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A Methodology for Identifying Materials Constraints to Implementation of Solar Energy Technologies

July 1978

Prepared for the U.S. Department of Energy
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A METHODOLOGY FOR IDENTIFYING MATERIALS CONSTRAINTS TO IMPLEMENTATION OF SOLAR ENERGY TECHNOLOGIES

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The need to logically understand the potential impacts of an energy technologies material requirements on the reserves and resources of that material as well as on the processing capability that exists to extract and produce the material is paramount to successful commercialization of a technology. Based upon this recognized need, a methodology has been developed by which one can characterize the technology (describe its material requirements for energy system components, subsystems, or technologies) and based upon forecasts for implementation of the technology determine the materials and processing impacts as a function of time.

This methodology pinpoints bulk and raw material requirements to produce a finished energy supply technology. The method can be used effectively in identifying those materials that may be in short supply and indicates the need for strategies to increase material processing capabilities, the availability of substitute materials and resource exploration. Thus, it can be used as a tool for estimating production requirements as well as planning materials research and development needs.

The attached report describes a computer screening methodology, linked to analytical methods to specify potential impacts. Two examples of photovoltaic systems have been used to explain the workings of the screening/analysis process.

The importance of this methodology with its data base is that it may be applied to any energy technology system or subsystem and used as a planning guide to analyze materials requirements between potentially competing technology options.

F.A. Koomanoff, Director
SPS Project Office
Office of Energy Research
Department of Energy

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INTRODUCTION

The expanding implementation of solar energy technology will involve the use of large amounts of common construction materials and, in some cases, relatively rare materials. Heavy use of such materials could produce upward pressures on the future cost of solar energy and/or limit the rate at which solar energy devices could be produced and placed in the energy market. Thus, the Environmental Research Assessment Branch, Division of Solar Energy, Department of Energy (DOE) initiated this study with the objective of developing a methodology for identifying those specific materials, processes, and resources that can potentially hinder the implementation of solar technologies. Using this method as a tool for early identification of potential materials problems during the solar research and development process allows for development and implementation of strategies for mitigating these materials problems; e.g., design modifications, industrial research and expansion, and resource exploration.

The materials cycle shown in Figure 1 provides the basis for the materials assessment methodology presented in this report. This conceptual materials cycle illustrates the flow of materials from their natural state in the earth's crust as ores or raw materials toward their use as final products and devices. The three major materials states shown are raw materials, bulk materials, and engineering materials (alloys). Although production increases in certain steps of this materials cycle could be achieved rather quickly (1-2 years), increasing production of bulk and raw materials would require significant lead time (5-20 years). For this reason, the bulk materials necessary to produce engineering materials for constructing solar energy systems and the raw materials necessary to produce the required bulk materials have the greatest potential impact on solar growth.

The materials assessment methodology involves two basic activities. First, a screening process is used to identify the bulk and raw materials

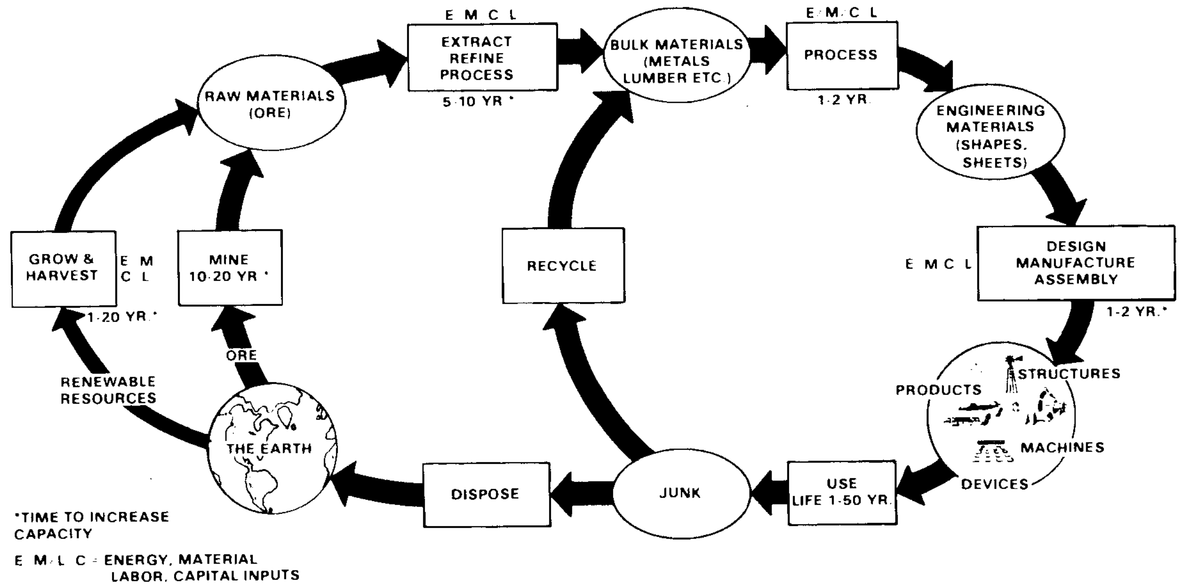

FIGURE 1. The Materials Cycle

that appear to be significant problems. An interactive computer system is used to perform this screening process. Second, a more detailed material assessment is performed on each material identified through screening to determine the severity of the material's problems.

The assessment of future solar materials is performed over the time frame when solar technologies will be emerging to compete with existing energy sources; i.e., the years 1977-2000. The process of estimating the materials needs of solar technologies over this time period involves the combination of a "solar development plan" with estimates of the materials requirements of specific solar designs. The solar development plan involves a forecast, for each design, of the date of commercial introduction and the total amount of peak energy production capacity in the year 2000. These two estimates are used to determine an exponential growth rate based on the natural constant e. The form of this equation allows for an ever increasing number of Giga-Watts electric (GWe) installed in each year. This growth function is frequently used to estimate the rate of introduction of new technologies. The solar development plans used for the examples discussed later in this report are based on a 50 GWe goal of peak power production in 2000 and an initial commercial introduction date in 1985. The resulting installed peak capacity in each year is shown in Figure 2.

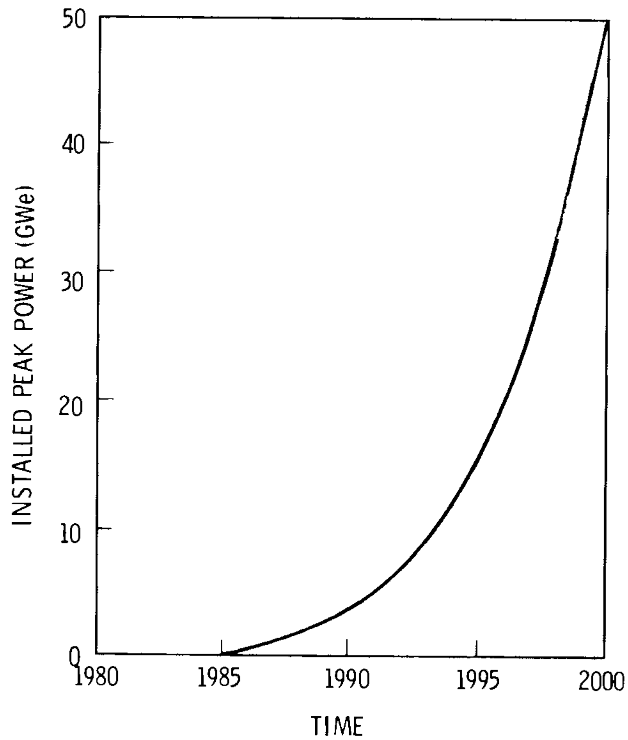

FIGURE 2. Installed Peak Capacity for Photovoltaic Development Plan

Subsequent sections of this report describe a comprehensive materials assessment methodology and demonstrate its application using an example photovoltaic development plan. The methodology is applicable to any of the following solar technologies.

- Solar Heating & Cooling of Buildings
- Agricultural and Process Heat
- Solar Photovoltaic Conversion
- Wind Conversion
- Solar Thermal Conversion
- Ocean Thermal Energy Conversion
- Fuels from Biomass
- Space Satellite Power Systems

To date, development of the methodology and its associated data base has emphasized solar heating and cooling of buildings, agricultural and process heat, and photovoltaic conversion technologies.

SUMMARY

A materials assessment methodology for identifying specific critical material requirements that could hinder the implementation of solar energy has been developed and demonstrated. The methodology involves an initial screening process, followed by a more detailed materials assessment. The screening portion of the methodology utilized specific screening factors and associated criteria to help identify potential material problems. The screening factors have been effective in identifying significant material problems worthy of subsequent detailed assessment.

The screening process has been computerized on a user-interactive system which allows the user to select a specific solar development plan between the years 1977-2000, a solar design or mix of designs which will accomplish the solar development plan, and variable decision criteria for each screening factor. In this way, the user can rapidly evaluate the material and resource requirements of various solar development scenarios and, in turn, the potential impact of these requirements on the technical and economic feasibility of alternative designs.

A detailed materials assessment is required on potential materials problems which are identified as a result of the screening process. The detailed assessment considers such materials concerns and constraints as: process and production constraints, reserve and resource limitations, lack of alternative supply sources, geopolitical problems, environmental and energy concerns, time constraints, and economic constraints. Evaluation of these issues can serve to more specifically identify those material problems of greatest concern and significance to a specific solar technology. This information can then be used to develop mitigation strategies for relieving the material problems such as design changes, R&D programs for material supply, or material management programs by the government.

The computerized screening process requires an extensive data base, which includes:

- The engineering and bulk material requirements for various solar technologies and systems; and
- Basic data on bulk and raw material availability throughout the world.

Data for 55 bulk and 53 raw materials are currently available on the data base. These materials are required in the example photovoltaic systems. One photovoltaic system and thirteen photovoltaic cells, ten solar heating and cooling systems, and two agricultural and industrial process heat systems have been characterized to define their engineering and bulk material requirements. Only the photovoltaic system with two alternative cells have been fully implemented on the interactive computer system; the other systems are currently being added to the data base. Other solar systems can be characterized and their materials requirements added to the data base allowing for subsequent computerized screening. The methodology can be applied in concept to any solar system which is adequately developed so that it's material requirements can ge characterized.

The materials assessment methodology has been demonstrated for a photovoltaic system utilizing two different cell designs. The screening process is performed for the various bulk and raw materials involved in this photovoltaic system and subsequent detailed assessments are performed for those materials which appear to be significant constraints.

DESCRIPTION OF CRITICAL MATERIALS ASSESSMENT METHODOLOGY

The technological environment surrounding the development and implementation of solar energy conversion systems is rapidly changing because solar technologies are continually evolving. The materials requirements for the various raw and bulk materials are, therefore, continually changing also. It was concluded that a structured methodology was required to identify materials problems of greatest concern. This methodology must be flexible enough to respond to changes in the solar designs and yet provide clear documentation of the process by which potential problem materials are identified.

The quantity of materials needed to implement solar energy conversion systems is dependent upon many factors including:

- Solar Design Characteristics,
- Solar Growth Rates, and
- Material Production Processes.

In addition, the significance of materials needs can only be determined by an evaluation of many related production factors such as:

- Resource Availability,
- Production Capacity,
- Materials Cost, and
- Materials Production Processes.

In response to these concerns, the methodology diagramed in Figure 3 was developed. The methodology combines estimates of the materials requirements with a development plan for a specific solar design. The resulting bulk materials requirements are transformed as a result of materials process analysis to raw materials requirements. These two groups of materials are then screened to assess the major concerns with materials usage and to identify potential materials problems. A detailed assessment of materials problems is then performed to evaluate the severity of each material problem and to identify alternative strategies for managing a materials usage.

DETERMINING SOLAR MATERIALS REQUIREMENTS

Solar System Characterization - The objective of solar system characterization is to estimate the engineering and bulk materials necessary to construct complete solar conversion systems. In achieving this objective, it is necessary to select "typical" solar designs which are representative

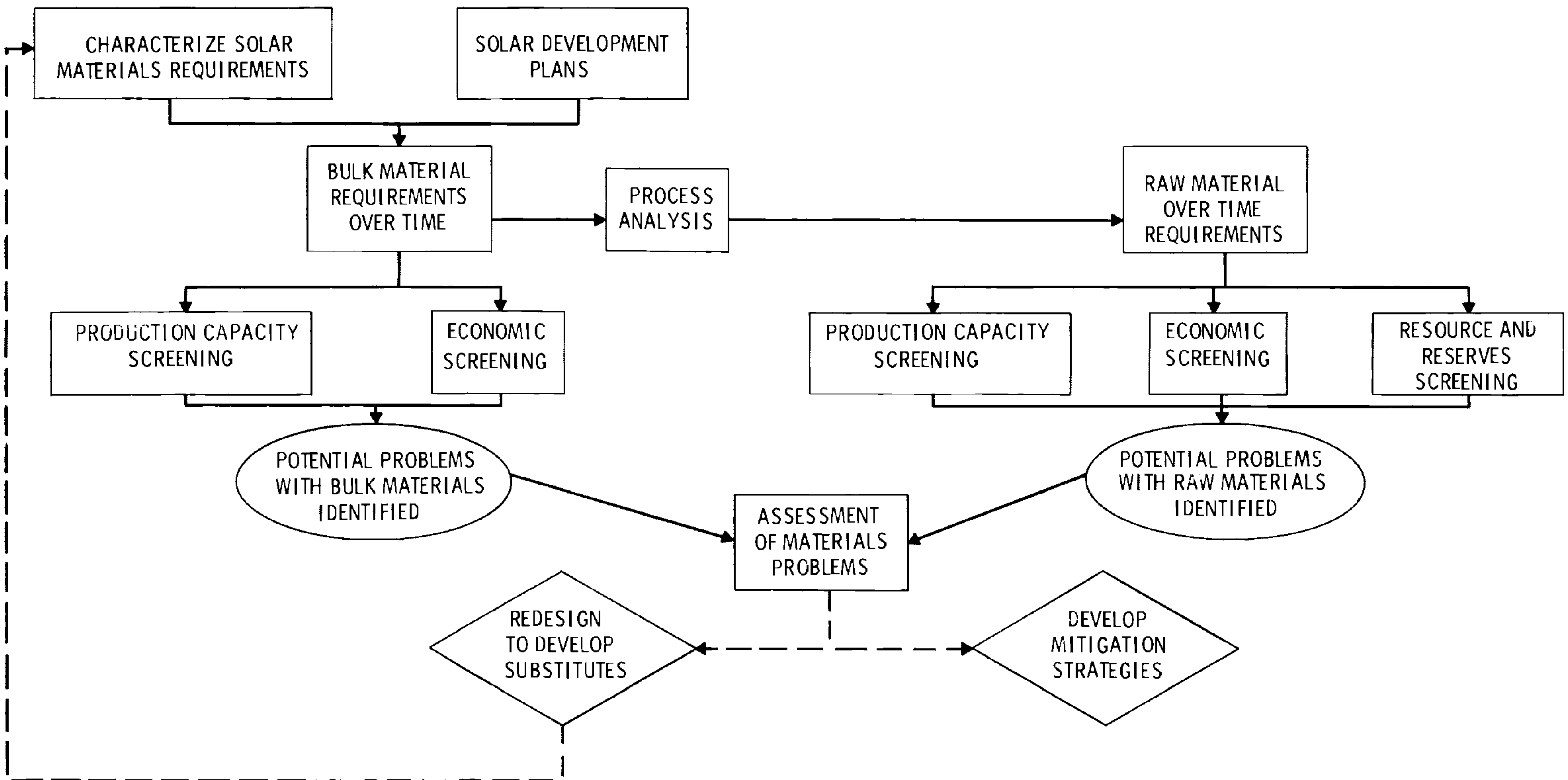

FIGURE 3. Flow Chart of Materials Assessment Methodology

of each of the solar technologies. Each design is broken down into functional components on which engineering materials needs are estimated. These functional components comprise the energy conversion system and allow for rapidly testing the effects of substituting redesigned components. Example functional components will be discussed in more detail later in this report. Following identification of engineering materials requirements, the engineering materials are transformed into their bulk material components.

System Selection - For each solar energy conversion technology a number of reference systems can be identified. In this study two reference systems were chosen with the aid of DOE staff. Actual system designs are preferable to components of systems to assure compatability between design characteristics of each component. Where possible, actual installations are selected as reference systems. A detailed list of engineering material requirements is then established for the functional components of each system.

Engineering Materials Accounting - Because of the dynamic environment in which solar designs exist, it was necessary to develop a structured approach to materials accounting. The approach chosen involves identification of functional components of all solar systems. Because of the basic similarities among solar systems, two major categories of functional components, Energy System and Plant Support Systems, have been identified. Each of these major categories are comprised of a set of functional components.

The energy system category includes operations that are performed on the input solar energy during its transformation to a more useful form. The plant support system category includes all functions not dealing directly with the manipulation of the power being collected. Examples of the subsystems within energy system operations are:

- Energy Concentrator
- Energy Collector
- Energy Transfer
- Energy Converter
- Energy Storage
- Energy Conditioner
- Energy System Controller

Examples of plant support subsystems are:

- Personnel Support Facilities
- Plant Utilities
- Plant Operation and Maintenance
- Plant Installation

Further functional detail can be provided by identifying the distinct components of the subsystems that make up the energy and plant support systems. For example, the energy collector is composed of the following functional components:

- Glazing
- Absorber
- Energy Transport
- Insulation
- Reflector
- Frame
- Seals
- Supports
- Miscellaneous

Characterizing materials requirements using these functional components allows for easily updating a solar design to reflect specific design changes in one or more components. The engineering materials requirements to construct each of the components in the solar system are estimated and documented using this materials accounting hierarchy. This provides the basis for determining the engineering material requirements of a specified solar system.

Information on engineering materials requirements is obtained from the component designer or manufacturer and typically is founded on construction drawings with bills of materials. In some cases, component design drawings are not available or the component design is proprietory. In those cases schematics, component descriptions, and sales literature followed by requests for additional information from the manufacturer have been an adequate substitute for the detailed design drawings.

Transformation of Engineering Materials to Bulk Materials - The detailed accounting of the materials contained in the components of a solar system is aggregated by material to identify the total amount of each engineering material used. It is necessary that we convert these engineering materials requirements into bulk materials requirements. This is accomplished by a transformation matrix that converts an engineering material into its constitutent bulk materials. The coefficients in this conversion matrix were based on the actual proportions of each bulk material present in each engineering material. For example, electrical grade 60-40 solder actually contains 63% tin and 37% lead.

While bulk materials used directly by solar technologies are identified during the solar system characterization as previously described, additional bulk materials may be used as process inputs in the production of other bulk materials required by the solar designs. These secondary bulk materials are identified during the process characterization phase, described later in this report, and are also included in the assessment methodology.

Output Normalization - Each solar system has associated with it a design energy output as estimated by the designers. Materials requirements necessary to achieve a specified energy output are attained by scaling using multiples of the designed system. For instance, the materials requirements for 100 Kw of photovoltaic power are assumed to be four times those for a single 25 Kw photovoltaic system. Estimates of materials requirements developed in this way are sufficiently accurate for purposes of materials problems assessment.

