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Preliminary Materials Assessment for the Satellite Power System (SPS)

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SUMMARY AND CONCLUSIONS

Presently, there are two SPS reference design concepts (one using silicon solar cells; the other using gallium arsenide solar cells). A materials assessment of both systems was performed based on the materials lists set forth in the DOE/NASA SPS Reference System Report: "Concept Development and Evaluation Program."[1]

This listing identified 22 materials (plus "miscellaneous and organics) used in the SPS. Tracing the production processes for these 22 materials, a total demand for over 20 different bulk materials (copper, silicon, sulfuric acid, etc.) and nearly 30 raw materials (copper ore, sand, sulfur ore, etc.) was revealed.

Assessment of these SPS material requirements produced a number of potential material supply problems. The more serious problems are those associated with the solar cell materials (gallium, gallium arsenide, sapphire, and solar grade silicon), and the graphite fiber required for the satellite structure and space construction facilities. In general, the gallium arsenide SPS option exhibits more serious problems than the silicon option, possibly because gallium arsenide technology is not as well developed as that for silicon.

The table on the next page summarizes potential material problems that have been identified. Problems of serious concern are denoted by an "A" in the table, and those of lesser but possible concern are denoted by a "B". The "A" materials are discussed briefly below. For more complete discussions including the "B" materials the reader is referred to Section VI of this report.

As shown in the table, the gallium required for solar cells in the gallium arsenide represents a potentially serious problem from a number of standpoints. It is a by-product of aluminum ore (bauxite) much of which is imported. It is also a high-cost material for which the SPS would be the primary consumer. This last problem could be alleviated if concurrent development of terrestrial photovoltaic programs or other uses for gallium emerged. However, this would also drive up the demand for what would be an already scarce commodity. The

SUMMARY OF ASSESSMENT RESULTS

PARAMETER	PERCENT SUPPLIED AS BY-PRODUCT	WORLD PRODUCTION GROWTH RATE	SPS PERCENT OF DEMAND	NET PERCENT IMPORTED	PERCENT WORLD RESOURCE CONSUMPTION	COST $/KW
THRESHOLD VALUE*	50%	10%	10%	50%	200%	$50/KW
Gallium	A	A	A	A		
Graphite Fiber		A	A			A
Sapphire		A	A			A
Silicon SEG		A	A			A
Gallium Arsenide		A	A			A
Electricity						A
Arsenic/Arsenic Trioxide	B			B		
Kapton		B	B			
Oxygen (liq)		B	B			
Silica Fiber		B	B			
Silver	B			B		
Silver ore				B	B	
Glass, borosil.			B			
Hydrogen (liq)		B				
Mercury				B		
Mercury ore				B		
Methane		B				
Petroleum						B
Steel						B
Tungsten				B		

Note: "A" signifies problem of serious concern
"B" signifies problem of possible concern

*Parameter value above which a potential problem exists. Materials in this table exceeded these values where an "A" or "B" is recorded.

production of gallium arsenide is also a problem in that it would need to be greatly expanded and the SPS would again be the dominant consumer. Also, the arsenic and arsenic trioxide needed to produce gallium arsenide represent additional problems due to the weak position of the U.S. arsenic industry (only one plant in operation). Synthetic sapphire used as the substrate for gallium arsenide solar cells is extremely expensive. The SPS program would require major production expansion and would become the primary consumer.

The cost and energy requirements (electricity) associated with the production of solar grade silicon has been and remains a significant problem. In addition, the SPS again would dominate the market, unless parallel terrestrial photovoltaic programs or other applications for high purity silicon were developed. Additional demand would have less impact on silicon than on gallium since the raw material is plentiful. However, it would compound production growth rate problems for the high purity material.

The production of photovoltaic materials requires large amounts of electrical energy. In the case of silicon the energy requirements is so large a silicon solar power satellite would need to operate at least five to six months just to generate enough electricity to make the amount of solar grade silicon used in its solar cells. For gallium arsenide the problem is less severe but possibly only because its defined production process is advanced state-of-the-art, while the silicon process is present or near-term state of the art. It is likely that the high dollar cost and high energy cost of solar materials is interrelated and when one problem is solved, so will the other.

The only problems of serious concern involving a material that appears in both SPS reference concepts are those associated with graphite fiber production. The production growth rate required to meet the combined requirements of the SPS and expected increased demand by the automobile industry could be in the 20-30 percent range sustained for a decade or more. Also, depending on the type of fiber selected, graphite fiber could become one of the highest material cost contributors to the SPS.

