 12.02 - Encapsulant thickness assumed - 0.125 inches.
- 12.03 - Assumed thicknesses in microns:
Active Layers		
and Substrate	Ga As	125
Back contact	Sn	5
Window Layer	$Ga_xAl_{1-x}As$	.3
	$X=0.2$	
p-Dopant	Zn	$.5 @ 10^{19} cm^{-3}$
h-Dopant	Ge	$125 @ 5 \times 10^{17} cm^{-3}$
- 12.07 - Carbon steel backing panel assumed .012 inches thick. It was also assumed that the supports (12.09) would be designed more efficiently to incorporate the additional support required for the thin steel backing.
- 12.09 - Same as note 12.04.
- 13.02 - Assumed one 5-panel row and one 4-panel row and 25 feet to control house from row ends. Therefore, electrical wire scales by .21 if wire cross section increases by .18/.10.
- 13.05 - Same as note 12.04.
- 15.01 - Steel buildings assumed on concrete pads with R-11 insulation and plywood interior paneling.
- 15.02 - Battery case in high density, high impact, structural foam. Polypropylene assumed.
- 16.02 - Weights estimated from total weight of the solid state inverter.
- 17.01 - Same as note 15.01.

Energy Storage Deleted

MIT-ILL AND UHL PHOTOVOLTAIC SYSTEM
AT NEAD, NEBRASKA
MODIFIED WITH 1985 TECHNOLOGY
GALLIUM ARSENIDE HETEROJUNCTION CELLS
A GEOMETRIC PACKING FACTOR OF 0.8 IS
ASSUMED FOR THIS CELL, WHICH REDUCES THE
TOTAL NUMBER OF 8-FOOT BY 25-FOOT PANELS
FROM 28 TO 9. THE UNITS PEAK POWER OF
25 KW IS DERIVED FROM 139 SQUARE METERS
OF GALLIUM ARSENIDE HETEROJUNCTION CELLS
AT 18% EFFICIENCY.
THE ARRAY OUTPUT (6.2 AMPS AT 150 VOLTS
PER PANEL) IS FED TO TWO BUILDINGS. ONE
HOUSES SYSTEM CONTROL EQUIPMENT AND
THREE 7.5 KVA INVERTERS. THE OTHER BUILDING
HOUSES 38 LARGE LEAD-ACID STORAGE BAT-
TERIES CAPABLE OF STORING 85 KW-HR.

THIS SYSTEM WAS BUILT BY THE MASSA-
CHUSETTS INSTITUTE OF TECHNOLOGY'S
LINCOLN LABORATORY. THE POWER PRODUCED
IS USED TO PUMP WATER TO IRRIGATE 80 ACRES
OF CORN AND SOYBEANS AT THE UNIVERSITY
OF NEBRASKA FIELD LABORATORY NEAR NEAD.
TECHNOLOGY_ PHOTOVOLTAICS
CAPACITY_ 25 KW PEAK
APPLICATION_ CROP IRRIG. + DRYING
LOCATION_ NEAD, NEBRASKA
INSOLATION_ 2000 KWH/M2/YR
SOLAR CONTRIBUTION_ LINE POWER
SUPPLEMENT_ 10%
SOLAR EFFICIENCY_ 174M2
PANEL AREA_ 139M2
CELL AREA_ AMBIENT
OPERATING TEMPERATURE_ ELECTRICAL
ENERGY TRANSPORT MEDIUM_ LEAD-ACID BATTERIES
STORAGE TYPE_ 85 KW-HR
STORAGE CAPACITY_ MATERIAL REQUIREMENTS

BY
FUNCTIONAL COMPONENTS

12.	ENERGY COLLECTOR		
12.02	ENCAPSULANT	SODA LIME GLASS	784.29
12.03	ABSORBER - GAPS 1 XTL HETEROJUNCTION AT 18% EFFICIENCY ACTIVE LAYERS		
		GALLIUM	44.58
		ARSENIC	47.75
	BACK CONTACT	TIN	4.08
	WINDOW LAYER		
		GALLIUM	8.02
		ALUMINUM	8.03
		ARSENIC	8.11
	N. DOPANT	GERMANIUM	3.08
	P. DOPANT	ZINC	8.08
	ANTI-REFLECTIVE COATING	TITANIUM	8.02
	FRONT CONTACT		
		GOLD	1.07
		ZINC	8.10
12.04	ENERGY TRANSPORT PANEL INTERCONNECTS		
		COPPER	11.68
		TEFLON	1.89

		ELECTRICAL BOXES, WIRERAYS, INSULATORS ETC.		
		CARBON STEEL	440.31	
		STAINLESS STEEL	68.00	
		COPPER	150.00	
		PLASTICS, LAMINATES	0.00	
		NYLON	0.17	
		ALUMINUM	5.10	
		RUBBER	7.54	
		60-40 SOLDER	7.07	
12.07	FRAME SOLAR CELL MODULE BACKING PANELS			
		CARBON STEEL	417.00	
12.09	SUPPORTS UPRIGHTS			
		6061 ALUMINUM	747.20	
		STAINLESS STEEL	68.72	
		CONCRETE	334.00	
	FRAMEWORK			
		6061 ALUMINUM	2902.79	
		STAINLESS STEEL	110.77	
		CARBON STEEL	96.07	
13.	ENERGY TRANSPORT			
13.02	ELECTRICAL WIRE			
		COPPER	50.00	
		PVC	5.04	
13.05	SUPPORTS CONDUIT			
		ALUMINUM	292.10	
		CARBON STEEL	2.22	
	CONDUIT SEALS			
		RUBBER	0.75	
15.	ENERGY STORAGE			
15.01	MISCELLANEOUS BATTERY BUILDING 10 FT X 20 FT			
		CARBON STEEL	0.00	
		CONCRETE	0.00	
		FIBERGLASS WOOD	0.00	
		PLYWOOD-SOFTWOOD	0.00	
	BATTERY COVERS	ACRYLIC	0.00	
	BATTERY INTERCONNECTS			
		COPPER	0.00	
		PHENOLIC	0.00	
		MICARTA	0.00	
		EPOXY	0.00	
15.02	PRIMARY STORAGE 30 BATTERIES 375 AMP-HR			
		3 PERCENT CALCIUM LEAD	0.00	
		5 PERCENT ANTIMONY LEAD	0.00	
		SULFURIC ACID	0.00	
		POLYPROPYLENE	0.00	
15.04	SUPPORT			
		STAINLESS STEEL	0.00	
		CARBON STEEL	0.00	
16.	ENERGY CONDITIONING			
16.02	INVERTER ENCLOSURE			
		CARBON STEEL	100.00	
	CORE CLAMPS			
		CARBON STEEL	34.00	
	CORES AND WINDINGS			
		COPPER	150.00	
		SILICON STEEL	417.00	
		VARNISH	0.00	
	INSULATION			
		POLYESTER	4.00	
	INSTRUMENTATION			
		PHENOLIC	4.00	
		COPPER	1.36	
		ZINC	0.00	
		SODA-LIME GLASS	0.00	
	SILICON CONTROLLED RECTIFIERS			
		COPPER	0.00	
		SILICON	0.11	
		ELECTRICAL PORCELAIN	0.34	

17.	ENERGY SYSTEM CONTROLLER		
17.01	MISCELLANEOUS		
	BUILDING 15 FT X 25 FT		
	CARBON STEEL	1497.00	
	CONCRETE	472.00	
	FIBERGLASS WOOL	544.00	
	PLYWOOD-SOFTWOOD	385.00	
17.02	METERS, SWITCHES, RELAYS,		
	TERMINAL BOARDS, ETC.		
	COPPER	29.50	
	CARBON STEEL	50.00	
	PHENOLIC	11.00	
	STAINLESS STEEL	64.00	
	PLASTICS	8.00	
17.03	SUPPORTS - CABINETS ETC.		
	ALUMINUM	160.00	
	STAINLESS STEEL	10.50	
	CARBON STEEL	1359.00	
	EPOXY/GLASS LAMINATE	0.24	