The peak output of most solar systems is given as part of the system design, except for the residential heating, cooling and hot water systems. In these cases, computer codes can be used to determine the peak energy output of each system to be studied.

Since the energy output of solar energy systems is directly dependent on insolation and weather, a normative or typical United States location is assumed.

Determining Raw Materials Requirements - Solar system characterization provides the bulk materials requirements of a solar system, as described in the previous section. Process characterization is required to determine the raw material requirements for producing the bulk materials used by a solar system. The most prevalent process is selected for producing each bulk material and the raw material requirements of this process are estimated.

Bulk Material Process Selection - For each bulk material there may be several alternative production processes. Each process may use different process inputs as either raw materials or bulk materials. Only those processes in current use by industry and producing the majority of the supply of a bulk material are considered in this report.

Once a process for producing a particular bulk material has been selected, the following process inputs are estimated:

- Secondary Bulk Materials
- Raw Materials
- Energy
- Capital
- Labor

The procedure for determining raw material requirements is shown in Figure 4. All important direct inputs needed to produce a bulk material are identified. If the process input is a raw material such as an ore, further expansion is not required. However, if the input is another bulk material, the inputs to produce this bulk material must be estimated. This procedure is carried out until the most important inputs are broken down into their raw materials requirements. The quantities of raw materials used are accumulated and represent the raw materials necessary to acquire the initial bulk material.

Secondary and Tertiary Materials Characterization - The secondary and tertiary material inputs include a mixture of raw materials and bulk materials. The quantity and type of secondary bulk materials going into the production

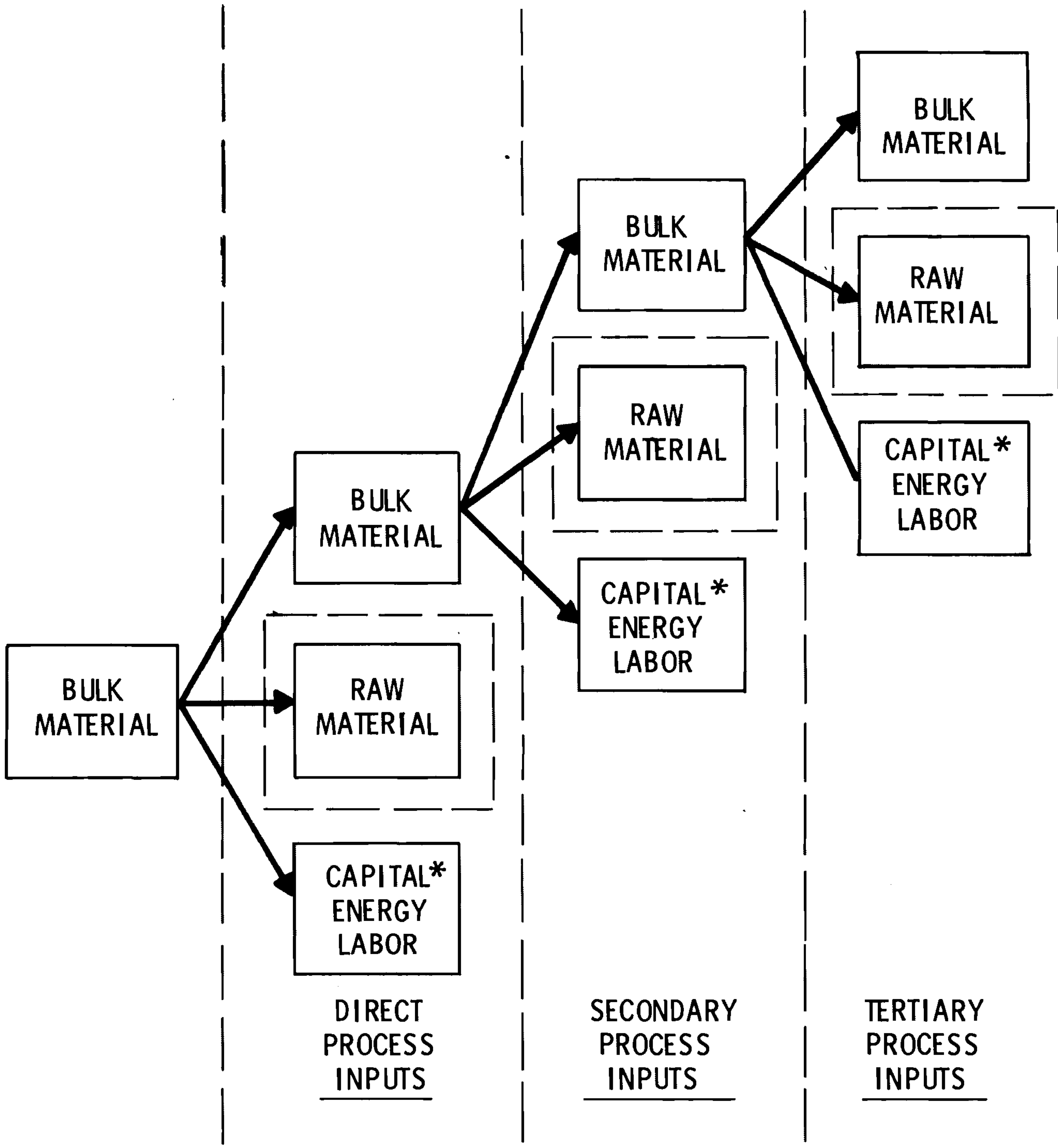

FIGURE 4. Process Characterization

*NOTE: Capital, Energy, and Labor Requirements are Estimated and Used to Identify Process Constraints for Those Materials Impacting on Solar Implementation of a metric ton of primary bulk material is estimated. The process of characterizing the secondary and tertiary materials is terminated when the amount of a secondary or tertiary bulk material required is small in comparison to the other materials. The exact limit used to terminate further process characterization is judgmental at best and varies depending on the material.

Example Characterization for Copper - To illustrate the procedure for process characterization, the bulk material copper is evaluated. Copper can be recovered by several processes; however, the most used processing system consists of mining, beneficiation, smelting, and refining. The raw materials required to produce copper, including direct, secondary, tertiary, and higher order inputs, are estimated as shown in Figure 5. The end product of this procedure provides appropriate conversion factors to convert bulk materials requirements into raw materials requirements. See Appendix D-1 for the raw materials requirements for producing one metric ton of copper.

SCREENING SOLAR MATERIALS

The solar system characterization and process characterization, as previously described, are key elements of the material assessment methodology. Specifically, these elements provided the basis for quantitative estimates of the bulk and raw materials necessary to attain a specific solar market penetration scenario using a particular solar technology. In this section we will discuss screening bulk and raw materials to separate potential problem materials from those materials that are unlikely to constrain solar implementation.

A significant number of materials are involved in the design and construction of solar technologies. Because of the large number of materials and the level of effort necessary to accomplish a detailed assessment of each material, it was necessary to develop screening that would focus material research on potential problem materials.

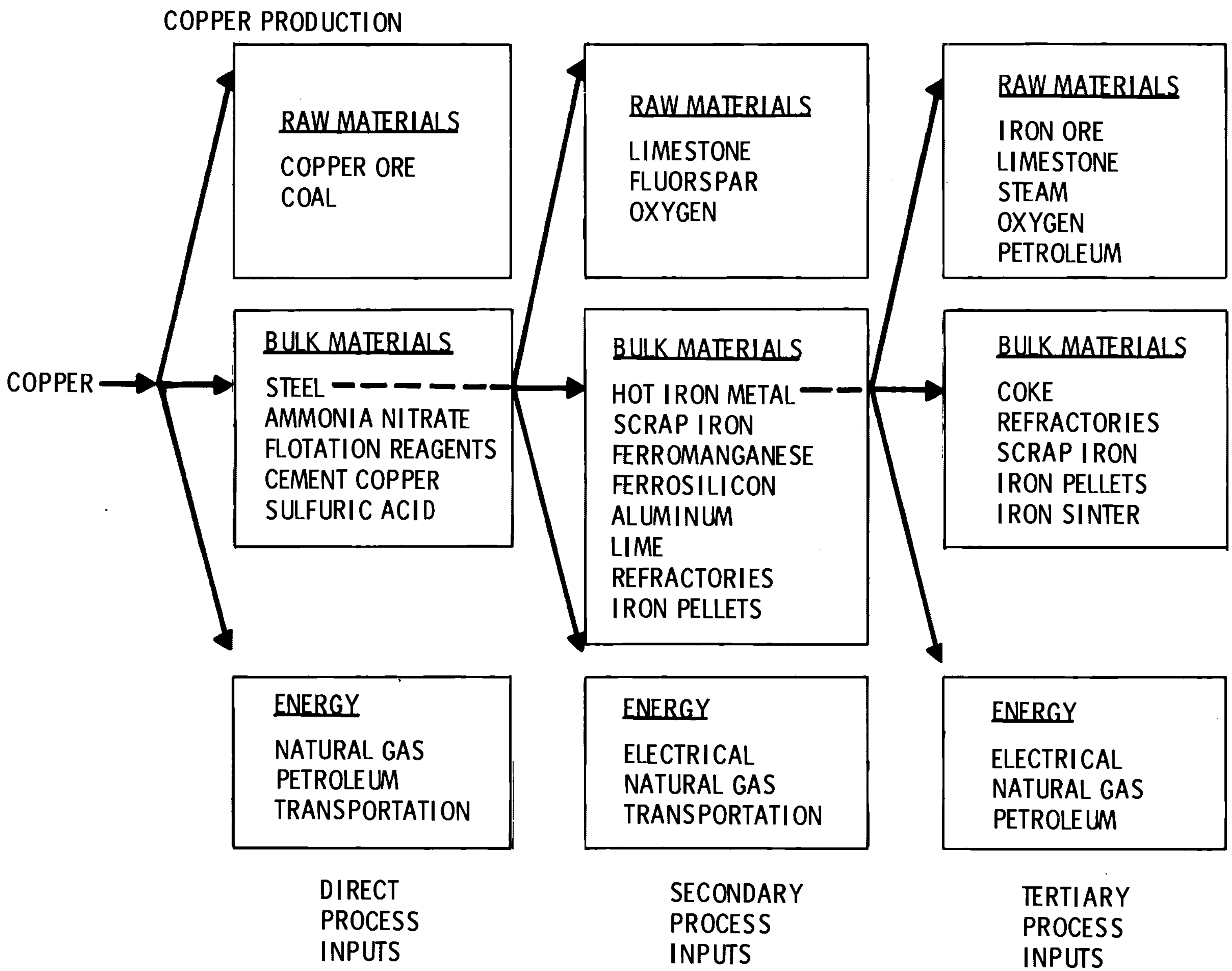

FIGURE 5. Example of Procedure to Determine Raw Material Requirements

The screening process involves an automated procedure for comparing the identified bulk and raw materials to a series of screening factors. These factors are selected because of their relationship to the general availability and economic cost of materials. Their selection is fundamental to the degree of validity and insight obtained from materials screening. Different factors have been selected for bulk materials and raw materials to identify the broad spectrum of materials problems inherent in using large quantities of these materials.

Bulk Materials Screening - Two major concerns exist relative to the use of bulk materials in the development of solar technologies. The first concern is relative to the existing production capacity for bulk materials and the ability of the industries producing bulk materials to increase production sufficiently to provide for forecasted use of solar energy. Secondly, the economic feasibility of utilizing bulk materials in solar designs is of particular importance. Therefore, bulk materials are screened relative to each of these concerns.

A set of five screening factors were developed to identify materials availability problems.

- Percentage of current consumption supplied as a byproduct
- Percent of current consumption that is imported
- Percent world consumption supplied by the largest supplier country outside the U.S.
- Production growth rate necessary to meet forecasted world consumption and solar requirements
- The largest single year market share consumed by solar over the period of the solar development plan

The economic feasibility of using bulk materials in the construction of solar devices is measured in terms of the contribution to the capital cost per unit of peak power output by the solar device. This index of economic feasibility is meant to identify those bulk materials representing a significant cost when compared with the peak power generation of the solar systems in which they are used. To avoid the additional complexity and expense of forecasting future materials prices, the assessment of economic feasibility is based on current materials prices. It is apparent that those materials representing significant contributions to the cost of constructing solar technologies, using current materials prices, are likely to be the primary contributors to the cost of installed peak power in the future. The screening factors for bulk materials screening and their associated problem areas are shown in Table 1.

Raw Materials Screening - Following the identification of potential problems relative to using bulk materials in solar designs, it is necessary to assess the potential problems that may exist relative to the consumption of raw materials needed to produce the bulk materials. In using raw materials three major concerns have been identified. They are as follows.

- Production Capacity
- Reserves and Resources
- Economic Feasibility

Four factors have been identified relative to the production capacity concerns in the use of raw materials to produce bulk materials.

- Percent of current consumption that is imported
- Percent of world consumption supplied by the largest supplier country outside of the U.S.
- Production growth rate necessary to meet forecasted world consumption and solar requirements
- Largest single year market share consumed by solar over the period of the solar development plan

These factors are designed to identify potential problems that may exist in expanding production capacity of raw materials in order to meet the materials requirements of solar. It is important to notice that expanding production capacity of raw materials requires significant lead times and involves complex mining and exploration activities.

TABLE 1. Important Factors for Screening Bulk Materials

Major Concern	Important Factors	Potential Problems
Production Capacity	Percent of Current Consumption Supplied as a By-Product	- Materials Availability Limited to Primary Material Production - Increasing Capacity may not be Technically or Economically Feasible
	Percent of Current Consumption that is Imported	- Uncertain Long-Term Availability - Potential for Geopolitical Problems - Potential Transportation Problems
	Percent of World Consumption Supplied by the Largest Supplier Country Outside of the U.S.	- Potential for Cartels - Possible Monopolistic or Oligopolistic Markets - Price Uncertainty
	Production Growth Rate Necessary to Meet Forecasted World Consumption and Solar Requirements	- Significant Time Lags to Increase Production - Possible Constraints From: • Capital • Labor • Energy • Raw Materials
	The Largest Single Year Market Share Consumed by Solar Over the Period of the Solar Development Plan	- Large Quantities of a Material Consumed in a Year May Cause Market Disequilibrium
Economic Feasibility	The Contributions to Capital Costs per Unit of Peak Power	- A Materials Use May be Uneconomical when Compared with the Peak Power Generation

Four factors were also selected to provide an assessment of potential reserves and resource problems.

- Percent of world reserves that will be consumed by the year 2000
- Percent of U.S. reserves that will be consumed by the year 2000
- Percent of world resources that will be consumed by the year 2000
- Percent of U.S. resources that will be consumed by the year 2000

These factors provide a comparison of estimated world and U.S. consumption, including the materials requirements for solar development, with current estimates of U.S. and world reserves and resources. This comparison pro vides an indicator of raw materials availability and can help to identify materials with uncertain or unknown supplies.

In discussing issues relative to reserves and resources it is important to understand the distinction made between these two terms. The relationship between reserves and resources is shown in the Mineral Resource Classification System developed jointly by the U.S. Geological Survey and the U.S. Bureau of Mines (see Figure 6).

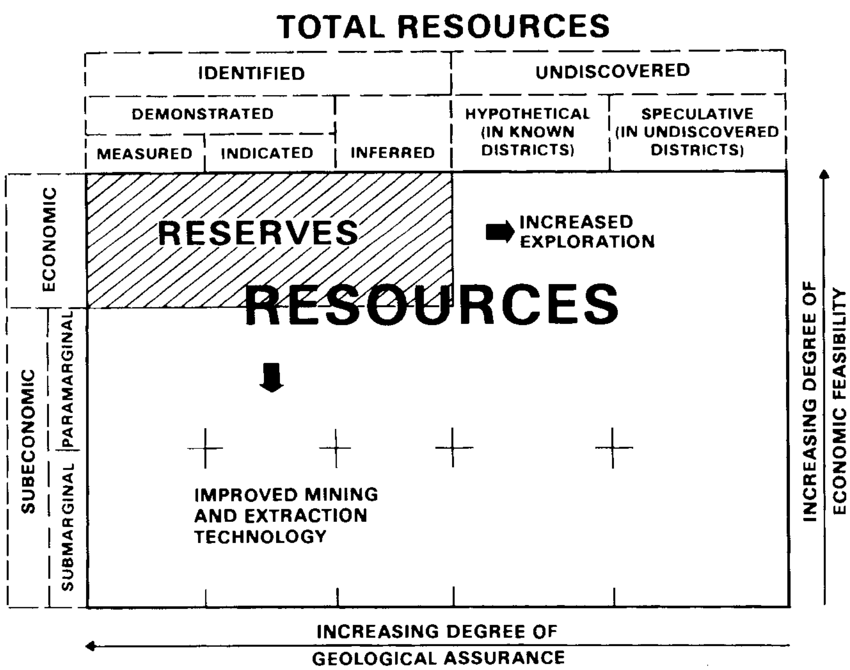

FIGURE 6. Classification of Mineral Resources[1]

This diagram illustrates changing qualities of resources in terms of increasing geologic assurance and increasing economic feasiblity. In this two-dimensional diagram reserves are represented by the shaded area. In this context reserves are defined to be that portion of the resource that is located in identified deposits and can be economically extracted given current technology and mineral prices. This diagram is a static representation of a dynamic system where the quantity of reserves is continually changing due to changes in extraction and mining technology, fluctuations in market prices, and also the extent ot exploration.

The last major concern, economic feasibility, has associated with it a factor conceptually similar to the assessment of economic feasibility used in screening bulk materials. In this assessment the current cost of each raw material will be compared with the estimated peak power of the solar system to determine the contribution of direct raw materials costs to the cost of installed solar power. This factor will identify those raw materials representing significant contributions to the cost of installed solar power and will help to identify those raw materials generating concerns relative to economic feasibility of solar technologies.

The screening factors for raw materials and their associated problem areas are shown in Table 2.

Threshold Criteria Levels - Each of the factors for screening bulk and raw materials can be measured quantitatively. This quantitative measure allows the use of threshold criteria to readily identify those materials and factors representing potential problems and requiring more detailed assessment.

The process of selecting specific threshold criteria for each factor involves a combination of both subjective judgment and known limitations inherent in using bulk and raw materials. The appropriate threshold criteria on a particular material will depend on the environment surrounding the production and use of that material. For this reason it appears that the concept of a threshold criteria may be specific for a particular material-factor. For the examples presented later in this report, generic

TABLE 2. Important Factors for Screening Raw Materials

Major Concerns	Important Factors	Potential Problems
Production Capacity	Percent of Current Consumption That is Imported	- Uncertain Long-Term Availability - Potential for Geopolitical Problems - Potential Transportation Problems
	Percent of World Consumption Supplied by the Largest Supplier Country Outside of the U.S.	- Potential for Cartels - Possibility for Monopolistic or Oligopolistic Markets - Price Uncertainty
	Production Growth Rate Necessary to Meet Forecasted World Consumption and Solar Requirements	- Significant Time Required to Increase Production - Possible Constraints from: Capital, Labor, Energy, & Raw Materials
	Largest Single Year Market Share Consumed by Solar over the Period of the Solar Development Plan	- Possible Market Disequilibrium and Price Instability
Reserves[a] and Resources	Percent of World Reserves that will be Consumed by the Year 2000	- Economically Recoverable World Reserves may not be Adequate to Supply the Needs of Solar and Prices may Increase
	Percent of U.S. Reserves that will be Consumed by the Year 2000	- Economically Recoverable U.S. Reserves may not be Adequate to Supply the Needs of Solar and Prices may Increase
	Percent of World Resources that will be Consumed by the Year 2000	- Sufficient Raw Materials may not be Identified, thus Requiring Exploration
	Percent of U.S. Resources that will be Consumed by the Year 2000	- Sufficient Domestic Resources may not be Available thus Requiring Increased Imports or Exploration
Economic Feasibility	The Contribution to Capital Costs of Raw Materials per Unit of Peak Power	- Current Raw Material Costs may be Significant when Compared with Peak Power Generation

(a) See Figure 6 for a definition of reserves and resources.

threshold criteria were derived on each factor and are meant to be applied to all bulk and raw materials used in the examples.