In all, potential problems were identified for some 20 SPS materials. Further investigations are needed to determine the severity and implications of these problems and to identify and define corrective actions. These investigations will need to consider factors such as the accuracy of resource and reserve estimates, improved raw material acquisition and beneficiation techniques, improved material production processes, materials acquisition/production economics (such as price/demand elasticity, capital investment requirements, and byproduct/co-product economics), and strategies to alleviate import dependency. In addition, the SPS materials characterization (materials list) used in this study is incomplete and lacks adequate traceability. A more complete characterization is needed that would improve confidence in analysis results.

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I - INTRODUCTION

Major new energy systems being studied to replace or supplement fossil-fuel systems will have significant impacts on society, industry, and various sectors of the economy. Some of these systems require huge amounts of land. Some of these systems require heavy capital investments. In many cases, international agreements may be necessary, often with military implications.

As a result of these potential impacts, there are many factors that require careful attention in considering new systems. Societal impacts, economic effects, and environmental concerns must be weighed, together with the issue of public acceptance. Governmental regulations, building codes, and other institutional factors also require close scrutiny. Of major importance among these many concerns is consideration of materials requirements. Vast quantities of materials can be needed--some of them rare, others costly, many already in heavy demand. The proposed 300-gigawatt Satellite Power System (SPS)(1) could require almost 900 million metric tons of bulk materials (ranging from the common, such as sand and gravel, to the rare or exotic, such as gallium arsenide).

The primary objective of this study was to explore the materials requirements of the SPS to identify potential materials problems and constraints so that appropriate responsive action could be defined and incorporated into overall SPS planning. The approach was to determine SPS materials requirements as identified by DOE/NASA studies(1) and assess the impacts of those requirements using the Battelle Materials Assessment Methodology.(2) The methodology consists of two basic elements: (1) an extensive materials data base that contains information defining the present and future availability of materials; and (2) a computer program (Critical Materials Assessment Program -- CMAP) that computes system (i.e., the SPS in this study) material requirements over time, compares requirements with availability (data

*Superscript numbers refer to references at the end of this report.

base), and flags potential problems or constraints. The results thus generated were reviewed and analyzed to determine the significance and seriousness of identified problems and to recommend appropriate action.

Prior to the conduct of the SPS assessment it was decided (by the Department of Energy and Battelle) to upgrade the computer program (CMAP) and the data base to assure the adequacy of present and future SPS materials studies and similar studies of other systems. CMAP was modified to provide automated tracing of production processes and chains of production processes so that materials required in intermediate production steps would be included in the assessment. Other modifications were instituted that relaxed previous constraints as to the time span that could be considered and the manner in which material demand could be specified. Previous analyses were limited to cases where the time period of interest did not extend beyond the year 2000, and where the growth of material demand occurred exponentially. The CMAP modifications permitted analyses to be extended to 2050, and allowed for the study of any arbitrary material demand growth function.

The entire data base was thoroughly reviewed and upgraded. The data base construction effort encompassed not only materials expected to be required for the SPS but also materials required for other systems (e.g. terrestrial photovoltaic systems and solar heating and cooling of buildings-SHACOB systems). The broader data base will be required for planned future comparative studies in which the material requirements of the SPS will be compared with alternative systems such as coal or nuclear power generating plants.

When the CMAP and data base modifications were completed the SPS materials assessment was conducted. This report focuses on that assessment. CMAP and the data base will be discussed only as necessary to clarify the SPS assessment. However, the entire data base is presented in Appendix A.

II - MATERIALS ASSESSMENT METHODOLOGY

One usually thinks of the flow of materials proceeding from raw materials to the final materials (Figure 1).[2] Take for example, copper. Copper ore is mined and sent to a mill and smelter. The bulk material, copper, that leaves this process may be formed into a final engineering material like brass (an alloy of copper and zinc). This brass may then be machined and fabricated into hardware components for the SPS or some other system. The tracking process needed in a materials assessment follows the opposite direction. First, the amount of brass in the system being studied must be determined. Then this is translated into its bulk materials, one of which is copper. At this point the bulk material copper would be reviewed for possible capacity constraints. Next the copper production process would be analyzed and