PHOTOVOLTAIC ARRAY ONLY

Energy Transport, Storage, Conditioning, and System Controller Deleted

MITCHELL AND UNL PHOTOVOLTAIC SYSTEM
 AT NEAD, NEBRASKA
 MODIFIED WITH 1985 TECHNOLOGY
 GALLIUM ARSENIDE HETEROJUNCTION CELLS
 A GEOMETRIC PACKING FACTOR OF 0.9 IS
 ASSUMED FOR THIS CELL, WHICH PRODUCES THE
 TOTAL NUMBER OF 8 FOOT BY 25 FOOT PANELS
 FROM 28 TO 3. THE UNL'S PEAK POWER OF
 25 KW IS DERIVED FROM 139 SQUARE METERS
 OF GALLIUM ARSENIDE HETEROJUNCTION CELLS
 AT 18% EFFICIENCY.
 THE ARRAY OUTPUT (6.2 AMPS AT 100 VOLTS
 PER PANEL) IS FED TO TWO BUILDINGS. ONE
 HOUSE'S SYSTEM CONTROL EQUIPMENT AND
 THREE 7.5 KVA INVERTERS. THE OTHER BUILDING
 HOUSES 38 LARGE LEAD-ACID STORAGE BATTERIES
 CAPABLE OF STORING 85 KW-HR.

THIS SYSTEM WAS BUILT BY THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY'S LINCOLN LABORATORY. THE POWER PRODUCED IS USED TO PUMP WATER TO IRRIGATE 80 ACRES OF CORN AND SOYBEANS AT THE UNIVERSITY OF NEBRASKA FIELD LABORATORY NEAR NEAD. TECHNOLOGY PHOTOVOLTAICS
 CAPACITY 20 KW PEAK
 APPLICATION CROP IRRIG. + DRYING
 LOCATION NEAD, NEBRASKA
 INSOLATION 2000 KWH/M2/YR
 SOLAR CONTRIBUTION LINE POWER
 SUPPLEMENT 18%
 SOLAR EFFICIENCY 174M2
 PANEL AREA 139M2
 CELL AREA
 OPERATING TEMPERATURE AMBIENT
 ENERGY TRANSPORT MEDIUM ELECTRICAL
 STORAGE TYPE LEAD-ACID BATTERIES
 STORAGE CAPACITY 85 KW-HR
 MATERIAL REQUIREMENTS
 BY
 FUNCTIONAL COMPONENTS

12.	ENERGY COLLECTOR		
12.02	ENCAPSULANT	SODA LIME GLASS	734.29
12.03	ABSORBER - GAPS 1 XTL HETEROJUNCTION AT 18% EFFICIENCY ACTIVE LAYERS		
		GALLIUM	44.50
		ARSENIC	47.75
	BACK CONTACT	TIN	4.00
	WINDOW LAYER	GALLIUM	0.02
		ALUMINUM	0.03
		ARSENIC	0.11
	N. DOPANT	GERMANIUM	0.00
	P. DOPANT	ZINC	0.00
	ANTI-REFLECTIVE COATING	TITANIUM	0.02
	FRONT CONTACT	GOLD	1.07
		ZINC	0.10
12.04	ENERGY TRANSPORT PANEL INTERCONNECTS		
		COPPER	11.60
		TEFLON	1.00

		ELECTRICAL BOXES, WIRINGAYS, INSULATORS ETC.		
		CARBON STEEL	448.31	
		STAINLESS STEEL	68.05	
		COPPER	198.88	
		PLASTICS, LAMINATES	8.20	
		NYLON	8.17	
		ALUMINUM	5.10	
		RUBBER	7.54	
		60-40 SOLDER	7.87	
12.07	FRAME			
	SOLAR CELL MODULE			
	BACKING PANELS	CARBON STEEL	417.00	
12.09	SUPPORTS			
	UPRIGHTS	6061 ALUMINUM	747.20	
		STAINLESS STEEL	68.72	
		CONCRETE	33448.00	
	FRAMEWORK	6061 ALUMINUM	3902.79	
		STAINLESS STEEL	148.77	
		CARBON STEEL	96.87	
13.	ENERGY TRANSPORT			
13.02	ELECTRICAL WIRE		0.00	
		COPPER	0.00	
		PVC	0.00	
13.05	SUPPORTS		0.00	
	CONDUIT	ALUMINUM	0.00	
		CARBON STEEL	0.00	
	CONDUIT SEALS	RUBBER	0.00	
15.	ENERGY STORAGE			
15.01	MISCELLANEOUS		0.00	
	BATTERY BUILDING		0.00	
	10 FT X 20 FT		0.00	
		CARBON STEEL	0.00	
		CONCRETE	0.00	
		FIBERGLASS WOOL	0.00	
		PLYWOOD-SOFTWOOD	0.00	
	BATTERY COVERS	ACRYLIC	0.00	
	BATTERY INTERCONNECTS		0.00	
		COPPER	0.00	
		PHENOLIC	0.00	
		MICARTA	0.00	
		EPOXY	0.00	
15.02	PRIMARY STORAGE		0.00	
	38 BATTERIES 375	AMP-HR	0.00	
		.3 PERCENT CALCIUM LEAD	0.00	
		5 PERCENT ANTIMONY LEAD	0.00	
		SULFURIC ACID	0.00	
		POLYPROPYLENE	0.00	
15.04	SUPPORT		0.00	
		STAINLESS STEEL	0.00	
		CARBON STEEL	0.00	
16.	ENERGY CONDITIONING			
16.02	INVERTER		0.00	
	ENCLOSURE		0.00	
		CARBON STEEL	0.00	
	CORE CLAMPS		0.00	
		CARBON STEEL	0.00	
	CORES AND WINDINGS		0.00	
		COPPER	0.00	
		SILICON STEEL	0.00	
		VARNISH	0.00	
	INSULATION	POLYESTER	0.00	
	INSTRUMENTATION		0.00	
		PHENOLIC	0.00	
		COPPER	0.00	
		ZINC	0.00	
		SODA-LIME GLASS	0.00	
	SILICON CONTROLLED		0.00	
	RECTIFIERS		0.00	
		COPPER	0.00	
		SILICON	0.00	
		ELECTRICAL PORCELAIN	0.00	

17.	ENERGY SYSTEM CONTROLLER	0.00
17.01	MISCELLANEOUS	0.00
	BUILDING 15 FT X 25 FT	0.00
	CARBON STEEL	0.00
	CONCRETE	0.00
	FIBERGLASS WOOL	0.00
	PLYWOOD-SOFTWOOD	0.00
17.02	METERS, SWITCHES, RELAYS,	0.00
	TERMINAL BOARDS, ETC.	0.00
	COPPER	0.00
	CARBON STEEL	0.00
	PHENOLIC	0.00
	STAINLESS STEEL	0.00
	PLASTICS	0.00
17.03	SUPPORTS - CABINETS ETC.	0.00
	ALUMINUM	0.00
	STAINLESS STEEL	0.00
	CARBON STEEL	0.00
	EPONY/GLASS LAMINATE	0.00

MIT-LL AND UNL PHOTOVOLTAIC SYSTEM

AT MEDO, NEBRASKA

MODIFIED WITH 560X FRESNEL LENS
CONCENTRATOR AND 1985 TECHNOLOGY GALLIUM
SINGLE CRYSTAL HETEROJUNCTION SOLAR CELLS

THIS SYSTEM USES POINT FOCUS, PASSIVELY COOLED
FRESNEL LENS MIRRORS. THE PERK POWER OF 25 KM/H IS

DERIVED FROM 1.25 SQUARE METERS OF GALLIUM FRESNELIE BATTERY ACTION. THE CONCENTRATOR RATIO IS
500 TO 1 WITH AN OPTICAL EFFICIENCY OF 80 PERCENT. THE CONCENTRATOR RATIO IS

THE BATTERY OUTPUT (2.7 KM PER HERRY) IS FED TO TWO PULSED

ONE HOUSES SYSTEM CONTROL EQUIPMENT AND THREE 7.5 KW/HR UNITS.