Because of the subjective aspects of threshold criteria, we have designed the process of screening to allow for parametric input of the desired threshold criteria limits. This provides users of this materials screen with the capability to change threshold criteria values and observe the effects on the identification of materials problems.

For the purpose of the examples presented in this report we have established the threshold criteria values shown in Table 3. For each factor a specific quantitative threshold limit was chosen and the reasons these values were selected are also shown in Table 3.

TABLE 3. Bulk Material Threshold Criteria

Factor	Value Selected	Reason Selected
Percent of normal supply derived as a by-product	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 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

TABLE 3. (continued)

Factor	Value Selected	Reason Selected
		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.	10%	When a single consumer of a material represents 10% of the world consumption, the possibility exists to significantly influence market prices.
The contributions to capital costs per unit of peak power.	\$50/KWe	Current capital costs for thermal power stations are reported to be about \$1000/KWe. We have estimated that if bulk material costs, using 1976 prices, are more than 5% of current capital costs or \$50/KWe, the economic feasibility of the material's use is in question.

A comparable set of threshold criteria have been developed for identifying potential raw materials problems. For each factor previously discussed the chosen value and the rational for selecting those values are shown in Table 4.

TABLE 4. Raw Material Threshold Criteria

Factor	Value Selected	Reason Selected
Percent of current consumption that is imported.	50%	When a large percentage of the material originates outside of the U.S., the uncertainty surrounding future materials prices and availability is increased. Fifty percent of current materials

TABLE 4. (continued)

Factor	Value Selected	Reason Selected
		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 &, 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 4. (continued)

Factor	Value Selected	Reason Selected
Percent of world resources that will be consumed by the year 2000	200%	The definition of reosurces 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/KWe	Bulk materials costs of $50/KWe are likely to be a direct problem &, therefore, a direct cost contribution of $50/KWe from a raw material will certainly be a problem. Arguments to lower this value appear to have validity, but the actual amount of the reduction in this limit that is reasonable is not known.

These threshold values are meant as general guidelines and should not be taken as absolute decision criteria. Sensitivity analysis will reveal those materials that are close to exceeding one or more threshold levels and the parametric nature of the current threshold values allows for rapidly changing these criteria and observing the effect in terms of potential materials problems identified.

The next section of this report discusses an interactive computer system developed to provide rapid feedback to decision makers concerning the effects of various assumptions.

Interactive Computer System for Screening - An interactive computer system was designed to provide for rapid screening of bulk and raw materials and to allow for easily changin the materials requirements as solar designs are developing. This computer system also provides a capability to test the sensitivity of materials problems to assumed plans for commercialization and also to provide a dynamic environment in which the effects of alternative threshold levels can be explored. A functional diagram of the interactive computer system is shown in Figure 7.

The user-supplied input includes the selection of a specific solar design which can be changed to represent a new or improved solar system. A projected solar development plan and the threshold levels are also specified by the user.

The user-supplied inputs are merged with a solar materials data base to provide an assessment of the materials used on each of the screening factors. The major components of this data base include the following.

- Solar design data, including engineering and bulk material requirements for specific solar systems (see Appendices A and E for solar systems which have been characterized to date).
- A bulk materials data base with information on bulk materials usage (see Appendix B).
- A raw materials data base with information on raw materials usage (see Appendix C).
- A conversion matrix resulting from process analysis that provides factors for bulk to raw materials conversion (see Appendix D).

This materials data is combined with a solar development plan to determine materials requirements over time and to evaluate each material on each factor. Potential material problems are identified by application of the user-supplied threshold criteria levels. It is important to examine different levels of threshold values; since actual performance values for each materials on each factor is reported, the senstivity of a particular threshold value is apparent.

These results provide users with a rapid screening of potential bulk and raw material problems and an identification of the material requirements necessary in order to support the solar development plan. Based on this output, a detailed assessment of potential problem materials is initiated to determine the severity of each potential problem identified and to develop strategies

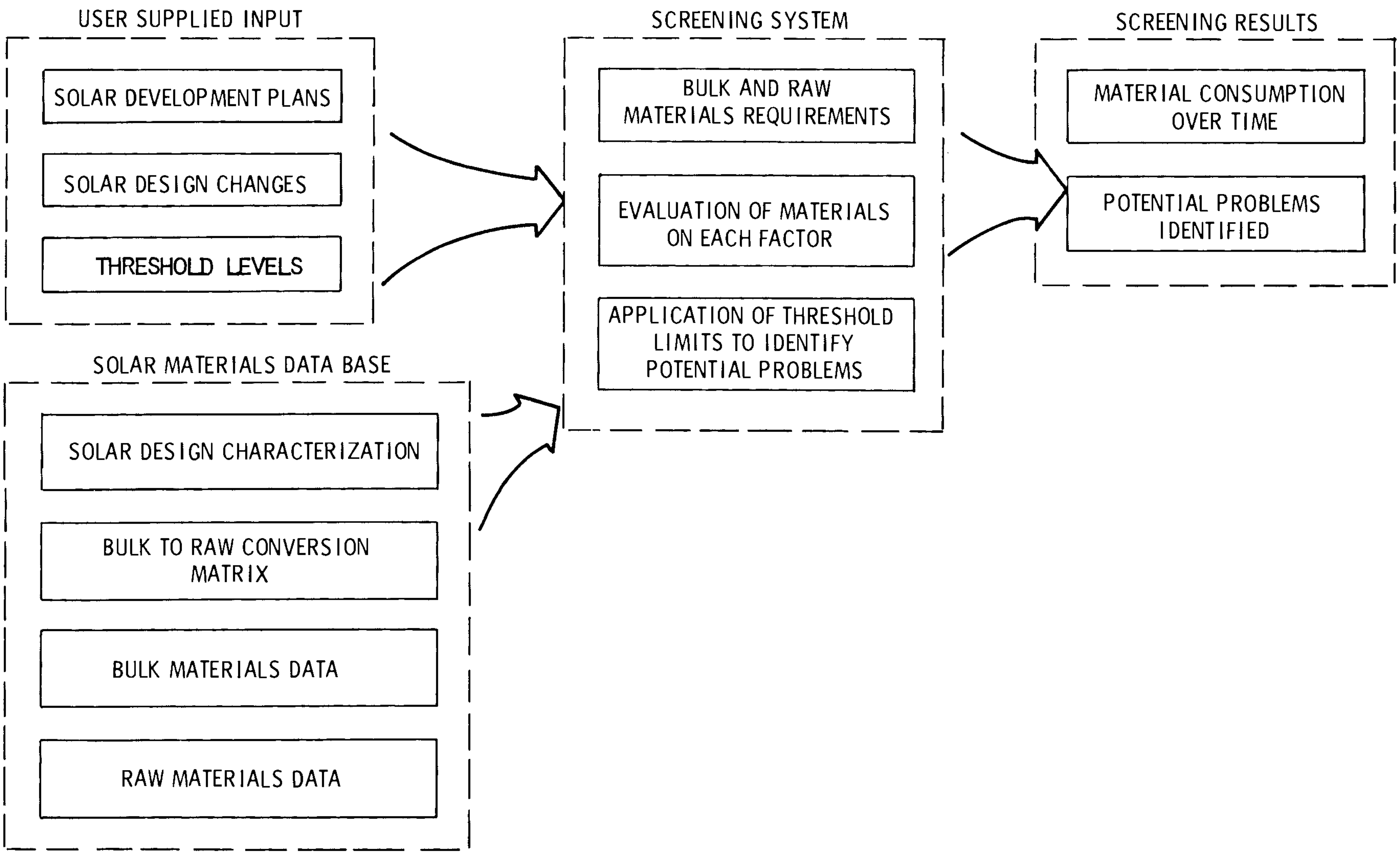

FIGURE 7. Interactive Screening System

for mitigating potential material problems in the implementation of solar technology.

ASSESSMENT OF POTENTIAL MATERIALS PROBLEMS

Many possible materials problems are identified as a result of screening. Some of the important problems are as follows.

- Process and production contraints
- Reserve and resource limitations
- Lack of alternative supply sources
- Geopolitical problems
- Environmental and energy concerns
- Time constraints
- Economic constraints

Each of the above problem areas can have a significant impact on the technical and economic feasibility of a solar design. Some of these problem areas are specific to bulk or raw materials while others can afflict both forms of materials.

An assessment of bulk materials problems includes an analysis of current U.S. and world production capacity, future cost trends, level of imports and stockpiles, and the potential that exists for substitution and recycle. In assessing raw materials problems it is necessary to analyze geologic availability in addition to the areas of concern analyzed for bulk materials. For this reason, problem assessment is divided into two categories: (1) those problems relating to bulk materials and (2) those relating to raw materials.

The factors used to identify potential materials problems are shown in Figure 8.as a series of questions involving the level of each factor when compared to the threshold criteria. A potential problem is identified if any of these questions is answered in the affirmative. The assessment of each of the potential problems involves a review of each of the concerns listed in the boxes under each question.

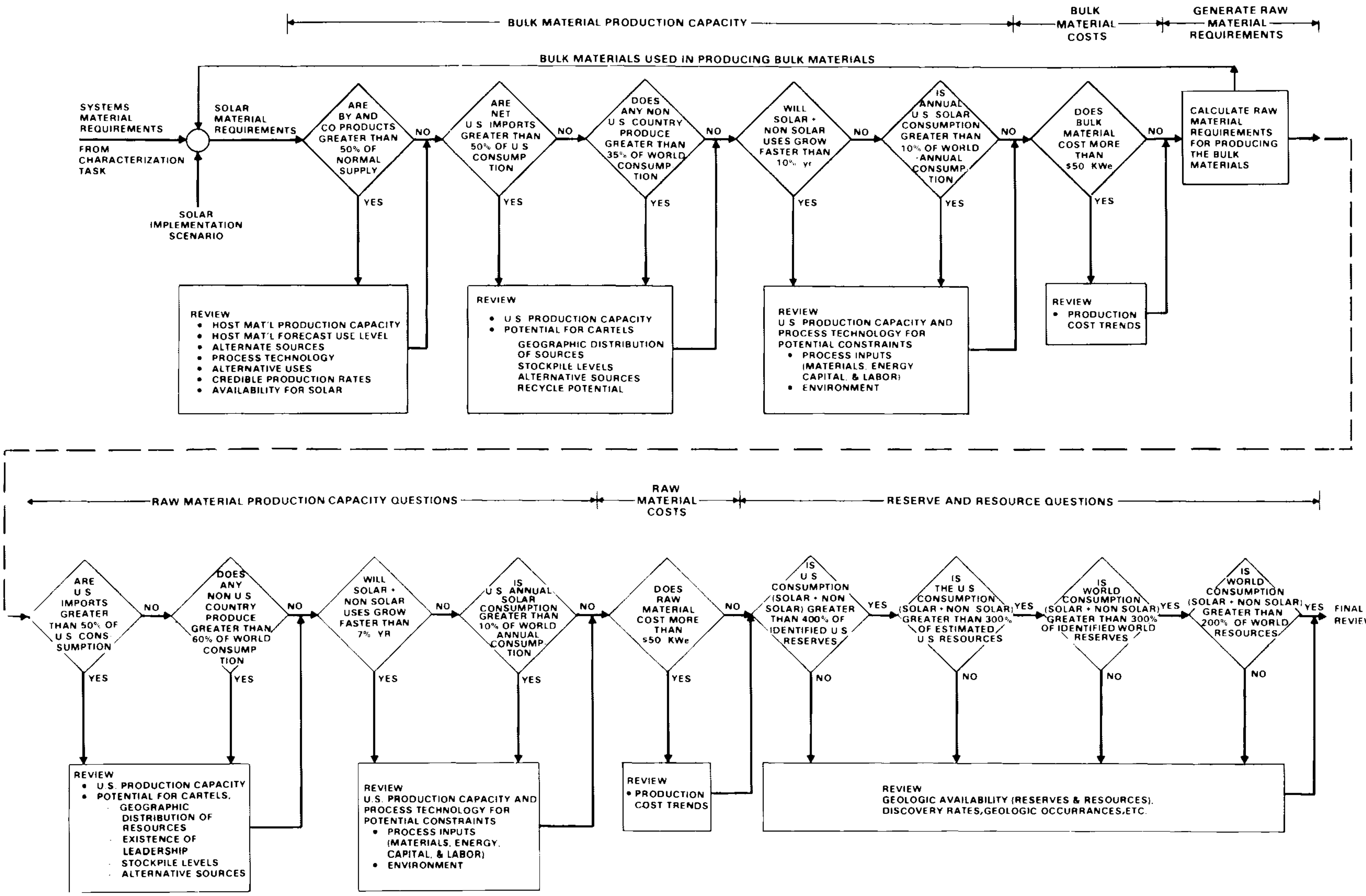

FIGURE 8. Assessment of Potential Materials Problems

EXAMPLE ANALYSIS OF POTENTIAL MATERIALS PROBLEMS

The assessment methodology is demonstrated in this section for a photovoltaic system. Two alternative photovoltaic cells will be used in the system built by the Massachusetts Institute of Technology-Lincoln Laboratory. This system (see Figure 9) 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.

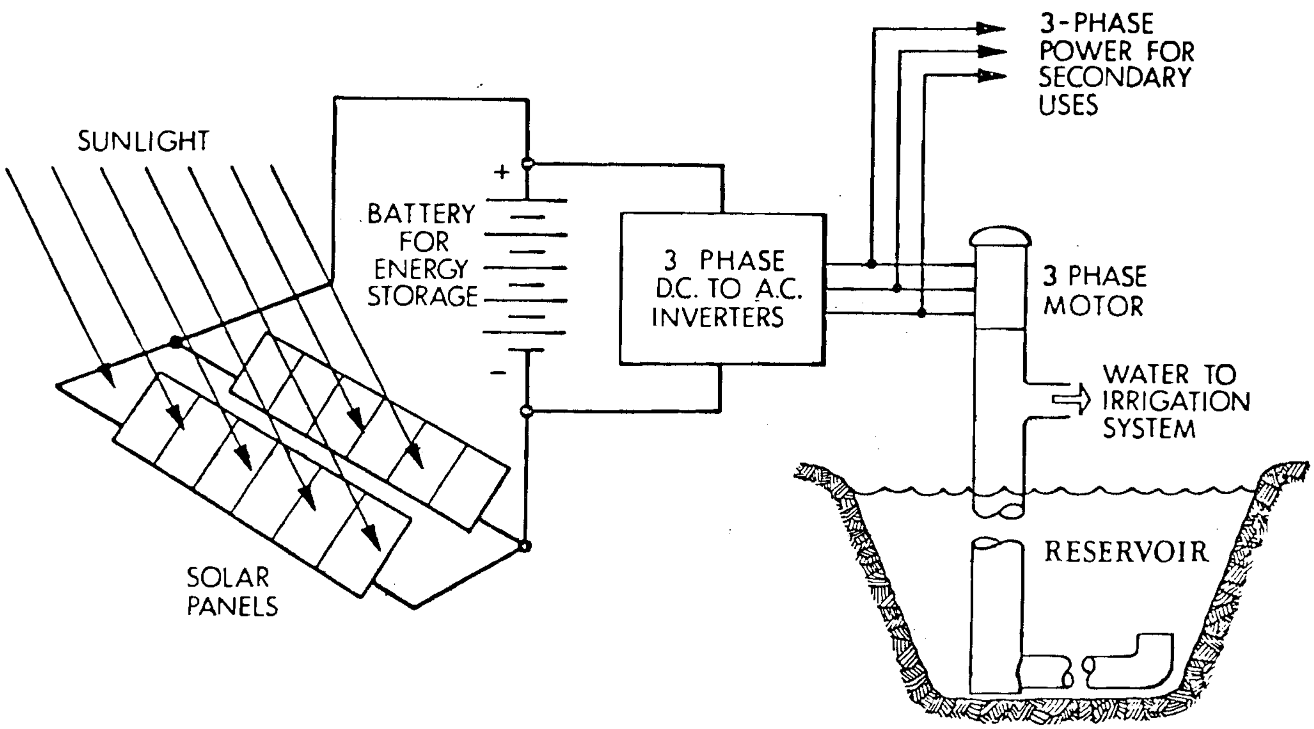

FIGURE 9. Massachusetts Institute of Technology-Lincoln Laboratory and University of Nebraska at Lincoln Photovoltaic System at Mead, Nebraska

(SOURCE: MIT-Lincoln Laboratory)

Photovoltaic System Design - A total of 28 flat panels, each 8 feet by 25 feet, comprise the solar cell array. 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 KW-hrs.

The system is a prototype of future photovoltaic systems with two 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 for 13 alternative photovoltaic cell designs have been assessed (see Appendix A). Two of these cell designs are being used in this report as an example assessment of the materials requirements and potential problems for a photovoltaic system.

One example uses silicon n/p single crystal cells thinner than those currently in production. The cell efficiency assumed is 10.4%, which is identical to the cells actually installed in the system at Mead, Nebraska. The engineering and bulk materials required to build 25 KW of peak power output are shown in Table 5.

Photovoltaic Development Plans - For this example, the solar development plan begins in 1985 and increases at an exponential rate achieving an installed on-line capacity of 50 GWe by 2000.

Achieving this goal of 50 GWe by 2000 for photovoltaics will probably require the development and commercialization of several photovoltaic designs. For the purposes of this example we have assumed that either of the cell designs may achieve the goal. In the future, it will be necessary to examine more complex solar development plans involving several designs. The current assessment methodology can accommodate solar development plans involving several solar technologies and designs.

MATERIAL SCREENING AND PROBLEM IDENTIFICATION

Bulk Material Screening - The two example designs, silicon n/p single crystal and the GaAs-MIS, will be screened to first identify those bulk materials that represent potnetial problems and then to identify those raw materials that may hinder the development of these designs.