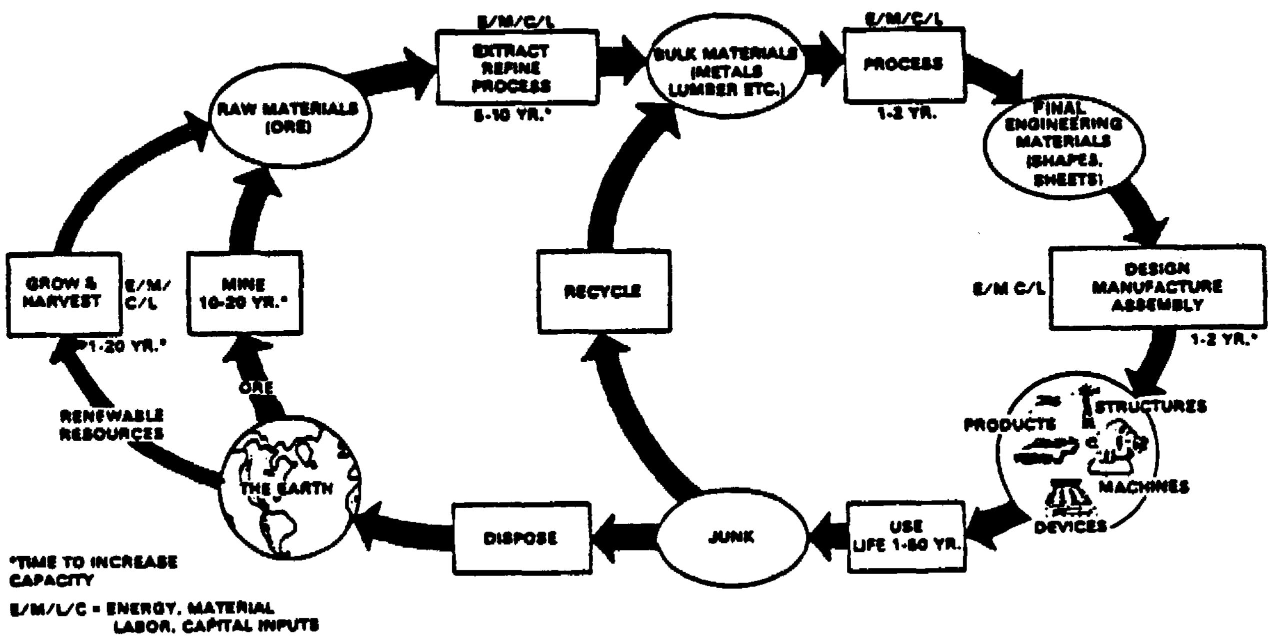

FIGURE 1. THE MATERIALS CYCLE

its material needs identified: copper ore, sulfuric acid, steel, electricity, coal, etc. The copper ore and all of the other bulk* and raw materials are then checked for potential capacity constraints and for availability of reserves and resources. Figure 2 describes the foregoing relationships graphically. The production of these secondary materials must also be analyzed to complete the materials assessment. This analysis logic could conceivably proceed on through several additional steps but in practice is terminated after two additional