THE OTHER BUILDING HOUSES 38 LARGE LENS ACID STORAGE BATTIES

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

OF 1000--7500 85 KM/HR

17.	ENERGY SYSTEM CONTROLLER		
17.01	MISCELLANEOUS		
	BUILDING 15 FT X 25 FT		
	CARBON STEEL	1497.00	
	CONCRETE	472.00	
	FIBERGLASS WOOL	544.00	
	PLYWOOD-SOFTWOOD	385.00	
17.02	METERS, SWITCHES, RELAYS,		
	TERMINAL BOARDS, ETC.		
	COPPER	29.50	
	CARBON STEEL	50.80	
	PHENOLIC	11.30	
	STAINLESS STEEL	64.40	
	PLASTICS	8.85	
17.03	SUPPORTS - CABINETS ETC.		
	ALUMINUM	160.00	
	STAINLESS STEEL	10.50	
	CARBON STEEL	1359.00	
	EPOXY/GLASS LAMINATE	0.24	

FOOTNOTES

12. This array structure is representative of designs for Silicon cells operating at 39X concentration. Material requirements are rough estimates based on data developed for costing purposes by General Electric Co., Valley Forge Space Center.

Assumed cell efficiency of 18% and optical efficiency of concentration to be 20%. Assumed gross cell area is two times active cell area. Seven arrays at 3.7 kw each required.

- 12.03 - Assumed thicknesses in microns:

Active Layers			
and Substrate	GaAs	125	
Back Contact	Sn	5	
Window Layer	$Ga_xAl_{1-x}As$	.3	
	(X=0.2)		
p-Dopant	Zn	.5 @ 10^{19} cm^{-3}	
h-Dopant	Ge	$125 @ 5 \times 10^{17} \text{ cm}^{-3}$	
A/R Coating	TiO ₂	.06	
Front Contact	Au/Zn	5 @ 90% trans	

- 12.04 - Assumed similar to Mead installation. Scaled by ratio of aperture areas, 0.92.
- 12.07 - Heat sink scaled by aperture area, all other by active cell area.
- 12.09 - Assumed 1.5 ft. diameter by 8 foot deep footings.
- 13.02 - Assumed seven 9 foot by 45 foot arrays. One 4 panel row and one 3 panel row. Wire length scales by 0.1. Wire size scales by 3.7/.93. Total scaling factor equals 0.44.
- 13.05 - Same as note 12.04.
- 15.01 - Steel buildings assumed on concrete pads with R-11 insulation and plywood interior paneling.
- 15.02 - Battery case is high density, high impact, structural foam. Polypropylene.
- 16.02 - Weights estimated from total weight of the solid state inverter.
- 17.01 - Same as note 15.01.

HIT-LL AND UNL PHOTOVOLTAIC SYSTEM
AT MEAD, NEBRASKA
MODIFIED WITH 1985 TECHNOLOGY
GALLIUM ARSENIDE MIS CELLS

A GEOMETRIC PACKING FACTOR OF 0.8 IS ASSUMED FOR THIS CELL, WHICH REDUCES THE TOTAL NUMBER OF 8-FOOT BY 25-FOOT PANELS FROM 28 TO 17. THE UNIT'S PEAK POWER OF 25 KW IS DERIVED FROM 250 SQUARE METERS OF GALLIUM ARSENIDE MIS CELLS AT 10 EFFICIENCY. THE ARRAY OUTPUT (6.2 AMPS AT 150 VOLTS PER PANEL) IS FED TO TWO BUILDINGS. ONE HOUSES SYSTEM CONTROL EQUIPMENT AND THREE 7.5 KVA INVERTERS. THE OTHER BUILDING HOUSES 39 LARGE LEAD-ACID STORAGE BATTERIES CAPABLE OF STORING 85 KW-HR.

THIS SYSTEM WAS BUILT BY THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY'S LINCOLN LABORATORY. THE POWER PRODUCED IS USED TO PUMP WATER TO IRRIGATE 90 ACRES OF CORN AND SOYBEANS AT THE UNIVERSITY OF NEBRASKA FIELD LABORATORY NEAR MEAD, NEBRASKA.

TECHNOLOGY	PHOTOVOLTAICS
CAPACITY	25 KW PEAK
APPLICATION	CROP IRRIG. + DRYING
LOCATION	MEAD, NEBRASKA
INSOLATION	2,000 KW/HR/M2/YR
SOLAR CONTRIBUTION	
SUPPLEMENT	LINE POWER
SOLAR EFFICIENCY	10%
PANEL AREA	313 M2
CELL AREA	250 M2
OPERATING TEMPERATURE	AMBIENT
ENERGY TRANSPORT MEDIUM	ELECTRICAL
STORAGE TYPE	LEAD-ACID BATTERIES
STORAGE CAPACITY	85 KW/HR
	MATERIAL REQUIREMENTS BY FUNCTIONAL COMPONENTS

12.	ENERGY COLLECTOR		
12.02	ENCAPSULANT	EVA	149.00
		ACRYLIC	18.90
12.03	ABSORBER - GALLIUM ARSENIDE MIS AT 10% EFFICIENCY		
	ACTIVE LAYER	GALLIUM ARSENIC	0.64
			0.09
	BACK CONTACT	TIN	7.18
	BARRIER LAYER	GOLD	0.03
	POSITIVE ELECTRODE	COPPER	0.56
	N - DOPANT	GERMANIUM	0.00
	ANTI-REFLECTIVE COATING	TANTALUM	0.09
	EPITAXY LAYER	GERMANIUM	33.25
	SUBSTRATE - GLAZING	SODA LIME GLASS	2440.00
12.04	ENERGY TRANSPORT		
	PANEL INTERCONNECTS	COPPER	21.03
		TEFLON	1.95

		ELECTRICAL BOXES WIREWAYS, INSULATORS ETC.		
		CARBON STEEL	7992	24
		STAINLESS STEEL	1422	00
		COPPER	3433	64
		PLASTICS, LAMINATES	3030	35
		NYLON	3030	30
		ALUMINUM	3110	10
		RUBBER	1358	00
		80-90 SOLDER	14	18
12	89	SUPPORTS		
		UPRIGHTS		
		6061 ALUMINUM	1245	00
		STAINLESS STEEL	124	00
		CONCRETE	60200	00
		FRAMEWORK		
		6061 ALUMINUM	7928	36
		STAINLESS STEEL	267	92
		CARBON STEEL	175	01
13		ENERGY TRANSPORT		
		ELECTRICAL WIRE		
		COPPER	103	00
		PVC	37	39
13	85	SUPPORTS		
		CONDUIT		
		ALUMINUM	054	39
		CARBON STEEL	4	19
		RUBBER	1	41
15		CONDUIT SEALS		
15		ENERGY STORAGE		
		MISCELLANEOUS		
		BATTERY BUILDING		
		10 FT X 20 FT		
		CARBON STEEL	1043	00
		CONCRETE	232	00
		FIBERGLASS MODL	354	00
		PLYWOOD-SOFTWOOD	198	00
		ROCKWELL	55	00
		BATTERY COVERS		
		BATTERY INTERCONNECTS		
		COPPER	14	00
		PHENOLIC	00	92
		MICRITH	0	91
		EPoxy		
15	02	PRIMARY STORAGE		
		39 BATTERIES 375		
		IMP-HR	1197	00
		5 PERCENT ANTIMONY LEAD	1438	00
		3 PERCENT CADMIUM LEAD	126	00
		SULFURIC ACID	207	00
		POLYPROPYLENE		
15	04	SUPPORT		
		STAINLESS STEEL	705	00
		CARBON STEEL	181	00
16		ENERGY CONDITIONING		
		INVERTER		
		ENCLOSURE		
		CARBON STEEL	126	00
		CORE OLIMPS		
		CARBON STEEL	24	00
		CORES AND WINDINGS		
		COPPER	150	00
		SILICON STEEL	417	00
		VARNISH	6	00
		INSULATION		
		POLYESTER	4	00
		INSTRUMENTATION		
		PHENOLIC	4	00
		COPPER	4	38
		ZINC	0	68
		500N-LINE GLASS	0	68
		SILICON CONTROLLED		
		RECTIFIERS		
		COPPER	5	00
		SILICON	0	11
		ELECTRICAL PORCELAIN	0	24