TABLE 5. Summary of Materials Contained in the MIT-LL and UNL Photovoltaic System at Mead, Nebraska

Modified using state-of-the-art silicon n/p single crystal cells - 10% efficiency, producing 25 KW of peak power

Engineering "Alloy" as Used in This System	Quantity Metric Tons	Bulk Material Constituents of Engineering "Alloy"	Quantity Metric Tons
Concrete	101.	Cement	14.1
		Sand and Gravel	29.3
		Stone	57.6
Carbon Steel	5.89	Iron	5.85
		Manganese	0.04
Silicon Steel	0.417	Iron	0.404
		Silicon	0.013
6061 Aluminum	13.9	Aluminum	13.6
		Magnesium	0.139
		Silicon	0.033
		Ferrochrome	0.049
		Copper	0.035
Polyvinyl Chloride	0.024	Polyvinyl Chloride	0.024
Aluminum	2.23	Aluminum	2.23
Copper	1.07	Copper	1.07
Plywood	0.503	Softwood	0.493
		Adhesive-Phenol Formald.	0.010
Lead-0.3% Calcium	1.44	Lead	1.44
		Calcium	4.32×10^{-3}
Lead-5% Antimony	1.20	Lead	1.14
		Antimony	0.06
Sulfuric Acid	0.726	Sulfuric Acid	0.726
Silicone	1.86	Silicone	1.86
Silicon	2.91×10^{-2}	Silicon	2.91×10^{-2}
Phosphorous	2.59×10^{-7}	Phosphorous	2.59×10^{-7}
Boron	2.26×10^{-9}	Boron	2.26×10^{-9}
Titanium	2.26×10^{-6}	Titanium	2.26×10^{-6}
Palladium	2.93×10^{-6}	Palladium	2.93×10^{-6}
Silver	6.55×10^{-4}	Silver	6.55×10^{-4}
Tantalum	1.68×10^{-4}	Tantalum	1.68×10^{-4}
Teflon	3.26×10^{-3}	Teflon	3.26×10^{-3}
Stainless Steel	1.24	Iron	0.818
		Ferrochrome	0.322
		Nickel	0.099
Plastics and Laminates	9.76×10^{-3}	Plastics and Laminates	9.76×10^{-3}
Rubber	2.49×10^{-2}	Rubber	2.49×10^{-2}
60-40 Solder	2.36×10^{-2}	Tin	1.49×10^{-2}
		Lead	0.87×10^{-2}
FRP Polyester	1.08	Polyester	0.57
		Fiberglass	0.51
Soda Lime Glass	0.68×10^{-3}	Soda Lime Glass	0.68×10^{-3}
Fiberglass Wool	0.898	Fiberglass	0.898
Acrylic	0.053	Acrylic	0.053
Phenolic	0.015	Phenolic	0.015
Epoxy	9.07×10^{-4}	Epoxy	9.07×10^{-4}
Polypropylene	0.207	Polypropylene	0.207
Varnish	6.80×10^{-3}	Alkyd Resin	6.80×10^{-3}
		Tung Oil	10.2×10^{-3}
		Linseed Oil	3.4×10^{-3}
Zinc	0.68×10^{-3}	Zinc	0.68×10^{-3}
Electrical Porcelain	0.34×10^{-3}	Porcelain	0.34×10^{-3}
Epoxy/Glass Laminate	0.24×10^{-3}	Epoxy	0.084×10^{-3}
		Fiberglass	0.156×10^{-3}
Nylon	0.5×10^{-3}	Nylon	0.5×10^{-3}
Micarta	9.16×10^{-4}	Phenolic	4.58×10^{-4}
		Cotton Fibers	3.21×10^{-4}
		Kraft Fibers	1.37×10^{-4}
Polyester	4.08×10^{-3}	Polyester	4.08×10^{-3}

By applying the same development plan to both of these photovoltaic systems, one can identify those materials that represent significant problems if the DOE goal of 50 GWe in the year 2000 is achieved by commercialization of either silicon n/p single crystal or the GaAs-MIS. While this is an unrealistic scenario for achieving the photovoltaic goal, it is useful for demonstrating the power of this methodology as a tool to provide early warning of materials problems and to impact on future solar R&D programs.

Sample output from the computer system analysis is shown in Table 6 for the silicon n/p single crystal example. Bulk material requirements and an evaluation of each bulk material on each of the important factors relative to bulk materials usage is also shown. The specified threshold levels at the top of each column are used to identify potential material problems. Used as decision criteria the threshold values identify problems with an asterisk (*).

The GaAs-MIS example results are shown in Table 7. Many of the materials that represent potential problems to the silicon n/p cells are identified as potential problems in the GaAs-MIS design.

By inspection of each of the materials on which potential problems have been identified (Tables 6 and 7), we have made a preliminary grouping of materials into three categories. The first category contains those materials whose technical availability or economic feasibility appear to have significant impact on commercial implementation of the solar designs. The second category contains those materials on which potential problems have been identified; however, as a result of a brief review, these problems do not appear to be of sufficient severity to impact significantly on the implementation of solar designs. The final group contains those materials on which no apparent problems have been identified.

The results of grouping these materials problems are shown in Table 8. Each of the materials in Group "A" represent potential problems of sufficient severity that additional, more detailed assessment is necessary in order to determine the significance of the problems identified and to recommend strategies for mitigating these problems. Stainless steel has

TABLE 6. Bulk Material Requirements for Silicon N/P Single Crystal

SOLAR SCENARIO:
INTRODUCTION YEAR - 1985.
COMMULATIVE 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	31721998.	0.	7.	10. *	13.	624. *	14.
ANTIMONY	119700.	100. *	6.	10. *	22.	9.	55. *
BORON	0.	20.	5.	0.	47. *	0.	0.
CEMENT	28258498.	0.	3.	0.	18.	20.	4.
COPPER	2212600.	1.	6.	2.	12.	68. *	45.
GLASS, FIBERS	2811500.	0.	8.	14. *	5.	19.	2.
GLASS, SODA LIME	1360.	0.	3.	0.	5.	0.	5.
IRON , STEEL	12513499.	1.	3.	0.	16.	80. *	10.
LEAD	5159000.	13.	5.	10. *	11.	46.	18.
LIME	8628.	0.	3.	0.	9.	0.	2.
MAGNESIUM	278800.	30.	6.	7.	26.	11.	0.
FERROMANGANESE	70650.	100. *	2.	0.	9.	0.	99. *
PALLADIUM	6.	100. *	3.	1.	30.	0.	96. *
PHOSPHOROUS	1.	0.	6.	0.	13.	0.	0.
PORCELAIN	680.	0.	0.	0.	10.	0.	0.
SAND & GRAVEL	58534996.	0.	4.	0.	10.	2.	0.
STONE	115054992.	0.	3.	0.	3.	6.	0.
SILICON	250720.	0.	3.	1.	14.	5.	8.
SILVER	1310.	70. *	4.	0.	7.	3.	46.
SULFURIC ACID	1452000.	20.	5.	0.	15.	1.	0.
TANTALUM	336.	100. *	5.	2.	37. *	0.	68. *
TIN	29736.	25.	2.	2.	29.	5.	65. *
TITANIUM	5.	0.	5.	0.	50. *	0.	50. *
ZINC	1360.	25.	3.	0.	21.	0.	88. *
STAINLESS STEEL	2473800.	0.	3.	4.	10.	49.	15.
FERROCHROME	97580.	5.	5.	0.	18.	4.	50. *
LINSEED OIL	6800.	0.	1.	0.	5.	0.	1.
ACRYLIC	106000.	0.	7.	0.	5.	2.	1.
ALKYD RESIN	13600.	0.	7.	0.	5.	0.	1.
EPOXY RESIN	1982.	0.	7.	0.	5.	0.	5.
GLUE, PHENOL, FORM	20120.	0.	7.	0.	5.	0.	5.
LUMBER, SOFTWOOD	985900.	0.	4.	0.	20.	1.	12.
PHENOLIC RESIN	31766.	0.	7.	0.	5.	0.	1.
PLASTIC, RESIN	19520.	0.	7.	0.	5.	0.	3.
POLYESTER RESIN	1152950.	0.	7.	4.	5.	18.	0.
PVC PLASTIC	48000.	0.	7.	0.	5.	1.	0.
RUBBER, SBR	49860.	0.	6.	0.	5.	1.	4.
SILICONES	3720000.	0.	10. *	70. *	5.	298. *	1.
TEFLON	6520.	0.	7.	2.	5.	1.	1.
NYLON	1000.	0.	5.	0.	5.	0.	1.
POLYPROPYLENE	414000.	0.	8.	1.	5.	5.	1.
COTTON FIBERS	641.	0.	2.	0.	16.	0.	1.
KRAFT FIBERS	275.	0.	3.	0.	10.	0.	15.
TUNG OIL	20400.	0.	0.	9.	45. *	0.	70. *

TABLE 7. Bulk Material Requirements for GaAs-MIS Thin Film Cell

SOLAR SCENARIO:
INTRODUCTION YEAR - 1985.
COMMULATIVE 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	17930998.	0.	7.	6.	13.	353. *	14.
ANTIMONY	119700.	100. *	6.	10. *	22.	9.	55. *
ARSENIC	2760.	100. *	1.	1.	34.	0.	37.
CEMENT	17086498.	0.	3.	0.	18.	12.	4.
COPPER	1380200.	1.	6.	1.	12.	42.	45.
GALLIUM	2560.	100. *	17. *	92. *	45. *	41.	75. *
GERMANIUM	13300.	100. *	16. *	96. *	29.	78. *	19.
GLASS, FIBERS	1796300.	0.	7.	9.	5.	12.	2.
GLASS, SODA LIME	4881350.	0.	3.	6.	5.	28.	5.
GOLD	78.	40.	2.	0.	58. *	5.	58. *
IRON , STEEL	12720999.	1.	3.	0.	16.	82. *	10.
LEAD	5152000.	13.	5.	10. *	11.	46.	18.
LIME	8628.	0.	3.	0.	9.	0.	2.
MAGNESIUM	168600.	30.	6.	4.	26.	7.	0.
FERROMANGANESE	71905.	100. *	2.	0.	9.	0.	99. *
PORCELAIN	680.	0.	0.	0.	10.	0.	0.
SAND & GRAVEL	35393996.	0.	4.	0.	10.	1.	0.
STONE	69564992.	0.	3.	0.	3.	4.	0.
SILICON	126400.	0.	3.	1.	14.	2.	8.
SULFURIC ACID	1452000.	20.	5.	0.	15.	1.	0.
TANTALUM	224.	100. *	5.	1.	37. *	0.	68. *
TIN	17892.	25.	2.	1.	29.	3.	65. *
TUNGSTEN	9660.	100. *	3.	3.	6.	3.	37.
ZINC	1360.	25.	3.	0.	21.	0.	88. *
STAINLESS STEEL	1791800.	0.	3.	3.	10.	36.	15.
FERROCHROME	59010.	5.	5.	0.	18.	3.	50. *
LINSEED OIL	6800.	0.	1.	0.	5.	0.	1.
ACRYLIC	106000.	0.	7.	0.	5.	2.	1.
ALKYD RESIN	13600.	0.	7.	0.	5.	0.	1.
EPOXY RESIN	1982.	0.	7.	0.	5.	0.	5.
GLUE, PHENOL, FORM	20120.	0.	7.	0.	5.	0.	5.
LUMBER, SOFTWOOD	985900.	0.	4.	0.	20.	1.	12.
PHENOLIC RESIN	31766.	0.	7.	0.	5.	0.	1.
PLASTIC, RESIN	18788.	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	30040.	0.	6.	0.	5.	0.	4.
TEFLON	3920.	0.	7.	1.	5.	1.	1.
NYLON	572.	0.	5.	0.	5.	0.	1.
POLYPROPYLENE	414000.	0.	8.	1.	5.	5.	1.
COTTON FIBERS	641.	0.	2.	0.	16.	0.	1.
KRAFT FIBERS	275.	0.	3.	0.	10.	0.	15.
TUNG OIL	20400.	0.	0.	9.	45. *	0.	70. *

TABLE 8. Potential Bulk Materials Problems

Group "A" Potentially Severe Problems	Group "B" Problems Identified	Group "C" No Problems Identified
Aluminum	Arsenic	Those materials listed in Tables 6 and 7 not listed in Group "A" or "B" at the left
Antimony	Boron	
Copper	Ferrochrome	
Gallium	Ferromanganese	
Germanium	Gold	
Iron & Steel	Glassfiber	
Silicones	Lead	
	Palladium	
	Silver	
	Tantalum	
	Tin	
	Titanium	
	Tungsten	
	Tung Oil	
	*Stainless Steel	

*Stainless steel was selected for Group "B" because it nearly exceeds several threshold levels.

been included as a Group "B" material because it nearly exceeds the threshold criteria on several important factors although it does not exceed the threshold on any screening factor.

Raw Materials Screening - For all bulk materials used in the construction of silicon n/p and GaAs-MIS systems the raw materials needed to produce these bulk materials are determined from process analysis. Sample output from screening these raw materials is shown in Tables 9 and 10, along with the estimated materials usage to construct 50 GWe of either design.

Table 9 presents the results of screening raw materials used in the silicon n/p single crystal system. Significant quantities of raw materials are required to construct 50 GWe of this system. Antimony ore and bauxite are possibly significant problems from a reserves and resources perspective. A rather large quantity of salt (120 million MT) is required to produce the required aluminum. This could represent an important contribution to the installed cost of constructing the design.

TABLE 9. Raw Material Requirements for Silicon N/P Single Crystal

SOLAR SCENARIO:
INTRODUCTION YEAR - 1985.
COMMULATIVE 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	119.	6.	10. *	1329. *	1207. *	22.	78.	66.	9.	55. *
ASBESTOS	1.	3.	0.	541. *	28.	34.	191.	129.	0.	90. *
BAUXITE	161420.	6.	13. *	2614. *	349. *	28.	15.	9.	48.	89. *
BORATE	91.	5.	2.	24.	0.	50.	16.	0.	1.	3.
BUTANE	56.	1.	0.	20.	2.	10.	12.	1.	0.	5.
CHROMITE	728.	4.	3.	4520. *	229.	27.	17.	4.	3.	66. *
CLAYS	4399.	2.	0.	0.	0.	10.	0.	0.	18.	0.
COAL	90475.	1.	0.	6.	1.	6.	13.	1.	28.	10.
COPPER ORE	2301.	6.	2.	103.	45.	12.	50.	23.	32.	37.
FELDSPAR	0.	3.	0.	5.	0.	10.	13.	0.	0.	5.
FLUORSPAR	1097.	5.	2.	360.	154.	22.	100.	56.	3.	50. *
GYPSUM	1356.	3.	0.	175.	0.	10.	11.	0.	0.	37.
IRON ORE	15384.	1.	0.	17.	3.	11.	9.	3.	6.	35.
LEAD ORE	5154.	5.	10. *	87.	43.	11.	109.	11.	52. *	33.
MANGANESE ORE	212.	3.	0.	100.	4.	24.	18.	11.	1.	100. *
NATURAL GAS	25732.	5.	0.	246.	277.	30.	93.	9.	0.	5.
NICKEL ORE	198.	4.	2.	3230. *	39.	37.	53.	22.	20.	75. *
NITROGEN, FIXED	1.	4.	0.	0.	0.	5.	0.	0.	0.	10.
PETROLEUM	3717.	3.	0.	562. *	210.	22.	110.	36.	9.	40.
PHOSPHATE ROCK	0.	6.	0.	48.	0.	13.	29.	0.	0.	0.
PROPANE	550.	1.	0.	192.	23.	10.	136.	11.	0.	5.
RUTILE	0.	1.	0.	221.	81.	90. *	44.	17.	0.	100. *
SALT	120220.	6.	4.	0.	0.	5.	0.	0.	43.	9.
SAND/GRAVEL	67895.	4.	0.	0.	0.	0.	0.	0.	3.	0.
SILVER ORE	1.	4.	1.	373.	245.	14.	208.	56.	2.	0.
STONE	115055.	3.	0.	0.	0.	3.	0.	0.	6.	0.
SULFUR	8588.	4.	2.	95.	2.	15.	90.	0.	8.	28.
TANTALUM ORE	0.	5.	2.	100.	1758. *	37.	98.	22.	0.	100. *
TIN ORE	30.	2.	2.	4404. *	1321. *	29.	73.	20.	5.	65. *
ZINC ORE	31.	3.	0.	146.	33.	19.	118.	6.	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	0.	3.	0.	0.	0.	20.	0.	0.	0.	1.
LUMBER	1065.	1.	0.	0.	0.	12.	0.	0.	3.	18.
SEA WATER	206315.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SOYBEAN	39.	3.	0.	0.	0.	12.	0.	0.	0.	0.
TUNG NUTS	41.	1.	7.	0.	0.	70. *	0.	0.	1.	80. *
WATER	47036.	3.	0.	17.	2.	0.	3.	0.	0.	0.
WHEAT	6.	3.	0.	0.	0.	10.	0.	0.	0.	0.
MISC.	924.	0.	0.	0.	0.	0.	0.	0.	9.	0.
STEAM	812050.	5.	3.	1.	0.	10.	0.	0.	28.	0.
LIMESTONE	134785.	3.	7.	0.	0.	5.	0.	0.	5.	2.
CU ANODES LIMES	12.	6.	0.	101.	44.	12.	49.	23.	0.	37.
COAL, BY PROD	1495350.	2.	6.	6.	1.	6.	13.	1.	0.	10.