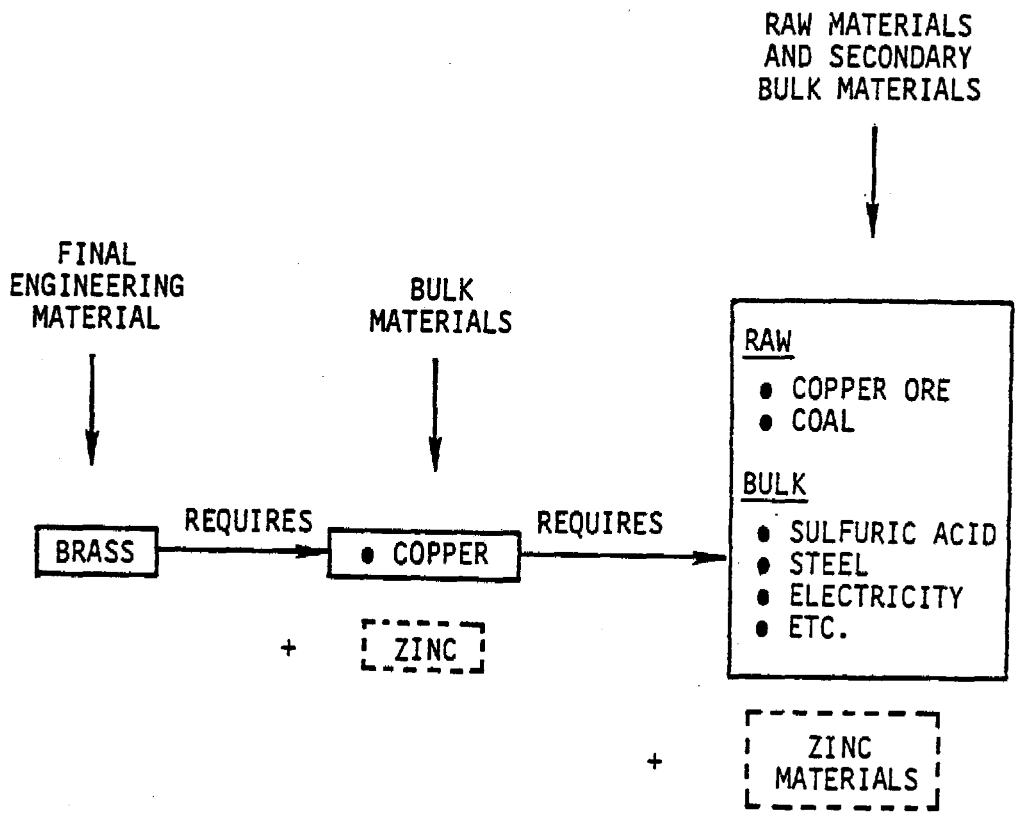

FIGURE 2. TYPICAL CONVERSION CHAIN OR MATRIX

*Bulk materials required to produce other bulk materials (e.g. sulfuric acid required to produce copper) are referred to as "secondary" bulk materials.