17.	ENERGY SYSTEM CONTROLLER		
17.01	MISCELLANEOUS		
	BUILDING 15 FT X 25 FT		
	CARBON STEEL	1497.00	
	CONCRETE	472.00	
	FIBERGLASS WOOL	544.00	
	PLYWOOD-SOFTWOOD	385.00	
17.02	METERS, SWITCHES, RELAYS,		
	TERMINAL BOARDS, ETC.		
	COPPER	29.50	
	CARBON STEEL	50.80	
	PHENOLIC	11.30	
	STAINLESS STEEL	64.40	
	PLASTICS	8.25	
17.03	SUPPORTS - CABINETS ETC.		
	ALUMINUM	160.00	
	STAINLESS STEEL	10.50	
	CARBON STEEL	1359.00	
	EPOXY/GLASS LAMINATE	0.24	

FOOTNOTES

10. A geometric packing factor of 0.8 is assumed for this modification. Required number of 8-foot by 25-foot panels is 17. Actual Mead installation required 28 panels.
- 12.02 - Encapsulant assumed to be .020 inch EVA with .002 inch acrylic UV barrier.
- 12.03 - Assumed thicknesses in microns:
Active Layer	GaAs	1
Back Contact	Sn	5
Barrier Layer	Au	.006
Positive Electrode	Cu	5 @ 95% trans
h-Dopant	Ge	$1.0 @ 5 \times 10^{15} \text{ cm}^{-3}$
A/R Coating	Ta ₂ O ₅	.051
Epitaxy Layer	Ge	25
Substrate	Glass	3000
- 12.04 - Scaled at 17/28 of actual Mead installation
- 12.09 - Same as note 12.04.
- 13.02 - Assumed one 8-panel row and one 9-panel row, and 25 feet to control house from row ends. Therefore, electrical wire scales by 0.39.
- 13.05 - Same as note 12.04.
- 15.01 - Steel buildings assumed on concrete pads with R-11 insulation and plywood interior paneling.
- 15.02 - Battery case is high density, high impact, structural foam. Polypropylene.
- 16.02 - Weights estimated from total weight of the solid state inverter.
- 17.01- Same as note 15.01.

MIT-ILL AND UNL PHOTOVOLTAIC SYSTEM
 AT NEED, NEBRASKA
 MODIFIED WITH 1985 TECHNOLOGY
 INDIUM TIN OXIDE/P-SILICON HETEROJUNCTION CELLS
 A GEOMETRIC PACKING FACTOR OF 0.8 IS
 ASSUMED FOR THIS CELL, WHICH REDUCES THE
 TOTAL NUMBER OF 9-FOOT BY 25-FOOT PANELS
 FROM 28 TO 17. THE UNITS PEAK POWER OF
 25 KW IS DERIVED FROM 250 SQUARE METERS
 OF INDIUM TIN OXIDE/P-SILICON HETEROJUNCTION CELLS AT
 10 EFFICIENCY.
 THE ARRAY OUTPUT (5.2 MPW AT 150 VOLTS
 PER PANEL) IS FED TO TWO BUILDINGS. ONE
 HOUSE'S SYSTEM CONTROL EQUIPMENT AND
 THREE 7.5 KVA INVERTERS. THE OTHER BUILDING
 HOUSES 38 LARGE LEAD-ACID STORAGE BATTERY
 TERIES CAPABLE OF STORING 85 KM-HR.

THIS SYSTEM WAS BUILT BY THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY LINCOLN LABORATORY. THE POWER PRODUCED IS USED TO PUMP WATER TO IRRIGATE 80 ACRES OF CORN AND SOYBEANS AT THE UNIVERSITY OF NEBRASKA FIELD LABORATORY NEAR NEED, NEBRASKA. PHOTOVOLTAICS
 CAPACITY - 25 KW PEAK
 CROP IRRIG + DRYING
 NEED, NEBRASKA
 2,000 KM/HR/M2/YR
 LINE POWER
 10'
 313 M2
 250 M2
 AMBIENT
 ELECTRICAL
 LEAD-ACID BATTERIES
 85 KM/HR
 MATERIAL REQUIREMENTS
 BY

12

ENERGY COLLECTOR

FUNCTIONAL COMPONENTS

12.02 ENCAPSULANT

EVA
 NOVALIC

149.00

12.03 ABSORBER - INDIUM TIN OXIDE/P-SI
 AT 10% EFFICIENCY

ACTIVE LAYER

SILICON

29.00

BACK CONTACT

ALUMINUM

3.20

WINDOW LAYER

INDIUM
 TIN

0.57
 0.03

P - DOPANT

BORON

0.09

FRONT CONTACT

ALUMINUM

0.17

12.04 ENERGY TRANSPORT
 PANEL INTERCONNECTS

COPPER
 TEFLON

21.03
 1.95

ELECTRICAL BOXES
 WIREMATS, INSULATORS
 ETC.

CARBON STEEL
 STAINLESS STEEL
 COPPER
 PLASTICS, LAMINATES
 NYLON
 ALUMINUM
 RUBBER
 60-40 SOLDER

792.94
 122.05
 343.61
 0.55
 0.20
 12.00
 11.10

12.07 FRAME
 SOLAR CELL MODULE
 BRACKING PANELS CARBON STEEL

749.00

17.02	METERS, SWITCHES, RELAYS, TERMINAL BOARDS, ETC.	
	COPPER	29.50
	CARBON STEEL	50.00
	PHENOLIC	11.30
	STAINLESS STEEL	64.40
	PLASTICS	8.85
17.03	SUPPORTS - CABINETS ETC.	
	ALUMINUM	160.00
	STAINLESS STEEL	10.50
	CARBON STEEL	1359.00
	EPOXY/GLASS LAMINATE	0.24

FOOTNOTES

10. A geometric packing factor of 0.8 is assumed for this modification. Required number of 8-foot by 25-foot panels is 17. Actual Mead installation required 28 panels.
- 12.02 - Encapsulant assumed to be .020 EVA with .002 inch acrylic UV barrier.
- 12.03 - Assumed thicknesses in microns:
Active Layer	Si	50
Back Contact	Al	5
Window Layer	$\text{In}_{1.9}\text{Sn}_{0.1}\text{O}_3$	.4
p- Dopant	B	$50 @ 10^{15} \text{ cm}^{-3}$
Front Contact	Al	5 at 95% trans
- 12.04 - Scaled at 17/28 of actual Mead installation.
- 12.07 - Carbon steel backing panel assumed .012 inches thick. It was also assumed that the supports (12.09) would be designed more efficiently to incorporate the additional support required for the thin steel backing.
- 12.09 - Same as note 12.04.
- 13.02 - Assumed one 8-panel row and one 9-panel row, and 25 feet to control house from row ends. Therefore, electrical wire scales by 0.39.
- 13.05 - Same as note 12.04.
- 15.01 - Battery case is high density, high impact, structural foam. Polypropylene assumed.
- 16.02 - Weights estimated from total weight of the solid state inverter.
- 17.01 - Same as note 15.01.

NIT-LL AND UNIL PHOTOVOLTAIC SYSTEM
AT NEAD, NEBRASKA
MODIFIED WITH 1985 TECHNOLOGY
SILICON MIS CELLS

A GEOMETRIC PACKING FACTOR OF 0.8 IS ASSUMED FOR THIS CELL, WHICH REDUCES THE TOTAL NUMBER OF 8-FOOT BY 25-FOOT PANELS FROM 28 TO 17. THE UNITED PEAK POWER OF 25 KW IS DERIVED FROM 250 SQUARE METERS OF SI MIS CELLS AT 10% EFFICIENCY.

THE ARRAY OUTPUT (6.2 AMPS AT 150 VOLTS PER PANEL) IS FED TO TWO BUILDINGS. ONE HOUSES SYSTEM CONTROL EQUIPMENT AND THREE 7.5 KVA INVERTERS. THE OTHER BUILDING HOUSES 38 LARGE LEAD-ACID STORAGE BATTERIES CAPABLE OF STORING 85 KW-HR.