TABLE 10. Raw Material Requirements for GaAs-MIS Thin Film Cell

SOLAR SCENARIO:
INTRODUCTION YEAR - 1985.
COMMULATIVE 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	119.	6.	10. *	1329. *	1207. *	22.	78.	66.	9.	55. *
ARSENIC TRIOXIDE	4.	1.	2.	120.	17.	34.	31.	6.	0.	96. *
ASBESTOS	0.	3.	0.	541. *	28.	34.	191.	129.	0.	90. *
BAUXITE	91350.	5.	8.	2439. *	325. *	28.	15.	9.	27.	89. *
BORATE	58.	5.	1.	24.	0.	50.	15.	0.	1.	3.
BUTANE	34.	1.	0.	20.	2.	10.	12.	1.	0.	5.
CHROMITE	519.	4.	2.	4469. *	226.	27.	17.	4.	2.	66. *
CLAYS	2731.	2.	0.	0.	0.	10.	0.	0.	11.	0.
COAL	63795.	1.	0.	6.	1.	6.	13.	1.	20.	10.
COPPER ORE	1367.	6.	1.	102.	45.	12.	50.	23.	19.	37.
FELDSPAR	454.	3.	1.	5.	0.	10.	13.	0.	0.	5.
FLUORSPAR	643.	5.	1.	357.	152.	22.	100.	56.	1.	50. *
GOLD ORE	0.	2.	1.	217.	93.	58.	109.	64.	5.	89. *
GYPSUM	820.	3.	0.	175.	0.	10.	11.	0.	0.	37.
IRON ORE	14808.	1.	0.	17.	3.	11.	9.	3.	6.	35.
LEAD ORE	5147.	5.	10. *	87.	43.	11.	109.	11.	52. *	33.
MANGANESE ORE	227.	3.	0.	100.	4.	24.	18.	11.	1.	100. *
NATURAL GAS	20033.	5.	0.	246.	277.	30.	93.	9.	0.	5.
NICKEL ORE	143.	4.	2.	3200. *	38.	37.	53.	22.	15.	75. *
NITROGEN, FIXED	1.	4.	0.	0.	0.	5.	0.	0.	0.	10.
PETROLEUM	2316.	3.	0.	562. *	210.	22.	110.	36.	6.	40.
PROPANE	549.	1.	0.	192.	23.	10.	136.	11.	0.	5.
SALT	67785.	6.	2.	0.	0.	5.	0.	0.	24.	9.
SAND/GRAVEL	43476.	4.	0.	0.	0.	0.	0.	0.	2.	0.
STONE	69565.	3.	0.	0.	0.	3.	0.	0.	4.	0.
SULFUR	6390.	4.	1.	95.	1.	15.	90.	0.	6.	28.
TANTALUM ORE	0.	5.	1.	100.	1751. *	37.	97.	22.	0.	100. *
TIN ORE	18.	2.	1.	4376. *	1313. *	29.	73.	20.	3.	65. *
TUNGSTEN ORE	10.	3.	3.	302.	101.	21.	76.	42.	3.	37.
ZINC ORE	31.	3.	0.	146.	33.	19.	118.	6.	1.	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	0.	3.	0.	0.	0.	20.	0.	0.	0.	1.
LUMBER	1043.	1.	0.	0.	0.	12.	0.	0.	3.	18.
SEA WATER	126850.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SOYBEAN	39.	3.	0.	0.	0.	12.	0.	0.	0.	0.
TUNG NUTS	41.	1.	7.	0.	0.	70. *	0.	0.	1.	80. *
WATER	41124.	3.	0.	17.	2.	0.	3.	0.	0.	0.
WHEAT	6.	3.	0.	0.	0.	10.	0.	0.	0.	0.
MISC.	748.	0.	0.	0.	0.	0.	0.	0.	7.	0.
STEAM	467980.	5.	2.	1.	0.	10.	0.	0.	16	0.
LIMESTONE	89640.	3.	5.	0.	0.	5.	0.	0.	4.	2.
BAUXITE, BY PROD	128000.	5.	11. *	2530. *	337. *	28.	15.	9.	0.	89. *
ZINC, BY PRODUCT	47295.	6.	50. *	320.	73.	19.	148.	8.	0.	88. *
COAL, BY PROD	189590.	1.	1.	6.	1.	6.	13.	1.	0.	10.

The raw material requirements to construct 50 GWe of the GaAs-MIS system are shown in Table 10. Most of these requirements are lower than those for the silicon system; however, bauxite and zinc byproducts represent bauxite and zinc ore production required to produce gallium and germanium and may represent problems in the development of this system if they exceed bauxite requirements for the primary material, aluminum.

A summary of potential raw materials problems identified in Tables 9 and 10 is shown in Table 11. Each of the materials in Group "A" represent potentially severe problems and will be discussed in more detail in the following section.

TABLE 11. Raw Material Screening Results for the Two Photovoltaic Designs

Group "A" Potentially Severe Problems	Group "B" Problems Identified	Group "C" No Problems Identified
Antimony Ore	Arsenic Trioxide	Those materials listed in Tables 9 and 10 not listed in Group "A" or "B" to the left.
Bauxite	Asbestos	
Bauxite Byproduct (Gallium Source)	Chromite	
Zinc Ore Byproduct (Germanium Source)	Fluorspar	
	Gold Ore	
	Lead Ore	
	Manganese Ore	
	Natural Gas	
	Nickel	
	Petroleum	
	Rutile	
	Tantalum Ore	
	Tin Ore	
	Tung Nuts	
	Zinc Ore	

ASSESSMENT OF MATERIALS PROBLEMS

The screening process rapidly identifies potential bulk and raw materials problems that may hinder the implementation of the example photovoltaic designs. Once materials problems are identified, a more detailed materials assessment provides an analysis of the most serious concerns and establishes alternative strategies available for mitigating or managing these materials problems.

The following discussion provides a detailed assessment of each bulk and raw material placed in Group "A" in Tables 8 and 11.

Aluminum Bulk Material Concerns - The screening process (Tables 6 and 7) identified two potential problems with aluminum bulk materials necessary to produce 50 GWe of peak power capacity using either of the reference solar cell designs. The first problem is associated with the high consumption of aluminum in the reference designs. The second and related problem is the high cost of aluminum per kilowatt of peak capacity. There are two possibilities for mitigating there 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, $624/KW and $355/KW from Tables 6 and 7. 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 10). Figure 10 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.

Aluminum - Raw Material Concerns - Bauxite - Tables 9 and 10 identify several potential problems relative to bauxite supply; the major concern relates to the lack of domestic sources of bauxite. Because of the reliance on imports for bauxite, the potential exists for cartels or foreign

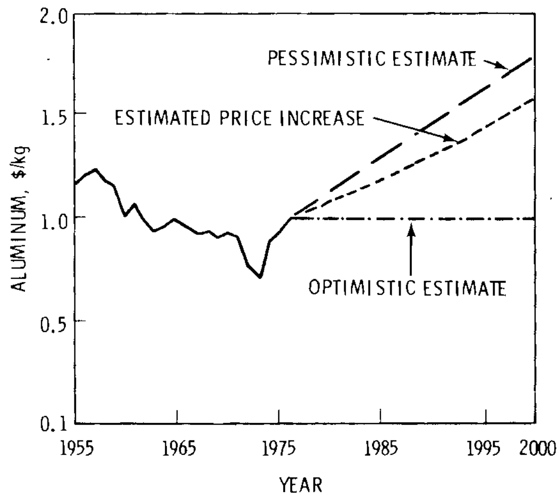

FIGURE 10. Price History and Future Price Estimates for Bulk Aluminum in 1976 Dollars

political actions to disrupt the normal supply of bauxite. A similar situation exists for foreign supplies of petroleum, thus bringing the OPEC cartel into existance. 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 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 identified in Tables 9 and 10. Although the projected consumption of U.S. bauxite reserves is very high, back up resources, the domestic clays cited above, are plentiful; therefore, bauxite as a raw material should not be a significant problem.

Antimony - Bulk and Raw Material Concerns - Although the screening process flags both bulk antimony and antimony ore as potential concerns, our detailed assessment concludes that 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.

Copper - Bulk Material Concerns - The only potential problem identified for copper is its cost in the silicon cell (Table 6). In the silicon n/p single crystal design the cost contribution of copper is $68/KW of capacity, the fourth highest cost material. This is $18/KW above the threshold level for cost concern. Three possible ways of reducing the cost contribution of copper in this design are:

1. Develop new and lower priced copper supplies.
2. Design for less copper use.
3. Substitute other materials for copper.

Copper price trends in constant dollars are shown in Figure 11 along with the decreasing copper ore grade over the last 25 years. Copper prices have historically increased about 2% per year while the ore grade utilized in copper production has steadily decreased at about 2% per year. Technological improvements in the production and mining processes for copper have reduced the direct man-hours per ton from about 25 to 17 in 1975 (see Figure 12). Without these technological improvements, it is likely that the price of copper would have risen at a rate greater than 2% per year. If the real price of copper continues to increase at about 2% per year, the constant dollar price for copper in the year 2000 will be about 50% higher than current copper prices. Copper prices are related to, and limited by, the price of functionally competitive materials. Aluminum is the primary competition, but, as we discussed previously, aluminum is likely to experience significant cost increases in the future. For this reason, competition is unlikely to constrain future price increases for copper. Declining ore grades, coupled with increased cost of

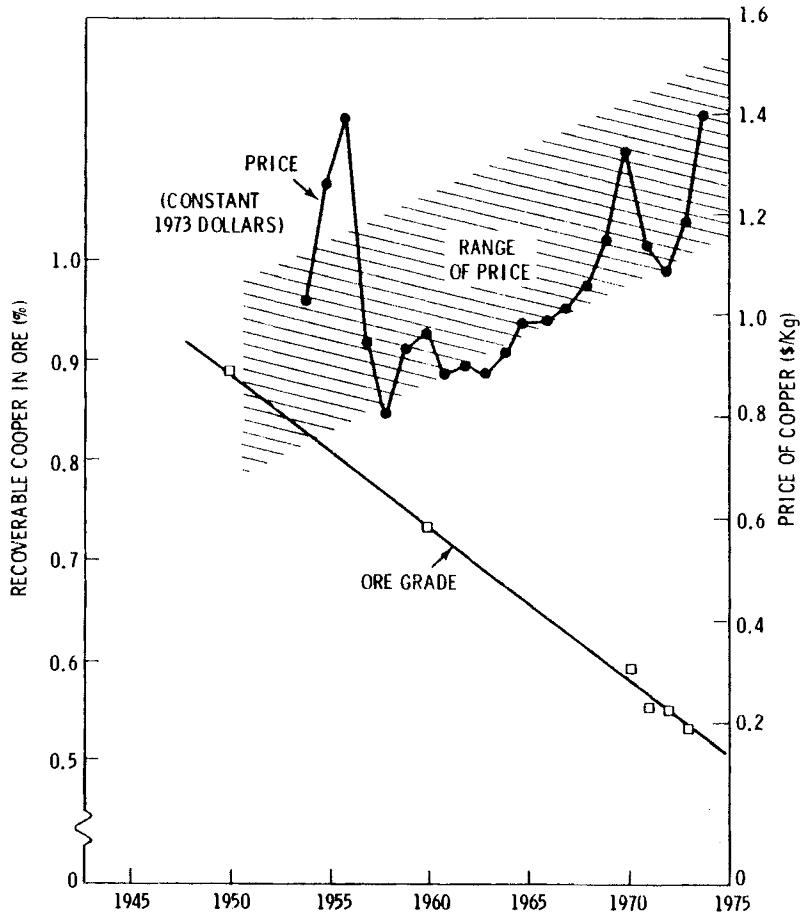

FIGURE 11. Copper Prices and Grade of Copper Ore

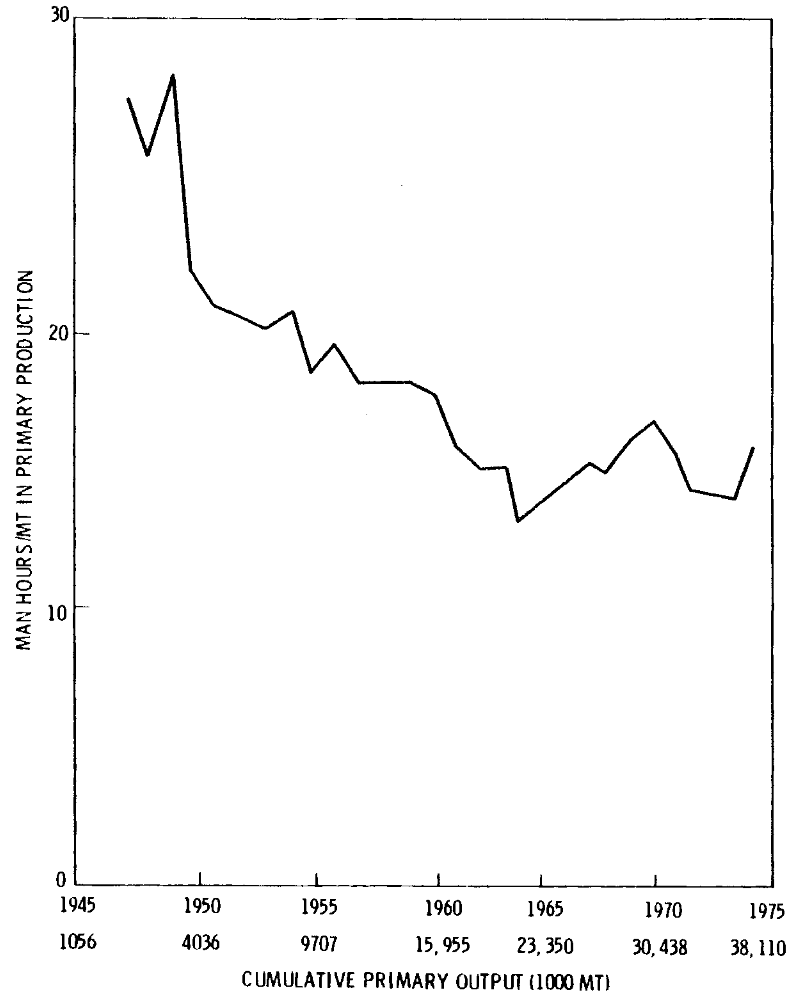

FIGURE 12. Productivity in the Copper Industry, 1947-1975

SOURCE: H.J. Schroeder, Copper Chapter in Mineral Facts and Problems, USBM Bulletin 667, pp. 293-310, 1976.

energy and environmental controls (as with aluminum), are expected to cause upward pressure on production costs and prices.

Designs which use less copper are possible if: (1) higher efficiency photovoltaic cells or concentrating designs are developed, (2) better geometric packing factors for arranging these cells are developed, or (3) transformation and/or voltage step-up designs which enable the use of smaller wires are developed. Implementing these alternatives could considerably reduce the quantity of copper used in these solar photovoltaic designs.

Aluminum is the only practical substitute for copper in these designs. Since the cost of aluminum is expected to increase faster than copper, the substitution of aluminum for copper will probably not lead to a cost reduction. Therefore, of the three alternatives only designs using less copper offer the potential to reduce the costs attributable to copper.

Gallium - Bulk Material Concerns - The screening process identified gallium in the Gallium Arsenide (GaAs) System as a potential problem material in meeting the goal of 50 GWe in the year 2000 (Table 7). Gallium is almost entirely derived as a byproduct. In order to meet the needs for gallium in the GaAs design, as well as other forecasted uses of gallium, a 17% compound growth rate in production is necessary. Photovoltaic uses alone would require 92% 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 the reference design, there is concern both to the stability of the price and supply. Under current prices, gallium contributes $41/KW to the capital cost of the system (Table 7).

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.

We have estimated that gallium for the development of the incremental peak capacity in the year 2000 requires approximately 28.4 million metric tons of bauxite. This represents about 11% of the forecasted bauxite production in the year 2000. Therefore, sufficient gallium should be available from expanded bauxite production alone to satisfy the needs of this photovoltaic system. 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 currently $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 the GaAs system is 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. A capacity of 50 GWe would require about 2,560 metric tons of gallium. Rapid expansion of gallium production is required by the development of this photovoltaic system, 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 13, 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 13 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.

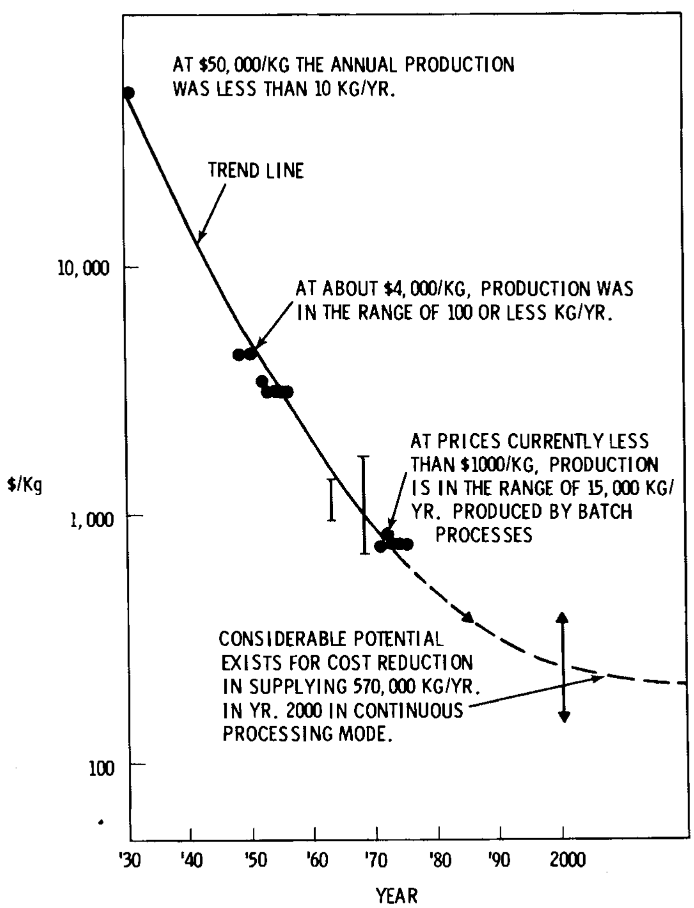

FIGURE 13. Price History for Gallium

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. 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 exists in aluminum production processes to meet the needs of the GaAs system, significant improvements are necessary in gallium recovery processes and large increases are necessary in gallium production capacity. 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 the GaAs system is 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 Bulk and Raw Material Concerns - Germanium, potentially a critical material in the GaAs photovoltaic system (see Table 7), generates the following concerns:

- 100% supplied as a byproduct of zinc production
- Compound growth rate of 16%/year
- Almost total dominance of the market by solar (96%)
- High cost contribution of $78/KWe

Table 10 reveals that solar requirements for "zince byproduct" (sludges needed as raw materials in germanium production) are very large compared to expected future production rates.

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:

1. finding a directly minable ore,
2. exploiting a new byproduct source, and/or
3. 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 the GaAs system 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 14. 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 produce a technology 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 GaAs-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) <u>a modest R&D program to determine the feasibility of a lower cost</u>

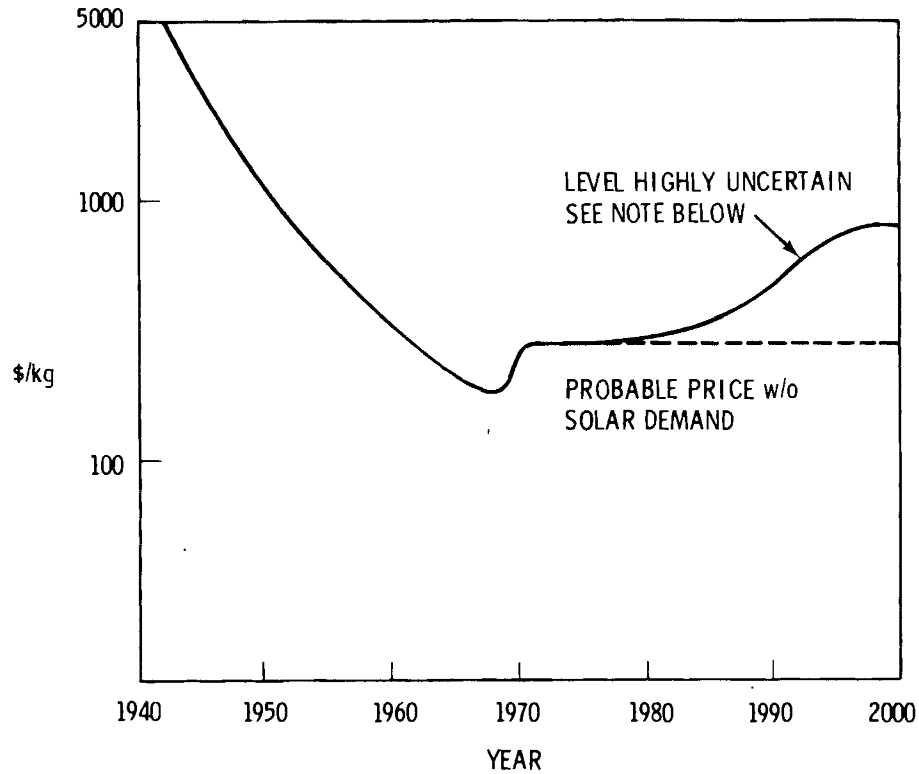

FIGURE 14. Price History and Future Price Outlook for Germanium (Data from U.S. Geological Survey Profesisonal Paper 820, p. 239.36)

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)

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 - The only concern for iron and steel is the $80/KWe to $82/KWe material cost in the systems examined. 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 non-solar supply and demand factors. The key question then is "Whether a significant probability exists for future price decreases in steel?" To be significant for these examples, a price decrease of 50% would be required. 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 design is an engineering prototype and not a commercial design, it is highly likely this can be accomplished.