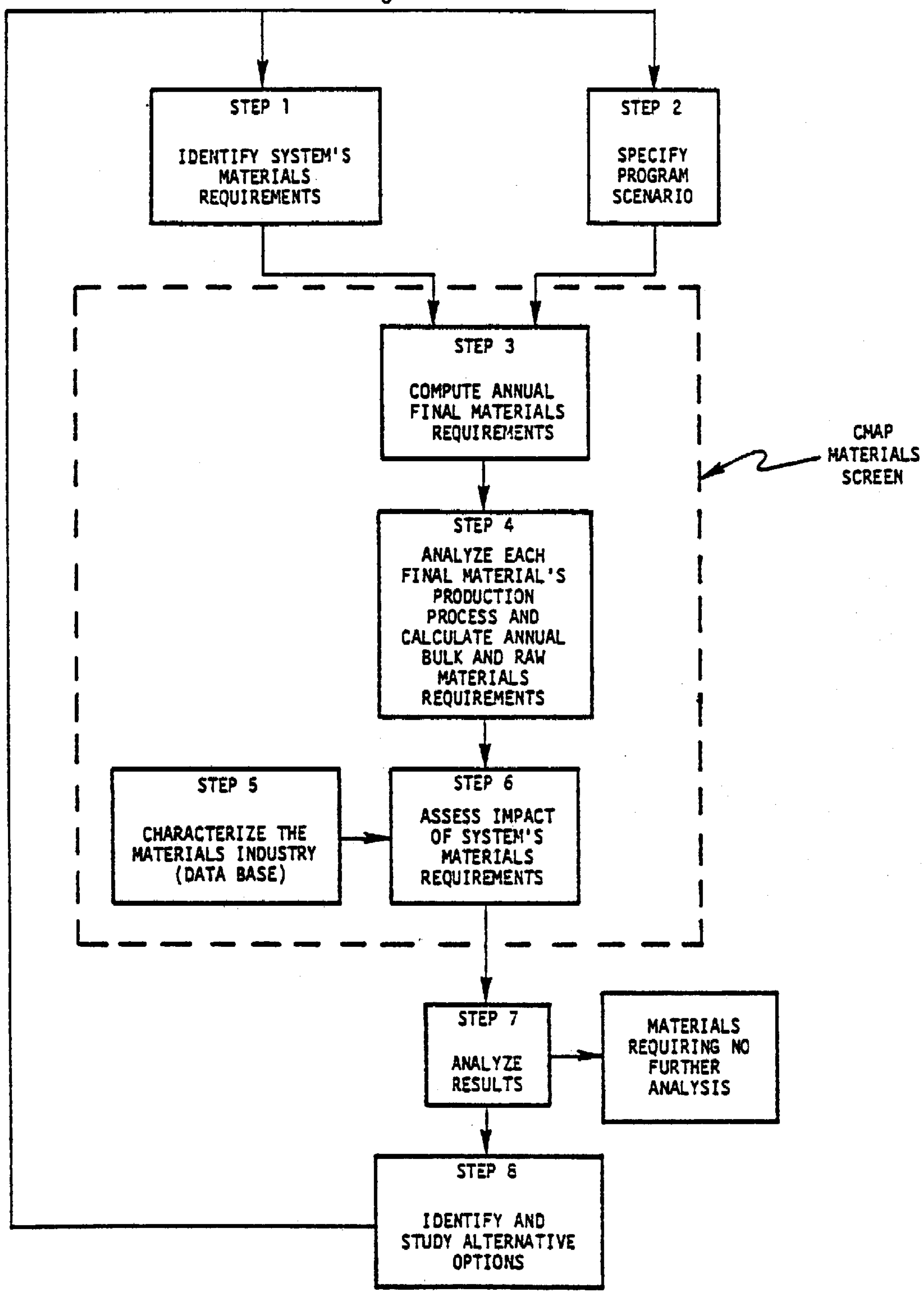

FIGURE 3. OVERVIEW OF THE METHODOLOGY

steps. At that point many production chains are complete and material quantities required for additional steps are generally insignificant.

When the above simplified example is expanded to a overall materials assessment of a total system such as the SPS, the problem becomes much more complex, involving large numbers of materials and production processes. The analysis required can best be described as consisting of the following eight basic steps: (refer also to Figure 3

Step 1. Identify Materials Requirements

The final construction materials (such as brass, concrete, composites, or solar-grade silicon) for a system under study are identified, preferably at the component or subsystem level. In addition, any expended materials (e.g. fuels) needed in the construction or operation of the system are also identified. This results in a listing of the quantities of all materials required for the construction, installation and operation of one system "unit" (such as one solar power satellite and its earthborn equipment, or one coal-fired generating plant) producing a specified amount of energy.

Step 2. Specify Program Scenario

A "scenario" is a statement of a system's ultimate size and the timing of its construction. The scenario gives the number of system units to be constructed per year for each year of the program's duration. The SPS scenario, for example, specifies two satellite units per year throughout the period from 2000 to 2029, for a total of 60 units each developing 5 gigawatts output. Thus the total power output at program completion would be 300 gigawatts.

Step 3. Compute Annual Materials Requirements

The annual materials requirements are calculated by multiplying the units per year by the quantities of each final material in one unit.

Step 4. Analyze Material Production Processes

Each final construction material is produced from bulk and secondary bulk materials* (such as copper, cement, graphite fiber, or sulfuric acid) and raw materials (such as sand and gravel, ore, or timber). Quantities of all such materials are calculated by year.

Step 5. Characterize the Materials Industry

For all materials, a data base is developed. It includes such factors as availability, source, production capacity, expected growth in demand, and prices on a domestic and worldwide basis for each material.

Step 6. Assess the System's Impact

The system's annual demand for each material (as determined in Steps 1-4) is compared to pertinent information in the data base for that material. This reveals the impacts of the system, expressed in such terms as percentage of total production required, percentage of raw material resources and reserves consumed*, or dependency on imports.

Step 7. Analyze the Results

The significance of each impact identified in Step 6 is assessed by comparison to a predetermined threshold value. Some impacts will be of no concern; others will require further study.

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* As noted earlier, bulk materials required to produce other bulk materials (e.g. sulfuric acid required to produce copper) are referred to as "secondary" bulk materials.

**For a given raw material, the term resource is defined to be an estimate (usually by the U.S. Bureau of Mines) of the total naturally occurring in situ deposits of that material. The term reserve is defined as that portion of the resource that is located in identified deposits and can be economically extracted given current technology and mineral prices. See Appendix B for additional explanation.

Step 8. Study Alternative Options

For those materials involving significant uncertainties, or potential constraints, alternative options are identified and studied. One option is materials substitutions. If this is considered, Steps 1 through 7 are repeated to evaluate the effect of the substitution. Other options open to managers and planners for reducing uncertainties include redesigning a component, subsystem, or an entire system; undertaking R&D aimed at alleviating an uncertainty; exploring for new resources; or developing incentives for expanding manufacturing capacity.

Steps 3 through 6 have been automated by developing a computerized analysis program and a comprehensive data base of information on materials and the materials industry.

The analysis program is known as the Critical Materials Assessment Program (CMAP) and its functions are those enclosed by the dashed line in Figure 3. CMAP can accumulate all requirements for a given material regardless of the ultimate usage of that material in a system. It can give the bulk and raw constituents of a material; calculate the impacts of a system's materials requirements relative to worldwide availability, source, demand, etc.; screen out materials that are of no concern; and identify those that are of concern.

The data base currently contains about 2000 data entries covering more than 260 materials. Bulk material information includes estimates of present and future U.S. and world consumption, prices, U.S. imports, and dominant non-U.S. suppliers. Information on raw materials includes the same kind of data plus estimates on U.S. and world reserves and resources.