THIS SYSTEM WAS BUILT BY THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY'S LINCOLN LABORATORY. THE POWER PRODUCED IS USED TO PUMP WATER TO IRRIGATE 80 ACRES OF CORN AND SOYBEANS AT THE UNIVERSITY OF NEBRASKA FIELD LABORATORY NEAR NEAD.

TECHNOLOGY	PHOTOVOLTAICS
CAPACITY	25 KW PEAK
APPLICATION	CROP IRRIG. & DRYING
LOCATION	NEAD, NEBRASKA
INSOLATION	2,000 KW/HR/M2/YR
SOLAR CONTRIBUTION	
SUPPLEMENT	LINE POWER
SOLAR EFFICIENCY	10%
PANEL AREA	313 M2
CELL AREA	250 M2
OPERATING TEMPERATURE	AMBIENT
ENERGY TRANSPORT MEDIUM	ELECTRICAL
STORAGE TYPE	LEAD-ACID BATTERIES
STORAGE CAPACITY	85 KW/HR

MATERIAL REQUIREMENTS
BY

FUNCTIONAL COMPONENTS

12.	ENERGY COLLECTOR		
12.02	ENCAPSULANT	EVA	149.00
		ACRYLIC	18.90
12.03	ABSORBER - SILICON MIS		
	AT 10% EFFICIENCY		
	ACTIVE LAYER	SILICON	29.00
	BACK CONTACT	ALUMINUM	3.38
	NEGATIVE ELECTRODE	COPPER	0.55
	BARRIER LAYER	CHROMIUM	0.01
	P-DOPANT	BORON	0.00
12.04	ENERGY TRANSPORT		
	PANEL INTERCONNECTS	COPPER	21.03
		TEFLON	1.95
	ELECTRICAL BOXES		
	WIREWAYS, INSULATORS		
	ETC.	CARBON STEEL	792.94
		STAINLESS STEEL	122.55
		COPPER	243.81
		PLASTICS, LAMINATES	0.55
		NYLON	0.20
		ALUMINUM	0.10
		RUBBER	13.00
		60-40 SOLDER	14.10
12.07	FRAME		
	SOLAR CELL MODULE		
	BACKING PANELS	CARBON STEEL	748.00

12.09	SUPPORTS		
	UPRIGHTS	6061 ALUMINUM	1345.00
		STAINLESS STEEL	124.00
		CONCRETE	60200.00
	FRAMEWORK	6061 ALUMINUM	7028.36
		STAINLESS STEEL	267.02
		CARBON STEEL	173.01
13.	ENERGY TRANSPORT		
13.02	ELECTRICAL WIRE	COPPER	103.00
		PVC	9.39
13.05	SUPPORTS		
	CONDUIT	ALUMINUM	551.89
		CARBON STEEL	4.19
	CONDUIT SEALS	RUBBER	0.00
			1.41
15.	ENERGY STORAGE		
15.01	MISCELLANEOUS		
	BATTERY BUILDING		
	10 FT X 20 FT	CARBON STEEL	1043.00
		CONCRETE	252.00
		FIBERGLASS WOOL	354.00
		PLYWOOD-SOFTWOOD	198.00
	BATTERY COVERS	ACRYLIC	53.00
	BATTERY INTERCONNECTS	COPPER	0.00
		PHENOLIC	14.60
		MICARTA	0.05
		EPOXY	0.92
			0.91
15.02	PRIMARY STORAGE		
	30 BATTERIES 375 AMP-HR		
		.3 PERCENT CALCIUM LEAD	1438.00
		5 PERCENT ANTIMONY LEAD	1197.00
		SULFURIC ACID	726.00
		POLYPROPYLENE	207.00
15.04	SUPPORT		
		STAINLESS STEEL	306.00
		CARBON STEEL	183.00
16.	ENERGY CONDITIONING		
16.02	INVERTER		
	ENCLOSURE	CARBON STEEL	106.00
	CORE CLAMPS	CARBON STEEL	34.00
	CORES AND WINDINGS	COPPER	150.00
		SILICON STEEL	417.00
		VARNISH	6.00
	INSULATION	POLYESTER	4.00
	INSTRUMENTATION	PHENOLIC	0.00
		COPPER	4.00
		ZINC	1.36
		SODA-LIME GLASS	0.00
	SILICON CONTROLLED		
	RECTIFIERS	COPPER	5.00
		SILICON	0.11
		ELECTRICAL PORCELAIN	0.34
17.	17.01 MISCELLANEOUS		
ENERGY	SYSTEM CONTROLLER		
	BUILDING 15 FT X 25 FT	CARBON STEEL	1497.00
		CONCRETE	472.00
		FIBERGLASS WOOL	344.00
		PLYWOOD-SOFTWOOD	205.00

17.02	METERS, SWITCHES, RELAYS, TERMINAL BOARDS, ETC.	
	COPPER	29.50
	CARBON STEEL	50.00
	PHENOLIC	11.30
	STAINLESS STEEL	64.40
	PLASTICS	8.85
17.03	SUPPORTS - CABINETS ETC.	
	ALUMINUM	160.00
	STAINLESS STEEL	10.50
	CARBON STEEL	1359.00
	EPOXY/GLASS LAMINATE	0.24

FOOTNOTES

10. A geometric packing factor of 0.8 is assumed for this modification. Required number of 8-foot by 25-foot panels is 17. Actual Mead installation required 28 panels.
- 12.02 - Encapsulant assumed to be .020 inch EVA with .002 inch acrylic UV barrier.
- 12.03 - Assumed thicknesses in microns:
Active Layer	Si	50
Back Contact	Al	5
Negative Electrode	Cu	5 at 95% trans
Barrier Layer	Cr	.005
p-Dopant	B	$50 @ 10^{15} \text{ cm}^{-3}$
- 12.04 - Scaled at 17/28 of actual Mead installation.
- 12.07 - Carbon steel backing panel assumed .012 inches thick. It was also assumed that the supports (12.09) would be designed more efficiently to incorporate the additional support required for the thin steel backing.
- 12.09 - Same as note 12.04.
- 13.02 - Assumed one 8-panel row and one 9-panel row, and 25 feet to control house from row ends. Therefore, electrical wire scales by 0.39.
- 13.05 - Same as note 12.04.
- 15.01 - Steel buildings assumed on concrete pads with R-11 insulation and plywood interior paneling.
- 15.02 - Battery case is high density, high impact, structural foam. Polypropylene assumed.
- 16.02 - Weights estimated from total weight of the solid state inverter.
- 17.01 - Same as note 15.01.

NIT-LI AND UNL PHOTOVOLTAIC SYSTEM
AT NEAD, NEBRASKA

MODIFIED WITH 1985 TECHNOLOGY

SI N/P SINGLE CRYSTAL CELLS AT 14 PERCENT EFFICIENCY

A GEOMETRIC PACKING FACTOR OF 0.8 IS ASSUMED FOR THIS CELL, WHICH REDUCES THE TOTAL NUMBER OF 8-FOOT BY 25-FOOT PANELS FROM 28 TO 17. THE UNITS PEAK POWER OF 25 KW IS DERIVED FROM 250 SQUARE METERS OF SI N/P SINGLE CRYSTAL CELLS AT 14% EFFICIENCY.

THE ARRAY OUTPUT (6.2 AMPS AT 150 VOLTS PER PANEL) IS FED TO TWO BUILDINGS. ONE HOUSES SYSTEM CONTROL EQUIPMENT AND THREE 7.5 KVA INVERTERS. THE OTHER BUILDING HOUSES 38 LARGE LEAD-ACID STORAGE BATTERIES CAPABLE OF STORING 85 KW-HR.

THIS SYSTEM WAS BUILT BY THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY'S LINCOLN LABORATORY. THE POWER PRODUCED IS USED TO PUMP WATER TO IRRIGATE 80 ACRES OF CORN AND SOYBEANS AT THE UNIVERSITY OF NEBRASKA FIELD LABORATORY NEAR NEAD.