Silicones - Bulk Material Concerns - The primary concern with silicones is their high cost $298/KWe in the silicon n/p single crystal designs (Table 6). Other concerns of lesser importance are the 10% growth rate requirement in production capacity and the 70% of world consumption required to meet photovoltaic uses.

Silicones are manufactured from abundantly available raw materials. There are four domestic producers; they operate seven silicone production facilities at widely scattered locations throughout the U.S. Silicones are made into a wide variety of end products. Production of these products has been increasing at the rate of 15%/year (Figure 15). Therefore, the 10% growth rate required to meet solar needs should be readily achievable.

The concentration of consumption in the solar market, however, might constrain expansion since more risk is involved in supplying a narrow market, particularly a new one in which technology changes rapidly. For this reason, we recommend undertaking periodic studies to determine the long range demand for silicones. These studies would assess the economic and technical feasibility of the solar design concepts, assess the potential market penetration, and evaluate alternative materials to silicones. If the long range demand for silicones can be reasonably assured on economic and technical grounds, then industry could be inspired to voluntarily expand capacity to meet demand.

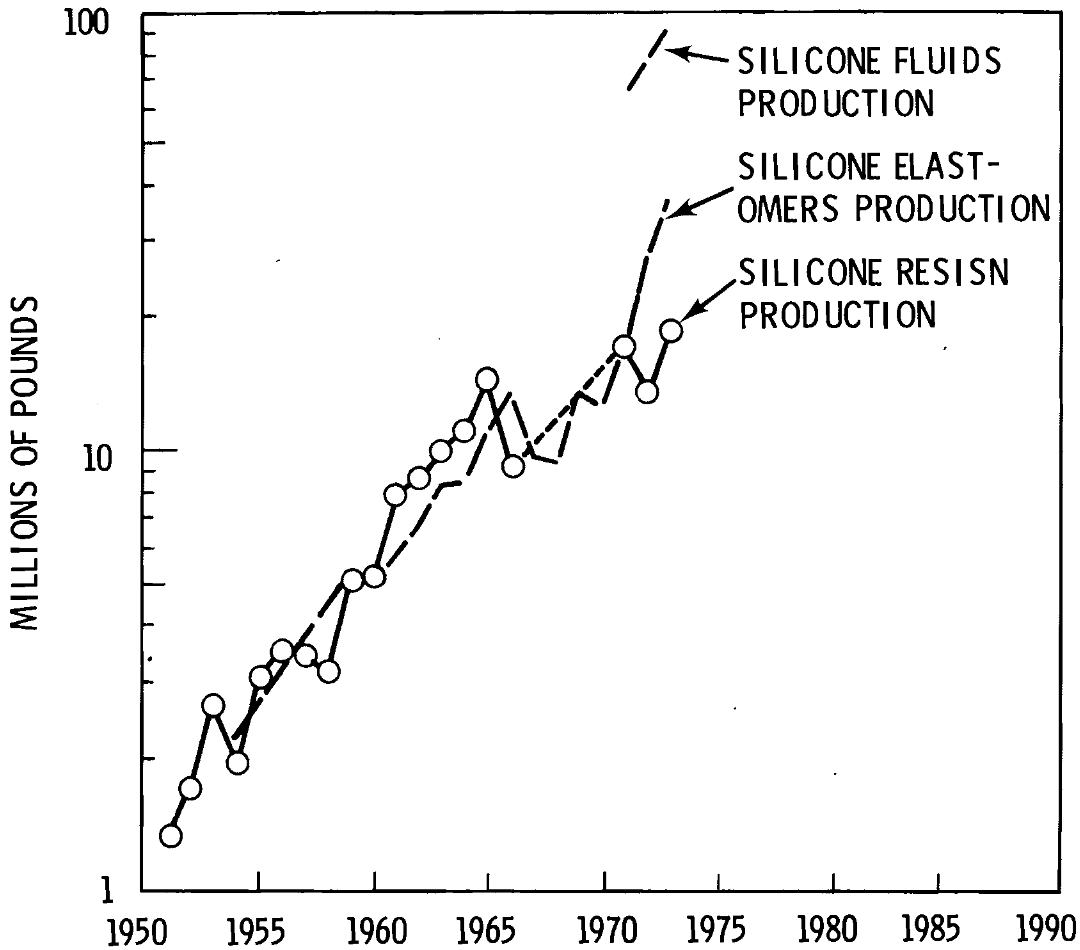

FIGURE 15. Silicone Production

The high cost for silicones should decrease with time as technology improvements and economies of scale are achieved in the manufacture of silicones. Prices for silicone products have dropped substantially since the early 1950's when silicones were first produced commercially (Figure 16.) We project continuing price declines, but at a slower rate because the industry is maturing and because the cost of energy required in the manufacturing process is increasing. However, even with a price decline, silicones will continue to be a major cost element in this photovoltaic system design.

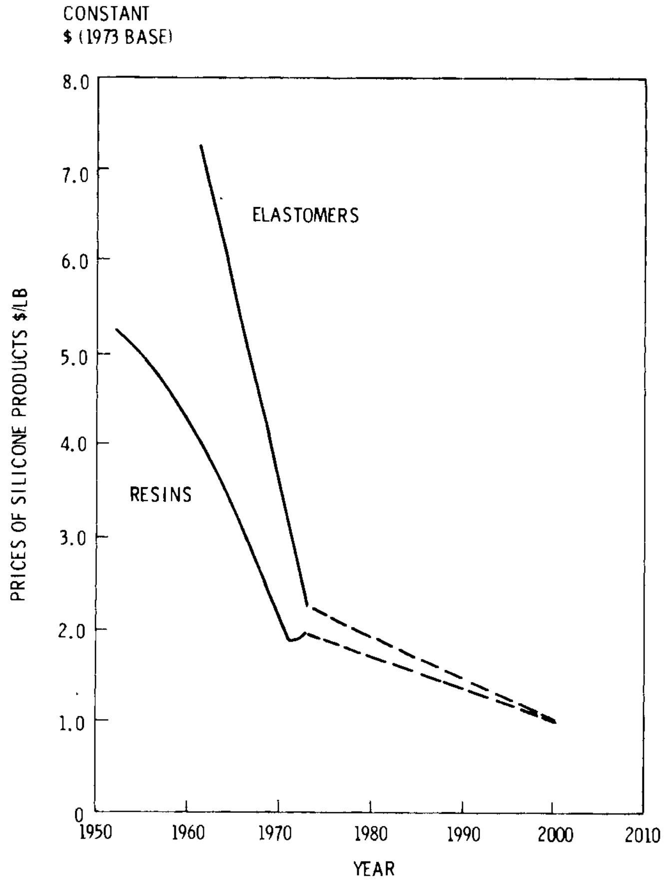

FIGURE 16. Price History and Future Price Forecast for Silicones

CONCLUSIONS

This methodology provides decision makers with a rapid and efficient determination of potential materials problems implicit in the implementation of a solar development plan. The results can be used to evaluate alternative designs, establish realistic goals, and design research programs to develop solutions to materials problems.

The usefulness of this methodology in identifying potential materials problems has been demonstrated. Future efforts will be directed toward additional data collection and analysis of materials problems for other solar designs.

An overview of key materials that could influence implementation of these two example photovoltaic systems are summarized in Table 12.

TABLE 12. Overview of Significant Materials Problems for the Silicon N/P Single Crystal and GaAs-MIS Designs

Materials	Problems with Photovoltaic Use	Mitigation Strategies
Aluminum	- Large amounts of Al consumed - High cost per peak KWe	- Develop more Al effecient designs - Develop suitable substitutes for Al
Bauxite	- Few domestic sources	- Because of the dispersed nature of world supplies and the availability of domestic clays, this does not appear to be a problem.
Antimony and Antimony Ore	- High % supplied as a by-product - 55% is currently imported.	- Antimony sources are widely distributed and substitutes have been identified. Not a serious problem.
Copper and Copper Ore	- High cost in the silicon cell design	- Develop designs with: (1) higher efficiency, (2) better geometric packing factors, (3) voltage step-up to minimize copper wiring.
Gallium	- Derived as a by-product of zinc & aluminum production - Significant growth in production capacity needed to meet needs of solar. - Nearly 1/2 of all Ga is supplied by one country outside the U.S. - Current imports are 75% of domestic consumption	- Support R&D into improved processes for Ga recovery. - Provide long-range incentives and guarantees to inspire capital investment. - Develop cell designs that minimize Ga requirements.

TABLE 12. (continued)

Material	Problems With Photovoltaic Use	Mitigation Strategies
Germanium	- 100% supplied as a by-product - High production growth rate required - High % of market required by solar - High cost per peak KWe	- Design for minimum use of germanium - Develop new sources and production processes to improve availability and cost
Iron and Steel	- High cost \$80-82 per KWe	- Reduce steel requirements in future designs
Silicones	- Very high cost \$298/KWe in the silicon n/p desgin	- Develop substitute sealers for future designs.

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APPENDIX A

SOLAR DESIGNS ON WHICH MATERIAL REQUIREMENTS HAVE BEEN CHARACTERIZED

Engineering and bulk material requirements for the 12 SHACOB and AIPH systems listed in this appendix have been estimated. In addition, material requirements for the 13 photovoltaic cells and one photovoltaic system have also been estimated.

SOLAR SYSTEMS CHARACTERIZATION

SHACOB & AIPH SYSTEMS CHARACTERIZED

Space Heating - Solaron Corporation System using 273 ft^2 of steel flat plate collectors - air heat transport.

Space Heating and Domestic Hot Water - Solaron Corporation System using 273 ft^2 of steel flat plate collectors - air heat transport.

Domestic Hot Water - Sunworks copper flate plate collectors (74 ft^2) - water and ethylene glycol heat transport.

Space Heating and Domestic Hot Water - American Heliothermal Corporation System using 268 ft^2 of steel flate plate collectors - water and propylene glycol heat transport.

Space Heating and Cooling and Domestic Hot Water - Ecosol Systems Inc. heat pump system using 258 ft^2 of KTA Corporation evacuated tube collectors - water heat transport.

Space Heating and Cooling and Domestic Hot Water - Kirtland Air Force Base, Exchange Main store using absorption chillers for cooling and 8320 ft^2 of Raypak, Inc., flat plate collectors with aluminum plate and copper tubing - water and ethylene glycol heat transport.

Passive Space Heating - Concrete Trombe wall behind 510 ft^2 of glazing.

Passive Space Heating - Water tank Trombe wall behind 510 ft^2 of glazing.

Passive Space Heating - Direct gain, masonry walls behind 256 ft^2 of glazing.

Industrial Process Hot Water from Solar Ponds - Accelerates chemical leaching of uranium ore at the Sohio mining and milling complex in Bibo, New Mexico. System design by Lawrence Livermore Laboratory uses 100,000 ft^2 of shallow solar ponds - water heat transport.

Industrial Process Heat for Kiln Drying Lumber - Installed on a conventional hardwood drying kiln at the Linden Lumber Company, Linden, Alabama. System design by Lockheed-Huntsville Research and Engineering Center uses 2,520 ft^2 of Chamberlain Manufacturing Corporation steel flat plate collectors - water and ethylene glycol heat transport.

Process Steam for Drying of Textiles at the Westpoint Pepperell Mill in Fairfax, Alabama - System design by Honewell, Incorporated uses 8,300 ft^2 of parabolic-trough, concentrating collectors - water and steam heat transport.

SHACOB AND AIPH SYSTEMS PLANNED FOR FUTURE CHARACTERIZATION

Process Hot Water for Dyeing Fabrics at the Riegel Textile Corporation plant in LaFrance, South Carolina - System design by General Electric Company uses 5,860 ft of G.E. evacuated tube collectors - water and ethylene glycol heat transport.

PHOTOVOLTAIC SYSTEMS CHARACTERIZED

1 Photovoltaic System Characterized for Silicon n/p Single Crystal Cell Based on the Installation at Meade, Nebraska.

1 System Constructed by Modification of the Meade System to Accommodate the Different Efficiency and Packing Factor fo the GaAs-MIS System.

PHOTOVOLTAIC CELLS CHARACTERIZED

Cadmium Sulfide - Copper Sulfide Back Wall

Cadmium Sulfide - Copper Sulfide Front Wall

Cadmium Sulfide Cadmium Telluride

Cadmium Sulfide Indium Phosphide

Copper Oxide - MIS

Cadmium Sulfide Copper Indium Selenide

Silicon Single Crystal

Silicon MIS

Indium - Tin Oxide

Tin-Oxide-Silicon

Amorphous Silicon

Gallium Arsenide, Concentrator Cell

Gallium Arsenide - Thin Film Cell

NOTE: Additional Photovoltaic System Characterizations will be Required to Evaluate the Cells which need Concentration of the Sunlight at Various Levels.

APPENDIX B

BULK MATERIALS DATA BASE

This appendix includes the data used to analyze each of the bulk materials in this report. Some of the information in this Appendix is in computer format due to space limitations. All consumption estimates are in metric tons.

BULK MATERIAL DATA SUMMARY

31-MAY-78

MATERIAL NAME	% SUPPLIED AS BY-PRODUCT	WORLD CONSUMPTION 1976 MILLIONS MT	WORLD CONSUMPTION 2000 MILLIONS MT	% FROM LARGEST NON US COUNTRY	PRICE $/MT	NET PERCENT IMPORTED	U. S. CONSUMPTION 1976 MILLIONS MT	U. S. CONSUMPTION 2000 MILLIONS MT
ALUMINUM	0.	13.	60.	13.	983.	14.	5.	19.
ANTIMONY	100.	0.	0.	22.	3630.	55.	0.	0.
ARSENIC	100.	0.	0.	34.	506.	37.	0.	0.
ASBESTOS	0.	5.	10.	40.	231.	90.	1.	1.
BORON	20.	0.	1.	47.	779.	0.	0.	0.
CEMENT	0.	697.	1440.	18.	36.	4.	68.	200.
CHROMIUM	0.	2.	5.	31.	360.	100.	0.	1.
COAL, BITUMINOUS	0.	3620.	4870.	6.	15.	10.	542.	1420.
COPPER	1.	7.	27.	12.	1533.	45.	2.	5.
GALLIUM	100.	0.	0.	45.	800000.	75.	0.	0.
GERMANIUM	100.	0.	0.	29.	292380.	19.	0.	0.
GLASS	0.	10.	18.	5.	285.	5.	2.	4.
GLASS, FIBERS	0.	1.	4.	5.	330.	2.	0.	1.
GLASS, SODA LIME	0.	10.	18.	5.	285.	5.	2.	4.
GOLD	40.	0.	0.	58.	3247200.	58.	0.	0.
IRON , STEEL	1.	654.	1280.	16.	321.	10.	128.	180.
LEAD	13.	4.	11.	11.	442.	18.	1.	2.
LIME	0.	108.	218.	9.	26.	2.	19.	39.
MAGNESIUM	30.	0.	1.	26.	2024.	0.	0.	0.
FERROMANGANESE	100.	13.	20.	9.	2.	99.	1.	2.
NICKEL	7.	1.	2.	28.	5302.	75.	0.	0.
PALLADIUM	100.	0.	0.	30.	1346400.	96.	0.	0.
PHOSPHOROUS	0.	15.	57.	13.	160.	0.	4.	9.
PORCELAIN	0.	1000000.	1000000.	10.	150.	0.	1000000.	1000000.
SAND & GRAVEL	0.	6060.	15700.	10.	2.	0.	697.	1820.
STONE	0.	7000.	13400.	3.	3.	0.	809.	2270.
SILICON	0.	2.	5.	14.	935.	8.	1.	1.
SILVER	70.	2.	4.	7.	115368.	46.	1.	2.
SULFUR	31.	48.	110.	15.	46.	15.	11.	23.
SULFURIC ACID	20.	170.	550.	15.	50.	0.	35.	100.
TANTALUM	100.	0.	0.	37.	36586.	68.	0.	0.
TIN	25.	0.	0.	29.	8316.	65.	0.	0.
TITANIUM	0.	0.	0.	50.	5940.	50.	0.	0.
TUNGSTEN	100.	0.	0.	6.	14704.	37.	0.	0.
ZINC	25.	6.	11.	21.	814.	88.	1.	2.
STAINLESS STEEL	0.	6.	13.	10.	1000.	15.	1.	2.
PIG IRON	0.	470.	920.	18.	205.	0.	818.	130.
FERROCHROME	5.	10.	32.	18.	2200.	50.	0.	0.
LINSEED OIL	0.	2.	2.	5.	220.	1.	0.	0.
ACRYLIC	0.	2.	7.	5.	1146.	1.	1.	2.

BULK MATERIAL DATA SUMMARY

31-MAY-78

MATERIAL NAME	% SUPPLIED AS BY-PRODUCT	WORLD CONSUMPTION 1976 MILLIONS MT	WORLD CONSUMPTION 2000 MILLIONS MT	% FROM LARGEST NON US COUNTRY	PRICE $/MT	NET PERCENT IMPORTED	U. S. CONSUMPTION 1976 MILLIONS MT	U. S. CONSUMPTION 2000 MILLIONS MT
ALKYD RESIN	0.	1.	5.	5.	1040.	1.	0.	2.
EPOXY RESIN	0.	0.	2.	5.	1500.	5.	0.	1.
EPOXY-FIBERGLASS	0.	0.	2.	5.	1500.	5.	0.	1.
GLUE, PHENOL, FORM	0.	2.	9.	5.	175.	5.	1.	3.
LUMBER, SOFTWOOD	0.	300.	780.	20.	38.	12.	70.	180.
PHENOLIC RESIN	0.	2.	9.	5.	600.	1.	1.	3.
PLASTIC, RESIN	0.	42.	220.	5.	825.	3.	14.	72.
POLYESTER RESIN	0.	1.	7.	5.	800.	0.	0.	2.
PVC PLASTIC	0.	11.	56.	5.	880.	0.	2.	11.
RUBBER, SBR	0.	6.	23.	5.	620.	4.	1.	4.
SILICONES	0.	0.	0.	5.	4000.	1.	0.	0.
TEFLON	0.	0.	0.	5.	6600.	1.	0.	0.
NYLON	0.	0.	1.	5.	2300.	1.	0.	0.
POLYPROPYLENE	0.	3.	18.	5.	660.	1.	1.	6.
COTTON FIBERS	0.	13.	19.	16.	885.	1.	2.	2.
KRAFT FIBERS	0.	60.	120.	10.	425.	15.	28.	60.
TUNG OIL	0.	0.	0.	45.	700.	70.	0.	0.