The information base also includes data on the consumption of primary (including by-products), secondary, and tertiary materials required to produce each unit of standard bulk material.

Over 100 information sources have been employed. The sources include many government publications, technical handbooks, special reports, technical papers, trade association and technical association data, journal articles and the like. Where no secondary source data are available, information has been obtained directly from producers. Data entries are referenced for further examination when necessary. A partial listing of references used is included in the reference list at the end of this report (3-25).

Application of the assessment methodology to the SPS is the subject of the next four sections of this report. As indicated in Figure 3, the input requirements for the CMAP analysis of the SPS are a listing of final materials used (those identifiable in the system hardware, plus expendables such as rocket propellants), and a specification of the SPS program scenario. These inputs are defined in Section III. The CMAP automated materials screen is discussed in Section IV. This section includes definition and discussion of the CMAP output format and interpretation of results. The SPS assessment is completed with analysis of screening results in Section V, and a concluding summary of the assessment (Section VI).

It should be noted that in this preliminary assessment only minimal attention has been given to the study of alternative options or mitigating strategies to deal with identified material problems (Step 8 in the methodology). In most cases, additional study is needed to determine the severity of identified problems before it will be known where mitigating strategies may be needed.

III - SPS MATERIALS REQUIREMENT

The present reference design concepts (one using silicon solar cells; the other using gallium arsenide solar cells) consist of six main elements. These are:

(1) Satellites placed in geosynchronous earth orbit (GEO) and consisting of photovoltaic arrays and microwave power conversion and transmission equipment.*

(2) Ground antennas for receiving microwave transmissions and equipment for conversion to AC power and utility interfacing.

(3) Launch vehicles for transporting cargo and personnel into low earth orbit (LEO).

(4) Facilities and equipment in LEO for fabricating and assembling satellite hardware and support equipment.

(5) Orbital transfer vehicles (OTV's) for transferring cargo and personnel to GEO.

(6) Facilities for constructing the satellites in GEO.

To perform the materials assessment, the material requirements** of these system elements must be identified, preferably at the subsystem level. However complete subsystem level material specifications for the SPS reference designs do not exist at present. In lieu of complete specification, the materials list published in the SPS reference design document[1] published by NASA was used in this study (see Table 1). This listing identifies twenty-two materials (plus "miscellaneous and organics") used in the various SPS elements.

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*Electrical energy generated by the photovoltaic array would be converted to microwave energy on board the satellite and transmitted to Earth.

**i.e. the final engineering and finished bulk materials identifiable in finished SPS components.

Table 1. Materials List for Reference System

RESOURCE REQUIREMENTS (METRIC TONS)

	Silicon System Concentration Ratio Ratio of 1	Common Satellite Construction Materials	Gallium Arsenide System Concentration Ratio of 2
5 GIGAWATT SATELLITE MASS	50,618		34,159
GFRTP[(1)]	6,359		7,680
Stainless Steel	5,723		5,305
Copper	6,873		4,834
Sapphire	0		3,376
Aluminum	2,204		4,122
GaAs	0		1,354
Teflon	0		1,152
Kapton	0		2,719
Silver	37		928
Mercury	89		89
Tungsten	646		646
Glass	19,271		0
Silicon	7,903		0
Misc. and Organics	1,880		1,947
LOW EARTH ORBIT STAGING AND OTV CONSTRUCTION	2,405		110[(2)]
GFRTP	640		
Aluminum	1,433		
Stainless Steel	108		
Copper	26		
Glass	20		
Silicon	9		

NOTES: (1) GFRTP (Graphite Fiber Reinforced Thermoplastic)

(2) Total mass estimate only is available at this time.

(continuation) Table 1. Materials List for Reference System

RESOURCE REQUIREMENTS (METRIC TONS)

	Silicon System Concentration Ratio Ratio of 1	Common Satellite Construction Materials	Gallium Arsenide System Concentration Ratio of 2
GEOSYNCHRONOUS ORBIT CONSTRUCTION	8,353		6,000[2]
GFRTP	2,551		
Aluminum	4,694		
Stainless Steel	390		
Copper	110		
Glass	30		
Silicon	13		
Misc. and Organics	565		
HEAVY LIFT LAUNCH VEHICLE (HLLV)		1,170	
Aluminum		470	
Titanium		248	
Stainless Steel		232	
Ceramic		103	
Copper		17	
Misc. and Organics		100	
PERSONNEL LAUNCH VEHICLE (PLV)		264	
Aluminum		106	
Titanium		56	
Stainless Steel		52	
Ceramic		23	
Copper		4	
Misc. and Organics		23	
PERSONNEL ORBITAL TRANSFER VEHICLE (PORTV)		116	
Aluminum		81	
Stainless Steel		23	
Copper		2	
Misc. and Organics		10	