TECHNOLOGY	PHOTOVOLTAICS
CAPACITY	25 KW PEAK
APPLICATION	CROP IRRIG. + DRYING
LOCATION	NEAD, NEBRASKA
INSULATION	2,000 KW/HR/M2/YR
SOLAR CONTRIBUTION	
SUPPLEMENT	LINE POWER
SOLAR EFFICIENCY	14%
PANEL AREA	224M2
CELL AREA	179M2
OPERATING TEMPERATURE	AMBIENT
ENERGY TRANSPORT MEDIUM	ELECTRICAL
STORAGE TYPE	LEAD-ACID BATTERIES
STORAGE CAPACITY	85 KW/HR
	MATERIAL REQUIREMENTS
	BY
	FUNCTIONAL COMPONENTS

12.	ENERGY COLLECTOR		
12.02	ENCAPSULANT	EVA	197.00
		ACRYLIC	13.50
12.03	ABSORBER - SI N/P		
	AT 14% EFFICIENCY		
	ACTIVE LAYERS		
	BACK CONTACT	SILICON	63.25
		ALUMINUM	2.41
	N - DOPANT	PHOSPHORUS	0.00
	P - DOPANT	BORON	0.00
	ANTI - REFLECTIVE		
	COATING	TANTALUM	0.12
	GRID CONTACT	TITANIUM	0.00
		PALLADIUM	0.00
		SILVER	0.17
12.04	ENERGY TRANSPORT		
	PANEL INTERCONNECTS		
		COPPER	15.91
		TEFLON	1.40
	ELECTRICAL BOXES		
	WIREWAYS, INSULATORS		
	ETC.		
		CARBON STEEL	566.19
		STAINLESS STEEL	87.50
		COPPER	245.35
		PLASTICS, LAMINATES	0.55
		NYLON	0.21
		ALUMINUM	6.56
		RUBBER	9.00
		60-40 SOLDER	10.10

12. 07	FRAME		
	SOLAR CELL MODULE		
12. 09	BACKING PANELS	CARBON STEEL	575. 00
	SUPPORTS		
	UPRIGHTS		
		6061 ALUMINUM	960. 00
		STAINLESS STEEL	88. 36
		CONCRETE	43000. 00
	FRAMEWORK		
		6061 ALUMINUM	5018. 46
		STAINLESS STEEL	191. 30
		CARBON STEEL	123. 53
13.	ENERGY TRANSPORT		
13. 02	ELECTRICAL WIRE		
		COPPER	73. 90
		PVC	6. 72
13. 05	SUPPORTS		
	CONDUIT		
		ALUMINUM	309. 67
		CARBON STEEL	2. 96
	CONDUIT SEALS	RUBBER	1. 00
15.	ENERGY STORAGE		
15. 01	MISCELLANEOUS		
	BATTERY BUILDING		
	10 FT X 20 FT		
		CARBON STEEL	1043. 00
		CONCRETE	252. 00
		FIBERGLASS WOOL	354. 00
		PLYWOOD-SOFTWOOD	198. 00
	BATTERY COVERS	ACRYLIC	53. 00
	BATTERY INTERCONNECTS		
		COPPER	14. 60
		PHENOLIC	0. 05
		MICARTA	0. 92
		EPOXY	0. 91
15. 02	PRIMARY STORAGE		
	38 BATTERIES 375 AMP-HR		
		3 PERCENT CALCIUM LEAD	1438. 00
		5 PERCENT ANTIMONY LEAD	1197. 00
		SULFURIC ACID	726. 00
		POLYPROPYLENE	207. 00
15. 04	SUPPORT		
		STAINLESS STEEL	306. 00
		CARBON STEEL	183. 00
16.	ENERGY CONDITIONING		
16. 02	INVERTER		
	ENCLOSURE		
		CARBON STEEL	106. 00
	CORE CLAMPS		
		CARBON STEEL	34. 00
	CORES AND WINDINGS		
		COPPER	150. 00
		SILICON STEEL	417. 00
		VARNISH	6. 00
	INSULATION		
		POLYESTER	4. 00
	INSTRUMENTATION		
		PHENOLIC	4. 00
		COPPER	1. 36
		ZINC	0. 68
		SODA-LIME GLASS	0. 68
	SILICON CONTROLLED		
	RECTIFIERS		
		COPPER	5. 00
		SILICON	0. 11
		ELECTRICAL PORCELAIN	0. 24
17.	ENERGY SYSTEM CONTROLLER		
17. 01	MISCELLANEOUS		
	BUILDING 15 FT X 25 FT		
		CARBON STEEL	1497. 00
		CONCRETE	472. 00
		FIBERGLASS WOOL	544. 00
		PLYWOOD-SOFTWOOD	305. 00

17.02	METERS, SWITCHES, RELAYS, TERMINAL BOARDS, ETC.	
	COPPER	29.50
	CARBON STEEL	50.00
	PHENOLIC	11.20
	STAINLESS STEEL	64.40
	PLASTICS	8.85
17.03	SUPPORTS - CABINETS ETC.	
	ALUMINUM	160.00
	STAINLESS STEEL	10.50
	CARBON STEEL	1359.00
	EPOXY/GLASS LAMINATE	0.24

FOOTNOTES

10. A geometric packing factor of 0.8 is assumed for this modification. Required number of 8-foot by 25-foot panels is 12. Actual Mead installation required 28 panels.
- 12.02 - Encapsulant assumed to be .020 inch EVA with .002 inch acrylic UV barrier.
- 12.03 - Assumed thicknesses in microns:
Active Layers	Si	200
Back Contact	Al	5
n-Dopant	P	0.2 at 10^{20} cm^{-3}
p-Dopant	B	50 at 10^{16} cm^{-3}
A/R Coating	Ta ₂ O ₅	0.1
Grid Coating	Ti/Pd/Ag	.004/.002/5 at 95% trans
- 12.04 - Scaled at 12/28 of actual Mead installation.
- 12.07 - Carbon steel backing panel assumed .012 inches thick. It was also assumed that the supports (12.09) would be designed more efficiently to incorporate the additional support required for the thin steel backing.
- 12.09 - Same as note 12.04.
- 13.02 - Assumed two 6-panel rows and 25 feet to control house from row ends. Therefore, electrical wire scales by .28 if wire cross section increases by .14/.10.
- 13.05 - Same as note 12.04.
- 15.01 - Steel buildings assumed on concrete pads with R-11 insulation and plywood interior paneling.
- 15.02 - Battery case is high density, high impact, structural foam. Polypropylene assumed.
- 16.02 - Weights estimated from total weight of the solid state inverter.
- 17.01 - Same as note 15.01

MIT-LL AND UNL PHOTOVOLTAIC SYSTEM
AT MEAD, NEBRASKA
MODIFIED WITH 30X PARABOLIC TROUGH
CONCENTRATOR AND 1985 TECHNOLOGY
SILICON N/P SINGLE CRYSTAL CELLS

THIS SYSTEM USES A LINE FOCUS PARABOLIC TROUGH ARRAY (12 x 2 AXIS TRACKING TURNABLE MOUNT) AND ACTIVE COOLING. THE PEAK POWER OF 25KW IS DERIVED FROM 7.0 SQUARE METERS OF SILICON SINGLE CRYSTALS OPERATING AT 14 PERCENT EFFICIENCY. THE CONCENTRATION RATIO IS 30 TO 1 WITH AN OPTICAL EFFICIENCY OF 85 PERCENT.

THE ARRAY OUTPUT IS FED TO TWO BUILDINGS. ONE HOUSES SYSTEMS CONTROL EQUIPMENT AND THREE 7.5 KVA INVERTERS. THE OTHER BUILDING HOUSES 30 LARGE LEAD-ACID BATTERIES CAPABLE OF STORING 85 KW-HR. HOUSES 80--72LEAD-ACID BATTERIES CAPABLE OF STORING 85 KW-HR. HOUSES 80--72LEAD-ACID BATTERIES CAPABLE OF STORING 85 KW-HR.