APPENDIX C

RAW MATERIALS DATA BASE

This appendix includes the data used to analyze each of the raw materials in this report. Some of the information in this Appendix is in computer format due to space limitations. All consumption estimates are in metric tons.

RAW MATERIAL DATA SUMMARY

31-MAY-78

MATERIAL NAME	WORLD CONSUMP 1976 MILLIONS MT	WORLD CONSUMP 2000 MILLIONS MT	PRICE $/MT	RAW RESERVES WORLD MILLIONS MT	RAW RESOURCES WORLD MILLIONS MT	% LARGEST COUNTRY	% RESERVES TOP 3 COUNTRIES	NET PERCENT IMPORTED	U. S. CONSUMP 1976 MILLIONS MT	U. S. CONSUMP 2000 MILLIONS MT	RAW RESERVES U. S. MILLIONS MT	RAW RESOURCES U. S. MILLIONS MT
ANTIMONY ORE	0.	0.	3630.	4.	5.	22.	19.	55.	0.	0.	0.	0.
ARSENIC TRIOXID	0.	0.	506.	4.	21.	34.	31.	96.	0.	0.	0.	3.
ASBESTOS	5.	10.	213.	87.	129.	34.	49.	90.	1.	1.	4.	70.
BARITE	5.	10.	23.	182.	2000.	5.	10.	41.	2.	2.	59.	227.
BAUXITE	75.	240.	15.	24000.	40000.	28.	59.	89.	14.	76.	40.	300.
BORATE	0.	1.	717.	88.	********	50.	90.	3.	0.	0.	18.	*********
BUTANE	3.	5.	35.	800.	6500.	10.	35.	5.	1.	1.	160.	1300.
CHROMITE	2.	5.	219.	518.	2450.	27.	96.	66.	0.	1.	0.	8.
CLAYS	600.	964.	200.	*********	********	10.	20.	0.	46.	164.	*********	*********
COAL	3620.	4870.	15.	808000.	********	6.	50.	10.	542.	1420.	397000.	3600000.
COAL BITUM/LIGN	3620.	4870.	15.	808000.	********	6.	50.	10.	542.	1420.	397000.	3600000.
COPPER ORE	7.	27.	691.	739.	1600.	12.	31.	37.	2.	5.	85.	193.
FELDSPAR	3.	7.	20.	909.	********	10.	3.	5.	1.	2.	545.	*********
FLUORSPAR	4.	14.	116.	202.	364.	22.	43.	50.	1.	4.	15.	34.
GOLD ORE	0.	0.	3247200.	0.	0.	58.	64.	89.	0.	0.	0.	0.
GYPSUM	61.	113.	5.	18200.	********	10.	20.	37.	16.	32.	318.	*********
IRON ORE	873.	1030.	20.	255000.	800000.	11.	40.	35.	125.	117.	17000.	108000.
LEAD ORE	4.	11.	509.	146.	1400.	11.	4.	33.	1.	2.	53.	108.
LIME	110.	217.	32.	*********	********	31.	59.	2.	18.	39.	*********	*********
MANGANESE ORE	10.	20.	327.	2000.	3300.	24.	90.	100.	1.	2.	0.	980.
NATURAL GAS	1000.	3020.	0.	47200.	470000.	30.	50.	5.	404.	548.	4620.	4100.
NICKEL ORE	1.	2.	5070.	55.	130.	37.	70.	75.	0.	0.	0.	15.
NITROGEN, FIXED	48.	114.	203.	*********	********	5.	20.	10.	12.	26.	*********	*********
PETROLEUM	2360.	4850.	122.	75500.	230000.	22.	45.	40.	551.	1310.	3740.	10000.
PHOSPHATE ROCK	106.	414.	22.	18500.	********	13.	60.	0.	32.	63.	2270.	6360000.
PROPANE	98.	130.	35.	2000.	25000.	10.	35.	5.	36.	41.	480.	4000.
RUTILE	1.	1.	600.	34.	90.	90.	80.	100.	0.	0.	3.	9.
SALT	167.	687.	18.	*********	********	5.	1.	9.	41.	124.	*********	*********
SAND/GRAVEL	6060.	15200.	2.	*********	********	0.	0.	0.	697.	1900.	*********	*********
SILVER ORE	0.	0.	115368.	0.	1.	14.	54.	0.	0.	0.	0.	0.
SODIUM NITRATE	48.	114.	203.	*********	********	5.	20.	10.	12.	26.	*********	*********
STONE	7000000.	********	3.	*********	********	3.	20.	0.	809000.	2730000.	*********	*********
SULFUR	48.	110.	46.	2000.	625000.	15.	27.	28.	11.	23.	410.	26000.
TANTALUM ORE	0.	0.	36586.	0.	0.	37.	83.	100.	0.	0.	0.	0.
TIN ORE	0.	0.	8316.	10.	37.	29.	45.	65.	0.	0.	0.	0.
TUNGSTEN ORE	0.	0.	14700.	2.	3.	21.	22.	37.	0.	0.	0.	0.
ZINC ORE	6.	11.	814.	159.	3000.	19.	34.	88.	1.	2.	27.	120.
COTTON	13.	19.	885.	*********	********	16.	35.	1.	2.	2.	*********	*********
FLAX SEED	2.	3.	160.	*********	********	25.	35.	20.	0.	0.	*********	*********
MILK BYPRODUCTS	100.	200.	220.	*********	********	20.	20.	1.	52.	100.	*********	*********

RAW MATERIAL DATA SUMMARY

MATERIAL NAME	WORLD CONSUMP 1976 MILLIONS MT	WORLD CONSUMP 2000 MILLIONS MT	PRICE $/MT	RAW RESERVES WORLD MILLIONS MT	RAW RESOURCES WORLD MILLIONS MT	% LARGEST COUNTRY	% RESERVES TOP 3 COUNTRIES	NET PERCENT IMPORTED	U. S. CONSUMP 1976 MILLIONS MT	U. S. CONSUMP 2000 MILLIONS MT	RAW RESERVES U. S. MILLIONS MT	RAW RESOURCES U. S. MILLIONS MT
LUMBER	1400.	1900.	140.	*********	********	12.	20.	18.	210.	340.	********	********
SEA WATER	********	********	0.	*********	********	0.	0.	0.	********	********	********	********
SOYBEAN	62.	120.	180.	*********	********	12.	35.	0.	31.	80.	********	********
TUNG NUTS	0.	0.	880.	*********	********	70.	35.	80.	0.	0.	********	********
WATER	1000000.	2000000.	0.	*********	********	0.	0.	0.	500000.	1000000.	********	********
WHEAT	340.	710.	130.	*********	********	10.	25.	0.	23.	30.	********	********
MISC.	********	********	500.	*********	********	0.	0.	0.	********	********	********	********
STEAM	2100.	6300.	2.	21000000.	********	10.	15.	0.	700.	2100.	2100000.	********
LIMESTONE	193.	388.	2.	*********	********	5.	10.	2.	33.	70.	********	********
CU ANODES LIMES	7.	27.	1521.	739.	1600.	12.	31.	37.	2.	5.	85.	193.
BAUXITE, BY PRO	75.	240.	0.	24000.	40000.	28.	59.	89.	14.	76.	40.	300.
ZINC, BY PRODUC	6.	11.	0.	159.	3000.	19.	34.	88.	1.	2.	27.	120.
COAL, BY PROD	3620.	4870.	0.	808000.	********	6.	50.	10.	542.	1420.	397000.	3600000.

**** - Represents a very large number exceeding the width of the field.

APPENDIX D

CONVERSION FACTORS FOR BULK TO RAW CONVERSION

This Appendix includes the results of process analysis and shows the number of metric tons of each raw material necessary to produce one metric ton of each bulk material.

BULK MATERIAL : ALUMINUM

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0000
	BAUXITE	5.0500
	COAL	2.0300
	FLUORSPAR	0.0696
	NATURAL GAS	0.0010
	PETROLEUM	0.1000
	SALT	2.9700
	SULFUR	0.2490
	WATER	0.2770
	MISC.	0.0008
	STTEAM	24.1000
	LIMESTONE	2.4000

BULK MATERIAL : ANTIMONY

RAW MATERIALS	NAME	AMOUNT(MT)
	ANTIMONY ORE	105.0000
	ASBESTOS	0.0245
	BAUXITE	0.0002
	CLAYS	0.0001
	COAL	19.8000
	FLUORSPAR	0.0001
	IRON ORE	0.1470
	MANGANESE ORE	0.0002
	NATURAL GAS	0.0160
	PETROLEUM	0.0003
	SALT	43.5000
	SAND/GRAVEL	0.4100
	SULFUR	0.1870
	LUMBER	0.0000
	WATER	3.0600
	MISC.	0.0107
	STTEAM	71.2000
	LIMESTONE	26.8000

BULK MATERIAL : ARGON

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : ARSENIC

RAW MATERIALS	NAME	AMOUNT(MT)
	ARSENIC TRIOXIDE	1.6000
	COAL	0.4400
	NATURAL GAS	0.0000
	WATER	0.0100
	MISC.	0.0000
	STTEAM	0.1500

BULK MATERIAL : ASBESTOS

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	1.0000

BULK MATERIAL : BARIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : BERYLLIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : BISMUTH

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : BORON

RAW MATERIALS	NAME	AMOUNT(MT)
	BORATE	7.6600
	COAL	0.0100
	FLUORSPAR	24.0000
	NATURAL GAS	0.0300
	SALT	164.0000
	SULFUR	15.9000
	WATER	13.0000
	MISC.	0.1500
	STTEAM	73.6000

BULK MATERIAL : BROMINE

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : CADMIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : CARBON BLACK

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : CEMENT

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0000
	BAUXITE	0.0000
	CLAYS	0.1450
	COAL	0.0920
	FLUORSPAR	0.0000
	GYPSUM	0.0480
	IRON ORE	0.0056
	MANGANESE ORE	0.0000
	NATURAL GAS	0.0656
	PETROLEUM	0.0000
	SALT	0.0000
	SAND/GRAVEL	0.0570
	SULFUR	0.0000
	LUMBER	0.0000
	WATER	0.0001
	MISC.	0.0000
	STTEAM	0.0011
	LIMESTONE	1.3700

BULK MATERIAL : CESIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : CHROMIUM

RAW MATERIALS	NAME	AMOUNT(MT)
	CHROMITE	3.0000

BULK MATERIAL : CLAYS

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : COAL, ANTHRACITE

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : COAL, BITUMINOUS

RAW MATERIALS	NAME	AMOUNT(MT)
	COAL BITUM/LIGNT	1.0000

BULK MATERIAL : COBALT

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : COLUMBIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : COPPER

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0000
	BAUXITE	0.0010
	CLAYS	0.0041
	COAL	0.4410
	COPPER ORE	220.0000
	FLUORSPAR	0.0031
	IRON ORE	2.1800
	MANGANESE ORE	0.0008
	NATURAL GAS	0.5140
	PETROLEUM	0.0139
	SALT	0.0006
	SAND/GRAVEL	0.0004
	SULFUR	0.0057
	LUMBER	0.0000
	WATER	4.7700
	MISC.	0.2880
	STTEAM	0.5070
	LIMESTONE	0.2040

BULK MATERIAL : CORRUNDUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : DIAMOND

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : DIATOMITE

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : FLUORINE

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : GALLIUM

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0055
	COAL	130.1000
	NATURAL GAS	0.0781
	SALT	95.4000
	SULFUR	0.4080
	WATER	21.5000
	MISC.	0.0135
	STTEAM	315.0000
	LIMESTONE	1109.0000
	BAUXITE, BY PROD	50000.0000

BULK MATERIAL : GERMANIUM

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0200
	BAUXITE	0.0026
	CHROMITE	0.5800
	CLAYS	0.0100
	COAL	91.7000
	FLUORSPAR	0.0100
	IRON ORE	6.0000
	MANGANESE ORE	1.6800
	NATURAL GAS	1.5800
	PETROLEUM	0.0350
	SALT	63.4000
	SAND/GRAVEL	13.6000
	SULFUR	100.0000
	LUMBER	0.0001
	WATER	117.0000
	MISC.	7.6000
	STTEAM	74.8000
	LIMESTONE	7.3000
	ZINC, BY PRODUCT	63500.0000

BULK MATERIAL : GRAPHITE

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : GYPSUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : HELIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : HYDROGEN

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : GLASS

RAW MATERIALS	NAME	AMOUNT(MT)
	COAL	0.4190
	FELDSPAR	0.0930
	NATURAL GAS	0.0002
	SALT	0.7590
	SAND/GRAVEL	0.6580
	WATER	0.0650
	STTEAM	0.2140
	LIMESTONE	0.7720

BULK MATERIAL : GLASS, FIBERS

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0000
	BAUXITE	0.4200
	BORATE	0.2500
	COAL	0.1500
	NATURAL GAS	0.0003
	SALT	0.2500
	SAND/GRAVEL	0.5600
	SULFUR	0.0010
	WATER	0.0900
	MISC.	0.0006
	STTEAM	2.2400
	LIMESTONE	0.9100

BULK MATERIAL : GLASS, SODA LIME

RAW MATERIALS NAME	AMOUNT(MT)
COAL	0.4190
FELDSPAR	0.0930
NATURAL GAS	0.0002
SALT	0.7590
SAND/GRAVEL	0.6580
WATER	0.0650
STTEAM	0.2140
LIMESTONE	0.7720

BULK MATERIAL : GOLD

RAW MATERIALS NAME	AMOUNT(MT)
ASBESTOS	0.1220
BAUXITE	0.1390
CLAYS	0.5810
COAL	233.0000
FLUORSPAR	0.4430
GOLD ORE	100000.0000
IRON ORE	311.0000
MANGANESE ORE	1.6900
NATURAL GAS	93.9000
PETROLEUM	31.3000
SALT	506.0000
SAND/GRAVEL	0.0630
SULFUR	4.3100
ZINC ORE	196.0000
LUMBER	0.0060
WATER	9130.0000
MISC.	50.0000
STTEAM	568.0000
LIMESTONE	1660.0000

BULK MATERIAL : INDIUM

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : IODINE

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : IRON , STEEL

RAW MATERIALS NAME	AMOUNT(MT)
ASBESTOS	0.0000
BAUXITE	0.0025
CLAYS	0.0106
COAL	1.1100
FLUORSPAR	0.0080
IRON ORE	5.6500
MANGANESE ORE	0.0212
NATURAL GAS	1.1100
PETROLEUM	0.0358
SALT	0.0015
SAND/GRAVEL	0.0012
SULFUR	0.0001
LUMBER	0.0001
WATER	0.0812
MISC.	0.0090
STTEAM	1.1200
LIMESTONE	0.5280

BULK MATERIAL : LEAD

RAW MATERIALS NAME	AMOUNT(MT)
ASBESTOS	0.0000
BAUXITE	0.0016
CLAYS	0.0002
COAL	0.4140
FLUORSPAR	0.0012
IRON ORE	0.1840
LEAD ORE	33.3000
MANGANESE ORE	0.0007
NITROGEN, FIXED	0.0003
PETROLEUM	0.0007
SALT	0.0470
SAND/GRAVEL	0.0900
SULFUR	0.0023
ZINC ORE	0.1000
LUMBER	0.0000
SEA WATER	1.0270
WATER	0.3840
MISC.	0.0060
STTEAM	0.1920
LIMESTONE	0.1720

BULK MATERIAL : LIME

RAW MATERIALS NAME	AMOUNT(MT)
NATURAL GAS	0.0001
SAND/GRAVEL	0.1600
WATER	0.0305
MISC.	0.0000
STTEAM	0.0005
LIMESTONE	2.8800

BULK MATERIAL : LITHIUM

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : MAGNESIUM

RAW MATERIALS NAME	AMOUNT(MT)
ASBESTOS	0.0030
COAL	0.2700
NATURAL GAS	0.0048
SALT	0.9100
SULFUR	0.0019
SEA WATER	721.0000
WATER	0.1345
STTEAM	0.6650
LIMESTONE	1.9370

BULK MATERIAL : FERROMANGANESE

RAW MATERIALS NAME	AMOUNT(MT)
CLAYS	0.0028
COAL	2.0600
MANGANESE ORE	1.9300
NATURAL GAS	0.0790
MISC.	0.0000
STTEAM	1.3100

BULK MATERIAL : MERCURY

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : MICA

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : MOLYBDENUM

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : NATURAL GAS

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : NICKEL

RAW MATERIALS NAME	AMOUNT(MT)
ASBESTOS	0.0000
BAUXITE	0.0004
CLAYS	0.0015
COAL	2.1100
FLUORSPAR	0.0011
IRON ORE	0.7900
MANGANESE ORE	0.0030
NATURAL GAS	0.1710
NICKEL ORE	100.0000
PETROLEUM	0.0050
SALT	0.2100
SULFUR	0.0000
LUMBER	0.0000
WATER	4.9700
MISC.	0.3900
STTEAM	1.0800
LIMESTONE	1.7200

BULK MATERIAL : NITROGEN, FIXED

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : OXYGEN, GAS

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : PALLADIUM

RAW MATERIALS NAME	AMOUNT(MT)
ASBESTOS	0.0008
COAL	0.2700
NATURAL GAS	0.6900
SALT	6.6400
SULFUR	8895.0000
WATER	186.0000
MISC.	0.0012
STTEAM	113800.0000
LIMESTONE	0.1920
CU ANODES LIMES	476190.0000

BULK MATERIAL : PEAT

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : PERLITE

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : PETROCHEMICALS

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : PHOSPHOROUS

RAW MATERIALS	NAME	AMOUNT(MT)
	COAL	2.3600
	NATURAL GAS	0.0002
	PHOSPHATE ROCK	10.3000
	SAND/GRAVEL	1.3600
	WATER	0.0510
	MISC.	0.0100
	STTEAM	0.8200

BULK MATERIAL : PLATINUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : PORCELAIN

RAW MATERIALS	NAME	AMOUNT(MT)
	CLAYS	0.4800
	FELDSPAR	0.3400
	SAND/GRAVEL	0.1800

BULK MATERIAL : POTASSIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : PUMICE

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : QUARTZ

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : RADIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : RHENIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : RUBIDIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : SALT

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : SAND & GRAVEL

RAW MATERIALS	NAME	AMOUNT(MT)
	SAND/GRAVEL	1.0000

BULK MATERIAL : STONE

RAW MATERIALS	NAME	AMOUNT(MT)
	NATURAL GAS	0.0000
	STONE	1.0000
	WATER	0.0100
	MISC.	0.0000
	STTEAM	0.0002

BULK MATERIAL : SELENIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : SILICON

RAW MATERIALS	NAME	AMOUNT(MT)
	COAL	1.2500
	NATURAL GAS	0.0001
	SAND/GRAVEL	2.1400
	WATER	0.0258
	MISC.	0.0000
	STTEAM	0.4300