(continuation) Table 1. Materials List for Reference System

RESOURCE REQUIREMENTS (METRIC TONS)

	Silicon System Concentration Ratio Ratio of 1	Common Satellite Construction Materials	Gallium Arsenide System Concentration Ratio of 2
CARGO ORBITAL TRANSFER VEHICLE (COTV)	1,100		679
Aluminum	3		369
GaAs	0		38
Teflon	0		32
Sapphire	0		93
Kapton	0		66
GFRTP	126		0
Copper	67		15
Silicon	256		17
Stainless Steel	14		40
Glass	623		0
Misc. and Organics	11		9
RECTENNA			
Steel		1,492,000	
Concrete		1,330,000	
Aluminum		140,000	
GaAs		9	

From Table 1[1] the "unit" materials demand (i.e. the materials required for one satellite, one ground rectenna, etc.) can be determined. To determine total demand the SPS program scenario must be specified--the number of satellites/rectennas to be constructed as a function of time. The present reference SPS program consist of two phases: a developmental phase, and an operational phase. The SPS development would begin in 1986 and culminate in the completion of the first 5 gigawatt (GW)* satellite/rectenna system in the year 2000. The operational phase would commence with the completion of a second 5GW system in 2000 and continue with the completion of two systems each year thereafter through the year 2029. Thus a total of 60 5GW systems (300 GW total power output) would be installed—5GW at the end of the development phase and 295GW during the operational phases.

Based on this scenario and the SPS unit material requirements NASA determined the total requirements for the developmental and operational phases to be as shown in Table 2.[1]

The materials listing in Table 2 was then the basis for the SPS materials screening and analyses that follow in subsequent sections of this report.

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*5 gigawatts delivered to the power grid.

Table 2. Materials for Initial 5 GW SPS and Subsequent Systems

(UNITS IN METRIC TONS)

SATELLITE PROGRAM MATERIALS	Through First 5 GW SPS		Two 5 GW Satellite/Year	
	Si	Ga	Si	Ga
GFRTP	12,447	7,680	12,716	15,360
Stainless Steel	7,621	6,511	11,446	10,610
Glass	33,650	0	38,542	0
Silicon	13,813	0	15,806	0
Copper	8,630	5,030	13,746	9,668
Aluminum	150,654	149,227	284,408	288,244
Silver	37	928	74	1,856
Molybdenum	2	0	4	0
Mercury	89	89	178	178
Tungsten	646	646	1,292	1,292
Steel	1,492,000	1,492,000	2,984,000	2,984,000
Concrete	1,330,000	1,330,000	2,660,000	2,660,000
Gallium Arsenide	7	1,696	14	2,708
Titanium	1,104	856	248	124
Ceramics	458	355	103	52
Misc. and Organics	3,084	8,663	3,700	3,984
Argon	20,559	4,876	18,690	4,664
H_2	107,406	61,227	128,547	80,920

(Table 2 continued)

	Through First 5 GW SPS		Two 5 GW Satellite/Year	
	Si	Ga	Si	Ga
O_2	2,268,033	1,164,528	2,728,506	1,680,710
CH_4	540,572	265,539	651,599	379,930
Sapphire	0	4,213	0	6,752
Teflon	0	1,441	0	2,306
Kapton	0	3,313	0	5,438

Note 1. Material masses through the first 5 GW SPS include:

a. Three Heavy Lift Launch Vehicles
b. Two Personnel Launch Vehicles
c. Two Personnel Orbital Transfer Vehicles
d. Twenty-three Cargo Orbital Transfer Vehicles for silicon satellite

or

e. Nine Cargo Orbital Transfer Vehicles for gallium arsenide satellite
f. One geosynchronous orbit construction base
g. One low earth orbit staging and OTV construction base
h. Fuel for all required flights

Note 2. Material masses for two 5 GW satellite/year columns includes only the two satellites, rectennas and fuel required for all flights necessary for both satellites to become operational.

IV - SPS MATERIALS SCREENING

Assessment of materials requirements with the aid of the Critical Materials Assessment Program (CMAP) is basically a two step process. First, total program materials requirements are screened, using CMAP, to determine which requirements represent potential problems. Second, potential problems are analyzed to determine severity and the need for additional action.