TECHNOLOGY	PHOTOVOLTAICS
CAPACITY	25 KW PEAK
APPLICATION	CROP IRRIGATION AND DRYING
LOCATION	MEAD, NEBRASKA
INSULATION	2,000 KW-HR/10MM/YR.
SOLAR CONTRIBUTION	
SUPPLEMENT	LINE POWER
SOLAR EFFICIENCY	12 PERCENT
OPERATURE AREA	210 MM ²
CONCENTRATION RATIO	30
ACTIVE CELL AREA	7.0 MM ²
OPERATING TEMPERATURE	
ENERGY TRANSPORT MEDIUM	ELECTRICAL
STORAGE TYPE	LEAD-ACID BATTERIES
STORAGE CAPACITY	85 KW-HR
	MATERIAL REQUIREMENTS
	BY
	FUNCTIONAL COMPONENTS

12.	ENERGY COLLECTOR		
12.02	ENCAPSULANT	ELASTOMER GRADE SILICONE	14.20
12.03	ABSORBER - SI N/P AT 14 PERCENT EFFICIENCY		
	ACTIVE LAYERS	SILICON	6.52
	BACK CONTACT	ALUMINUM	0.19
	N-DOPANT	PHOSPHORUS	0.00
	P-DOPANT	BORON	0.00
	ANTI REFLECTIVE COATING	TANTALUM	0.01
	GRID CONTACT	TITANIUM	0.00
		PALLADIUM	0.00
		SILVER	0.04
12.04	ENERGY TRANSPORT		
	PANEL INTERCONNECTS	COPPER	15.01
		TEFLON	1.40
	ELECTRICAL BOXES, WIREWAYS, INSULATORS ETC.	CARBON STEEL	560.10
		STAINLESS STEEL	87.50
		COPPER	245.35
		PLASTICS, LAMINATES	0.30
		NYLON	0.21
		ALUMINUM	6.56
		RUBBER	0.00
		60-40 SOLDER	10.10
12.05	CONCENTRATOR OPTICS		
	SUPPORTS, REFLECTORS, BRACKETS, ETC.	ALUMINUM	2500.00
12.07	SOLAR CELL MOUNT	AND HEATSINK	
		COPPER	100.00
		ALUMINUM	1000.00
		TEFLON	1.00
		POLYPROPYLENE	5.50
		SODA LIME GLASS	72.00
		PVC PLASTIC	255.00

12.09	PRIMARY SUPPORT STRUCTURE		
	CARBON STEEL		2208.00
12.10	TRACKING AND CONTROLS		
	SCREW JACKS		
	GEAR REDUCERS	CARBON STEEL	78.00
	A. C. MOTORS	CARBON STEEL	81.00
		CAST IRON	11.00
		COPPER	11.00
		CARBON STEEL	4.30
	LINKAGE RODS		
		CARBON STEEL	87.00
	SHAFT SLEEVE BEARINGS		
		CARBON STEEL	50.00
	PINTLE BEARING		
		CARBON STEEL	54.00
	WHEEL ASSEMBLIES		
		CARBON STEEL	87.00
	TRACK		0.00
		CONCRETE	53000.00
	CONTROLS, INSTRUMENTATION		0.00
		COPPER	9.00
		CARBON STEEL	15.00
		PHENOLIC	3.00
		STAINLESS STEEL	3.00
12.11	ACTIVE COOLING COMPONENTS		
	PUMPS AND MOTOR		
		CAST IRON	40.00
		CARBON STEEL	10.00
		TEFLON	0.30
		ALUMINUM	0.20
	VALVES		0.00
		LEADED TIN BRONZE	17.00
		CARBON STEEL	13.00
	TROUGH PIPING		
		COPPER	80.00
	SUPPLY RETURN PIPING		
		CPVC	55.00
	EXPANSION TANK		
		CARBON STEEL	45.00
		NEOPRENE	50.00
	HOSES		
		RUBBER	10.00
13.	ENERGY TRANSPORT		
	13.02 ELECTRICAL WIRE		
		COPPER	174.00
		PVC	15.00
	13.05 SUPPORTS		
	CONDUIT		
		ALUMINUM	309.50
		CARBON STEEL	2.06
	CONDUIT SEALS		
		RUBBER	1.00
15.	ENERGY STORAGE		
	15.01 MISCELLANEOUS		
	BATTERY BUILDING		
	10 FT X 20 FT		
		CARBON STEEL	1043.00
		CONCRETE	252.00
		FIBERGLASS WOOL	354.00
		PLYWOOD-SOFTWOOD	198.00
	BATTERY COVERS	ACRYLIC	53.00
	BATTERY INTERCONNECTS		
		COPPER	14.60
		PHENOLIC	0.35
		MICARTA	0.92
		EPOXY	0.91
	15.02 PRIMARY STORAGE		
	30 BATTERIES 375 AMP-HR		
		5 PERCENT ANTIMONY LEAD	1197.00
		13 PERCENT CALCIUM LEAD	1438.00
		SULFURIC ACID	706.00
		POLYPROPYLENE	207.00
	15.04 SUPPORT		
		STAINLESS STEEL	366.00
		CARBON STEEL	133.00

16.	ENERGY CONDITIONING		
16.02	INVERTER		
	ENCLOSURE		
	CORE CLAMPS	CARBON STEEL	195.00
		CARBON STEEL	34.00
	CORES AND WINDINGS		
		COPPER	130.00
		SILICON STEEL	417.00
		VARNISH	6.00
	INSULATION	POLYESTER	4.00
	INSTRUMENTATION		
		PHENOLIC	4.00
		COPPER	1.35
		ZINC	0.60
		SODA-LIME GLASS	0.60
	SILICON CONTROLLED		
	RECTIFIERS		
		COPPER	5.00
		SILICON	0.11
		ELECTRICAL PORCELAIN	0.14
17.	ENERGY SYSTEM CONTROLLER		
17.01	MISCELLANEOUS		
	BUILDING 15 FT X 25 FT		
		CARBON STEEL	1437.00
		CONCRETE	472.00
		FIBERGLASS WOOL	544.00
		PLYWOOD-SOFTWOOD	305.00
17.02	METERS, SWITCHES, RELAYS,		
	TERMINAL BOARDS, ETC.		
		COPPER	29.50
		CARBON STEEL	50.00
		PHENOLIC	11.30
		STAINLESS STEEL	64.40
		PLASTICS	0.05
17.03	SUPPORTS - CABINETS ETC.		
		ALUMINUM	160.00
		STAINLESS STEEL	10.50
		CARBON STEEL	1359.00
		EPOXY/GLASS LAMINATE	0.24

SI 1 xTL-30x PARATROUGH

FOOTNOTES

12. Material requirements are rough estimates based on data developed for costing purposes by GE Company, Valley Forge Space Center. Assumed 14% cell efficiency, 85% optical efficiency and gross cell area twice active cell area. Material requirements scaled by aperture area, 210/550 of GE Company design.
- 12.02 - Assumed .020 inch thick RTV silicone encapsulant over gross cell area.
- 12.03 - Assumed thicknesses in microns:
Active Layers	Si	200
Back Contact	Al	5
h-Dopant	P	0.2 at 10^{20}cm^{-3}
p-Dopant	B	50 at 10^{16}cm^{-3}
A/R Coating	Ta ₂ O ₅	0.1
Grid Contact	Ti/Pd/Ag	.004/.002/5 at 95% trans
- 13.02 - Assume 4 rows of three troughs and 2 rows of 1 trough to get wire length factor of 0.33. Wire size factor is 1.85/.93 . Therefore, Mead installation scaled by 0.66.
- 13.05 - Same as note 12.04.
- 15.01 - Steel buildings assumed on concrete pads with R-11 insulation and plywood interior paneling.
- 15.02 - Battery case is high density, high impact, structural foam. Polypropylene assumed.
- 16.02 - Weights estimated from total weight of the solid state inverter.
- 17.02 - Same as note 15.01.