BULK MATERIAL : SILVER

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0000
	BAUXITE	0.0040
	CLAYS	0.0160
	COAL	7.4800
	FLUORSPAR	0.0121
	IRON ORE	8.7400
	MANGANESE ORE	0.0440
	NATURAL GAS	2.0500
	PETROLEUM	2.4500
	SALT	7.5300
	SAND/GRAVEL	0.0020
	SILVER ORE	7127.0000
	SULFUR	1.6600
	ZINC ORE	3.9200
	LUMBER	0.0002
	WATER	92.7000
	MISC.	1.2300
	STTEAM	12.8000
	LIMESTONE	37.4000

BULK MATERIAL : SODIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : STRONTIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : SULFUR

RAW MATERIALS	NAME	AMOUNT(MT)
	SULFUR	1.0000

BULK MATERIAL : SULFURIC ACID

RAW MATERIALS	NAME	AMOUNT(MT)
	SULFUR	0.3400

BULK MATERIAL : TALC

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : TANTALUM

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0087
	COAL	2.4700
	FLUORSPAR	4.8800
	NATURAL GAS	0.0053
	PROPANE	8.0300
	SALT	51.4000
	SULFUR	2.1300
	TANTALUM ORE	370.0000
	WATER	1.4800
	MISC.	0.0221
	STTEAM	32.3000
	LIMESTONE	2.2100

BULK MATERIAL : TELLURIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : THALLIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : THORIUM

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : TIN

RAW MATERIALS	NAME	AMOUNT(MT)
	CLAYS	0.1600
	COAL	0.2850
	TIN ORE	10000.0000
	LIMESTONE	0.0470

BULK MATERIAL : TITANIUM

RAW MATERIALS NAME	AMOUNT(MT)
ASBESTOS	0.0001
COAL	1.0800
NATURAL GAS	0.1950
RUTILE	4.1700
SALT	2.1800
SULFUR	0.0046
SEA WATER	184.0000
WATER	0.7840
MISC.	0.0150
STTEAM	1.8000
LIMESTONE	0.7730

BULK MATERIAL : TUNGSTEN

RAW MATERIALS NAME	AMOUNT(MT)
ASBESTOS	0.0038
BAUXITE	0.0007
CLAYS	0.0032
COAL	8.1100
COPPER ORE	9.6500
FLUORSPAR	0.0025
IRON ORE	1.7500
MANGANESE ORE	0.0100
NATURAL GAS	0.6000
PETROLEUM	0.0100
SALT	25.0000
SAND/GRAVEL	0.0684
SULFUR	0.1000
TUNGSTEN ORE	167.0000
LUMBER	0.0000
WATER	73.3000
MISC.	0.0900
STTEAM	29.5000
LIMESTONE	10.8000

BULK MATERIAL : URANIUM

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : VANADIUM

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : VERMICULITE

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : WATER

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : YTTRIUM

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : ZINC

RAW MATERIALS NAME	AMOUNT(MT)
ASBESTOS	0.0000
BAUXITE	0.0001
CLAYS	0.0003
COAL	0.0330
FLUORSPAR	0.0002
IRON ORE	0.1700
MANGANESE ORE	0.0480
NATURAL GAS	0.0350
PETROLEUM	0.0010
SALT	0.0000
SAND/GRAVEL	0.0000
SULFUR	0.0290
ZINC ORE	17.8000
LUMBER	0.0000
WATER	0.6140
MISC.	0.3020
STTEAM	0.0350
LIMESTONE	0.0160

BULK MATERIAL : ZIRCONIUM

RAW MATERIALS NAME	AMOUNT(MT)

BULK MATERIAL : STAINLESS STEEL

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0000
	BAUXITE	0.0000
	CHROMITE	0.6380
	CLAYS	0.0540
	COAL	1.1300
	FLUORSPAR	0.0001
	IRON ORE	3.4600
	MANGANESE ORE	0.0002
	NATURAL GAS	0.0140
	NICKEL ORE	8.0000
	PETROLEUM	0.0220
	SALT	0.0170
	SAND/GRAVEL	1.0300
	SULFUR	0.0000
	LUMBER	0.0270
	WATER	0.4760
	MISC.	0.0440
	STTEAM	0.8330
	LIMESTONE	1.3900

BULK MATERIAL : PIG IRON

RAW MATERIALS	NAME	AMOUNT(MT)
	CLAYS	0.0030
	COAL	0.9730
	IRON ORE	5.1200
	NATURAL GAS	0.0003
	PETROLEUM	0.0300
	WATER	0.0700
	MISC.	0.0080
	STTEAM	0.9900
	LIMESTONE	0.2750

BULK MATERIAL : FERROCHROME

RAW MATERIALS	NAME	AMOUNT(MT)
	CHROMITE	2.4800
	CLAYS	0.2040
	COAL	1.2300
	NATURAL GAS	0.0004
	SAND/GRAVEL	1.0600
	LUMBER	0.1060
	WATER	0.1190
	MISC.	0.0310
	STTEAM	0.3450
	LIMESTONE	4.1800

BULK MATERIAL : LINSEED OIL

RAW MATERIALS	NAME	AMOUNT(MT)
	FLAX SEED	2.9400

BULK MATERIAL : ACRYLIC

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0006
	COAL	0.4000
	NATURAL GAS	37.5000
	PROPANE	0.8600
	SALT	3.4200
	SULFUR	0.4140
	MISC.	0.0016
	STTEAM	2.4500
	LIMESTONE	0.1400

BULK MATERIAL : ALKYD RESIN

RAW MATERIALS	NAME	AMOUNT(MT)
	PETROLEUM	0.1400
	SOYBEAN	2.8900
	WATER	0.0400
	COAL, BY PROD	10370.0000

BULK MATERIAL : EPOXY RESIN

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0100
	COAL	0.7000
	NATURAL GAS	0.0046
	PROPANE	0.4900
	SALT	12.3000
	SULFUR	0.0400
	WATER	0.6900
	MISC.	0.0020
	STTEAM	15.0000
	LIMESTONE	5.0000
	COAL, BY PROD	491.0000

BULK MATERIAL : EPOXY-FIBERGLASS

RAW MATERIALS	NAME	AMOUNT(MT)

BULK MATERIAL : CALCIUM

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0000
	BAUXITE	2.2700
	COAL	1.3600
	FLUORSPAR	0.0313
	NATURAL GAS	0.0008
	PETROLEUM	0.0450
	SALT	1.3400
	SULFUR	0.1120
	WATER	0.2100
	MISC.	0.0003
	STTEAM	10.8000
	LIMESTONE	9.1400

BULK MATERIAL : GLUE, PHENOL, FORM

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0062
	COAL	0.1120
	NATURAL GAS	0.0005
	SALT	2.2600
	SULFUR	0.0100
	MILK BYPRODUCTS	0.0094
	WATER	0.5800
	WHEAT	0.2800
	MISC.	0.0003
	STTEAM	3.5500
	LIMESTONE	1.2400
	COAL, BY PROD	163.0000

BULK MATERIAL : LUMBER, SOFTWOOD

RAW MATERIALS	NAME	AMOUNT(MT)
	LUMBER	1.0000
	WATER	21.2000

BULK MATERIAL : PHENOLIC RESIN

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0006
	COAL	0.3360
	NATURAL GAS	0.0019
	SALT	8.0600
	SULFUR	0.0337
	MILK BYPRODUCTS	0.0336
	WATER	0.5050
	MISC.	0.0011
	STTEAM	12.7000
	LIMESTONE	4.4300
	COAL, BY PROD	582.0000

BULK MATERIAL : PLASTIC, RESIN

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0006
	COAL	0.3360
	NATURAL GAS	0.0019
	SALT	8.0600
	SULFUR	0.0337
	MILK BYPRODUCTS	0.0336
	WATER	0.5050
	MISC.	0.0011
	STTEAM	12.7000
	LIMESTONE	4.4300
	COAL, BY PROD	582.0000

BULK MATERIAL : POLYESTER RESIN

RAW MATERIALS	NAME	AMOUNT(MT)
	NATURAL GAS	1.3800
	WATER	0.3100
	COAL, BY PROD	1137.0000

BULK MATERIAL : PVC PLASTIC

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0004
	COAL	1.5200
	NATURAL GAS	0.0003
	SALT	1.2700
	SULFUR	0.0026
	WATER	0.0300
	MISC.	0.0126
	STTEAM	1.2500
	LIMESTONE	3.5400

BULK MATERIAL : RUBBER, SBR

RAW MATERIALS	NAME	AMOUNT(MT)
	BUTANE	1.1100
	NATURAL GAS	0.1100
	SALT	0.1000
	SULFUR	0.0034
	WATER	2.0000
	COAL, BY PROD	178.0000

BULK MATERIAL : SILICONES

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0014
	BAUXITE	0.0000
	CLAYS	0.0001
	COPPER ORE	6.6000
	FLUORSPAR	0.0001
	IRON ORE	0.0650
	MANGANESE ORE	0.0000
	NATURAL GAS	0.8580
	PETROLEUM	0.0004
	SALT	4.3300
	SAND/GRAVEL	0.6600
	SULFUR	0.0092
	LUMBER	0.0000
	WATER	0.0090
	STTEAM	2.9400
	LIMESTONE	0.3260

BULK MATERIAL : TEFLON

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0019
	COAL	0.3400
	FLUORSPAR	1.7400
	NATURAL GAS	0.3700
	SALT	6.1000
	SULFUR	0.7500
	WATER	0.0500
	STTEAM	3.9500
	LIMESTONE	0.4500

BULK MATERIAL : NYLON

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0003
	BUTANE	0.8300
	COAL	0.2400
	NATURAL GAS	0.3200
	SALT	1.5700
	SULFUR	0.0020
	WATER	85.9000
	MISC.	0.0010
	STTEAM	2.8300
	LIMESTONE	0.1200
	COAL, BY PROD	447.0000

BULK MATERIAL : POLYPROPYLENE

RAW MATERIALS	NAME	AMOUNT(MT)
	ASBESTOS	0.0011
	COAL	0.1900
	NATURAL GAS	0.0005
	PROPANE	1.1000
	SALT	5.9200
	SULFUR	0.0100
	WATER	0.1200
	MISC.	0.0024
	STTEAM	3.1800
	LIMESTONE	0.2400

BULK MATERIAL : COTTON FIBERS

RAW MATERIALS	NAME	AMOUNT(MT)
	COTTON	1.0000

BULK MATERIAL : KRAFT FIBERS

RAW MATERIALS	NAME	AMOUNT(MT)
	COAL	0.2800
	NATURAL GAS	0.0002
	LUMBER	2.0000
	WATER	0.0500
	MISC.	0.4300
	STTEAM	6.6200
	LIMESTONE	1.0400

BULK MATERIAL : TUNG OIL

RAW MATERIALS	NAME	AMOUNT(MT)
	TUNG NUTS	2.0000

APPENDIX E

Characterization of
MIT-LL and UNL PHOTOVOLTAIC SYSTEM
at Mead, Nebraska

Modified with State-of-the-Art
Silicon n/p Single Crystal Cells at 10% Efficiency
and GaAs MIS Thin Film Cells at 10% Efficiency

MIT-LL and UNL Photovoltaic System
at Mead, Nebraska

Modified with State-of-the-Art

Silicon n/p Single Crystall Cells - 10% Efficiency

This sytem 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.

A total of 28 flat panels, each 8 feet by 25 feet, comprise the array. The units peak power of 25 KW is derived from 240 square meters of silicon operating at 10.4% efficiency. The state-of-the-art silicon cells use less material than those now in production.

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.

MIT-LL AND UNL PHOTOVOLTAIC SYSTEM
AT MEAD, NEBRASKA

MODIFIED WITH STATE OF THE ART SILICON N/P
SINGLE CRYSTAL CELLS - 10% EFFICIENCY

TECHNOLOGY:	PHOTOVOLTAICS
CAPACITY:	25 KW PEAK
APPLICATION:	CROP IRRIGATION AND DRYING
LOCATION:	MEAD, NB
INSOLATION:	2000 KW-HR/M*M/YR
SOLAR CONTRIBUTION:	
SUPPLEMENT:	LINE POWER
SOLAR EFFICIENCY:	10%
COLLECTOR AREA:	240M*M
OPERATING TEMPERATURE:	AMBIENT
ENERGY TRANSPORT MEDIUM:	ELECTRICAL
STORAGE TYPE:	LEAD-ACID BATTERIES
STORAGE CAPACITY:	85 KW-HR

MATERIAL REQUIREMENTS
BY
FUNCTIONAL COMPONENTS

			KILOGRAMS
12.	ENERGY COLLECTOR		
	12.02 GLAZING	SILICONE	1860.
	12.03 ABSORBER - SIN/P SINGLE CRYSTAL 10% EFFICIENCY		
	ACTIVE LAYERS	SILICON	29.1
	N-DOPANT	PHOSPHOROUS	2.59-04
	P-DOPANT	BORON	2.26-06
	GRID CONTACT	TITANIUM	2.26-03
		PALLADIUM	2.93-03
		SILVER	.655
	BACK CONTACT	ALUMINUM	3.38
	AR COATING	TANTALUM	.168
	12.04 ENERGY TRANSPORT		
	PANEL INTERCONNECTS	COPPER	35.0
		TEFLON	3.26
	ELECTRICAL BOXES, WIREWAYS, INSULATORS, ECT		
		CARBON STEEL	1320.
		STAINLESS STEEL	204.
		COPPER	572.
		PLASTICS, LAMINATES	.91
		NYLON	.50
		ALUMINUM	15.3
		RUBBER	22.6
		60-40 SOLDER	23.6
	12.07 FRAME		
	SOLAR CELL MODULE BACKING PANELS		
		FRP POLYESTER	1080.
		ALUMINUM	1140.
	12.09 SUPPORTS		
	UPRIGHTS	6061 ALUMINUM	2240.
		STAINLESS STEEL	206.
		CONCRETE	1.002+05
	FRAMEWORK	6061 ALUMINUM	1.17+04
		STAINLESS STEEL	446.
		CARBON STEEL	298.

			KILOGRAMS
13.	ENERGY TRANSPORT		
	13.02 ELECTRICAL WIRE	COPPER	264.
		PVC	24.
	13.05 SUPPORTS		
	CONDUIT	ALUMINUM	909.
		CARBON STEEL	6.90
	CONDUIT SEALS	RUBBER	2.33
14.	ENERGY CONVERSION*		
15.	ENERGY STORAGE		
	15.01 MISCELLANEOUS		
	BATTERY BUILDING 10FT X 20FT	CARBON STEEL	1043.
		CONCRETE	252.
		FIBERGLASS WOOL	354.
		PLYWOOD-SOFT WOOD	198.
	BATTERY COVERS	ACRYLIC	53.
	BATTERY INTERCONNECTS	COPPER	14.6
		PHENOLIC	.045
		MICARTA	.916
		EPOXY	.907
	15.02 PRIMARY STORAGE		
	38 BATTERIES, 375 AMP-HR AT 6 VOLTS	LEAD-5% ANTIMONY	1197.
		LEAD-0.3% CALCIUM	1438.
		SULFURIC ACID	726.
		POLYPROPYLENE	207.
	15.04 SUPPORT	STAINLESS STEEL	306.
		CARBON STEEL	183.
16.	ENERGY CONITIONING		
	16.02 INVERTER		
	ENCLOSURE	CARBON STEEL	106.
	CORE CLAMPS	CARBON STEEL	34.0
	CORES, WINDINGS	COPPER	150.
		SILICON STEEL	417.
		VARNISH	6.80
	INSULATION	POLYESTER	4.08
	INSTRUMENTATION	PHENOLIC	4.08
		COPPER	1.36
		ZINC	.68
		GLASS-SODA LIME	.68
	SILICON CONTROLLED RECTIFIERS	COPPER	5.0
		SILICON	.11
		ELECTRICAL PORCELAIN	.34

* Not Applicable to this Design.

17. ENERGY SYSTEMS CONTROLLER		*KILOGRAMS*
17.01 MISCELLANEOUS BUILDING 15FT X 25FT		
	CARBON STEEL	1497.
	CONCRETE	472.
	FIBERGLASS WOOL	544.
	PLYWOOD-SOFT WOOD	305.
17.02 METERS, SWITCHES, RELAYS, TERMINAL BOARDS, ETC		
	COPPER	29.5
	CARBON STEEL	50.8
	PHENOLIC	11.3
	STAINLESS STEEL	64.4
	PLASTICS	8.85
17.03 SUPPORTS - CABINETS, ETC		
	ALUMINUM	160.
	STAINLESS STEEL	10.5
	CARBON STEEL	1359.
	EPOXY/GLASS LAMINATE	.24

MIT-LL and UNL Photovoltaic System

at Mead, Nebraska

GaAs-MIS Thin Film Cell Modification

State-of-the-Art Cells at 10% Efficiency

A geometric packing factor of 0.8 is assumed for this GaAs 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 GaAs-MIS Thin Film Cells operating 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 sytem 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.

MIT-LL AND UNL PHOTOVOLTAIC SYSTEM
AT MEAD, NEBRASKA

GAAS MIS THIN FILM CELL MODIFICATION
STATE-OF-THE-ART CELLS AT 10% EFFICIENCY

TECHNOLOGY:	PHOTOVOLTAICS
CAPACITY:	25 KW PEAK
APPLICATION:	CROP IRRIGATION AND DRYING
LOCATION:	MEAD, NB
INSOLATION:	2000 KW-HR/M*M/YR
SOLAR CONTRIBUTION:	
SUPPLEMENT:	LINE POWER
SOLAR EFFICIENCY:	10%
COLLECTOR AREA:	250M*M
OPERATING TEMPERATURE:	AMBIENT
ENERGY TRANSPORT MEDIUM:	ELECTRICAL
STORAGE TYPE:	LEAD-ACID BATTERIES
STORAGE CAPACITY:	85 KW-HR

			KILOGRAMS
12.	ENERGY COLLECTOR		
12.02	GLAZING	SODA LIME GLASS	2440.
12.03	ABSORBER-GAAS MIS THIN FILM 10% EFFICIENCY ACTIVE REGION	GALLIUM	1.28
		ARSENIC	1.38
	N-DOPANT	GERMANIUM	4.0-07
	EPITAXY LAYER	GERMANIUM	6.65
	BARRIER LAYER	GOLD	.039
	GRID ELECTRODE	COPPER	.558
	BACK CONTACT	TUNGSTEN	4.83
	AR COATING	TANTALUM	.112
12.04	ENERGY TRANSPORT PANEL INTERCONNECTS	COPPER	21.0
		TEFLON	1.96
		CARBON STEEL	794.
		STAINLESS STEEL	123.
		COPPER	344.
		PLASTICS, LAMINATES	.544
		NYLON	.286
		ALUMINUM	9.07
		RUBBER	13.6
		60-40 SOLDER	14.2
12.07	FRAME SOLAR CELL BACKING PANEL	CARBON STEEL	748.
12.09	SUPPORTS UPRIGHTS	6061 ALUMINUM	1350.
		STAINLESS STEEL	124.
		CONCRETE	6.030+04
	FRAMEWORK	6061 ALUMINUM	7080.
		STAINLESS STEEL	268.
		CARBON STEEL	173.

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