MIT-LL AND UNL PHOTOVOLTAIC SYSTEM
 AT MEAD, NEBRASKA
 MODIFIED WITH 1985 TECHNOLOGY
 TIN OXIDE/N-SILICON HETEROJUNCTION CELLS
 A GEOMETRIC PACKING FACTOR OF 0.8 IS
 ASSUMED FOR THIS CELL, WHICH REDUCES THE
 TOTAL NUMBER OF 8-FOOT BY 25-FOOT PANELS
 FROM 28 TO 17. THE UNIT'S PEAK POWER OF
 25 KW IS DERIVED FROM 250 SQUARE METERS
 OF TIN OXIDE/N-SILICON HETEROJUNCTION CELLS AT .10
 EFFICIENCY.
 THE ARRAY OUTPUT (6.2 AMPS AT 150 VOLTS
 PER PANEL) IS FED TO TWO BUILDINGS. ONE
 HOUSES SYSTEM CONTROL EQUIPMENT AND
 THREE 7.5 KVA INVERTERS. THE OTHER BUILDING
 HOUSES 38 LARGE LEAD-ACID STORAGE BAT-
 TERIES CAPABLE OF STORING 85 KW-HR.

THIS SYSTEM WAS BUILT BY THE MASSA-
 CHUSETTS INSTITUTE OF TECHNOLOGY'S
 LINCOLN LABORATORY. THE POWER PRODUCED
 IS USED TO PUMP WATER TO IRRIGATE 80 ACRES
 OF CORN AND SOYBEANS AT THE UNIVERSITY
 OF NEBRASKA FIELD LABORATORY NEAR MEAD.
 TECHNOLOGY_ PHOTOVOLTAICS
 CAPACITY_ 25 KW PEAK
 APPLICATION_ CROP IRRIG. + DRYING
 LOCATION_ MEAD, NEBRASKA
 INSOLATION_ 2,000 KW/HR/M2/YR
 SOLAR CONTRIBUITION_
 SUPPLEMENT_ LINE POWER
 SOLAR EFFICIENCY_ 10%
 PANEL AREA_ 313 M2
 CELL AREA_ 250 M2
 OPERATING TEMPERATURE_ AMBIENT
 ENERGY TRANSPORT MEDIUM_ ELECTRICAL
 STORAGE TYPE_ LEAD-ACID BATTERIES
 STORAGE CAPACITY_ 85 KW/HR
 MATERIAL REQUIREMENTS
 BY
 FUNCTIONAL COMPONENTS

12.	ENERGY COLLECTOR		
12.02	ENCAPSULANT	EVA	149.60
		ACRYLIC	18.90
12.03	ABSORBER - TIN OXIDE/N-SILICON		
	AT 10% EFFICIENCY		
	ACTIVE LAYER	SILICON	29.00
	N - DOPANT	PHOSPHORUS	0.00
	BACK CONTACT	ALUMINUM	0.00
	WINDOW LAYER	TIN	0.41
	FRONT CONTACT	ALUMINUM	0.17
12.04	ENERGY TRANSPORT		
	PANEL INTERCONNECTS	COPPER	21.03
		TEFLON	1.95
	ELECTRICAL BOXES		
	WIREWAYS, INSULATORS		
	ETC.	CARBON STEEL	792.94
		STAINLESS STEEL	122.50
		COPPER	342.61
		PLASTICS, LAMINATES	0.55
		NYLON	0.30
		ALUMINUM	0.10
		ROBBER	13.50
		60-40 SOLDER	14.18
12.07	FRAME		
	SOLAR CELL MODULE		
	BACKING PANELS	CARBON STEEL	748.00

12.09	SUPPORTS UPRIGHTS	6061 ALUMINUM STAINLESS STEEL CONCRETE	1245 00 124 00 68200 00
13.	ENERGY TRANSPORT ELECTRICAL WIRE	6061 ALUMINUM STAINLESS STEEL CARBON STEEL	7828 70 287 92 173 01
13.05	SUPPORTS CONDUIT	COPPER PVC	103 00 103 00
15.	CONDUIT SEALS	ALUMINUM CARBON STEEL RUBBER	554 02 4 19 1 41
15.01	ENERGY STORAGE MISCELLANEOUS BATTERY BUILDING 10 FT X 20 FT	CONCRETE FIBERGLASS WOOL PLYWOOD-SOFTWOOD ACRYLIC INTERCONNECTS COPPER PHENOLIC MICRITA EPOXY	252 00 394 00 198 00 562 00 14 00 14 00 0 02 0 01
15.02	PRIMARY STORAGE 30 BATTERIES 375	AMP-HR 3 PERCENT ANTIMONY LEAD 5 PERCENT ANTIMONY LEAD SULFURIC ACID POLYPROPYLENE	1438 00 1197 00 1725 00 297 00
15.04	SUPPORT	STAINLESS STEEL CARBON STEEL	385 00 183 00
16.	ENERGY CONDITIONING INVERTER ENCLOSURE	CARBON STEEL CARBON STEEL	106 00 34 00
16.02	CORE CLAMPS CORES AND WINDINGS COPPER SILICON STEEL VARNISH	159 00 417 00 6 00	
	INSULATION	POLYESTER	4 00
	INSTRUMENTATION	PHENOLIC COPPER ZINC 500V-LINE GLASS	4 00 1 35 0 00 0 00
	SILICON CONTROLLED RECTIFIERS	COPPER SILICON ELECTRICAL PORCELAIN	5 00 0 11 0 34
17.	ENERGY SYSTEM CONTROLLER MISCELLANEOUS BUILDING 15 FT X	25 FT CARBON STEEL CONCRETE FIBERGLASS WOOL PLYWOOD-SOFTWOOD	1497 00 472 00 544 00 385 00

17.02	METERS, SWITCHES, RELAYS, TERMINAL BOARDS, ETC.	
	COPPER	29.50
	CARBON STEEL	50.00
	PHENOLIC	11.30
	STAINLESS STEEL	64.40
	PLASTICS	8.85
17.03	SUPPORTS - CABINETS ETC.	
	ALUMINUM	160.00
	STAINLESS STEEL	10.50
	CARBON STEEL	1359.00
	EPOXY/GLASS LAMINATE	0.24

FOOTNOTES

10. A geometric packing factor of 0.8 is assumed for this modification. Required number of 8-foot by 25-foot panels is 17. Actual Mead installation required 28 panels.
- 12.02 - Encapsulant assumed to be .020 inch EVA with .002 inch acrylic UV barrier.
- 12.03 - Assumed thicknesses in microns:
Active layer	Si	50
h. Dopant	P	$50 @ 10^{15} \text{ cm}^{-3}$
Back contact	Al	5
Window Layer	SnO_2	.3
Front Contact	Al	5 at 95% trans
- 12.04 - Scaled at 17/28 of actual Mead installation.
- 12.07 - Carbon steel backing panel assumed .012 inches thick. It was also assumed that the supports (12.09) would be designed more efficiently to incorporate the additional support required for the thin steel backing.
- 12.09 - Same as note 12.04.
- 13.02 - Assumed one 8-panel row and one 9-panel row, and 25 feet to control house from row ends. Therefore, electrical wire scales by 0.39.
- 13.05 - Same as note 12.04.
- 15.01 - Steel buildings assumed on concrete pads with R-11 insulation and plywood interior paneling.
- 15.02 - Battery case is high density, high impact, structural foam. Polypropylene assumed.
- 16.02 - Weights estimated from total weight of the solid state inverter.
- 17.01 - Same as note 15.01.

DISTRIBUTION

No. of Copies

OFFSITE

27 DOE Technical Information Center

10 Fred Koomanoff
Space Power Systems Project Office
Office of Energy Research
Department of Energy
Washington, D.C. 20545

4 Paul D. Maycock
Office of Energy Technology
Department of Energy
Bicentennial Building
600 E Street, N.W.
Washington, D.C. 20004

1 A. A. Churm
DOE Patent Division
9800 South Cass Avenue
Argonne, Illinois 60439

ONSITE

DOE Richland Operations Office

H. E. Ransom

57 Pacific Northwest Laboratory

S. A. Smith
T. A. Nelson (2)
W. E. Gurwell (2)
C. H. Bloomster
R. L. Watts (44)

Technical Information Files (5)

Publishing Coordination (2)