Materials Screening

CMAP Program Operation

CMAP performs three principal functions: (1) calculation of total materials requirements; (2) determination (for each material) of a set parameters that characterize the materials demand impact; and, (3) comparison of the parameter values so determined with certain "threshold" values for those parameters, which, when exceeded, signify potential problems. When threshold values are exceeded, "flags" are set on the output printout that call attention to the potential problem.

Calculation of materials requirements begins with the SPS materials list presented in Section III (Table 2). Total amounts of the 22 materials on that list required to support the specified (in Section III) SPS program scenario are calculated. Then, using information stored in the materials data base, production processes required to produce those 22 materials are analyzed to determine secondary bulk material and raw material requirements. The results, which will be presented later, were a demand for over 50 different bulk materials (copper, silicon, sufuric acid, etc.), and nearly 30 raw materials (copper ore, sand, sulfur ore, etc.).

Once total materials demand has been established attention turns to the material parameters and threshold values on which the screening is based. Since the parameters of interest and threshold values differ somewhat for bulk and raw materials, the screening of these two types of materials is done separately (separate output printouts are produced).

Before proceeding with a general discussion of the screening, a few additonal words regarding the threshold values used are in order. One of the parameters of interest for bulk materials is the production growth rate required to meet the demand of the SPS and all other industries (retrievable from the materials data base). The threshold value for this parameter is currently set at 10% per year. Thus, if the required growth rate exceeds 10% a flag is set on the printout signifying that a <u>potential</u> production capacity problem exist. If the material in question has a relatively small production base (e.g. graphite reinforced thermoplastic) then a 10% growth rate might not be difficult to achieve. However, if the material in question already has a large production base (e.g. aluminum) then a 10% growth rate would represent an enormous requirement for additonal capital, labor, facilities, etc., and a definite problem exists.

Thus, in reality, an accurate "threshhold value" for a given parameter might be different for each material considered. However, any attempt to incorporate this reality into CMAP would make the automated screening intractable and defeat its entire purpose. Therefore a single threshold value is postulated for each parameter--a value, based on Battelle's materials assessment experience, that is representative and generally conservative for the majority of materials. These threshold values are not intended to be absolute measures of material criticality, but merely indicators that can speed and simplify the analysis of results. The responsibility for accurately interpreting those results properly remains the task of the experienced analyst.

<u>Bulk Materials Screening</u>

The parameters of interest for bulk materials are listed below. These parameters are determined for each material required.

- Percent of the material which is produced as a by-product of another material production process

- World production growth rate (per year) required to meet SPS and all other projected demands
- Maximum percent demand (in any given year) of the SPS as a portion of total world demand
- Percent of the world production attributable to a single foreign source
- Material purchase cost contribution to SPS power installed, $/KW
- Net percent of U.S. material consumption that is imported (from all foreign sources).

In the following paragraphs these parameters are discussed, the rationale for assessing criticality is developed, and currently used threshold values are identified.

Percent Supplied as By-Product. The threshold value is set here at 50 percent. The frequent implication that by-product dependence is constraining is often misleading. Materials sometimes considered today as by-products may be viewed at other times as co-products or even primary products depending upon supply/demand and market price conditions. Hence the term by-product material should not necessarily be viewed as a "low-cost" or an "undesirable" material production consequence of a process stream. The economics of many extractive and manufacturing processes are highly dependent upon by-product/co-product recovery. That economic dependence or leverage frequently becomes important in assessing criticality of the material. Where economic dependence is not present, only strong demand and attractive market prices will bring forth the capital investment required to recover the amounts of the by-product material needed.

Growing demand for the primary product is of basic importance to sustaining given levels of by-product production. If the system requirements for the by-product material are small, or if the market is "glutted", even declining primary material production levels can maintain adequate by-product supplies.

World Production Growth Rate. The threshold value here is 10 percent. Many small volume or new materials can readily maintain a 10 percent annual rate of growth. However large volume, capital intensive commodities would have great difficulty in sustaining such a growth rate. Therefore any growth rate over 5 percent for high volume commodity materials, raw or bulk, should also be reviewed.

Maximum Percent System Demand, One Year World. This threshold is set at 10 percent. This figure represents the system's market impact on material consumption at its potentially highest demand level relative to demand for that material for other uses. At high percentage of demand levels, the system demand can be a market driver, perhaps bringing about higher prices or even cartelization. This criterion may also be viewed as a trigger for closer examination of opportunity costs--that is, the systems potential for adverse impact on other segments of the economy demanding the same material.

Percent From One Nation, Non-U.S. This threshold level is set at 35 percent. It represents a measure of supply domination in world markets by any one non-U.S. nation. If the system material demand is also a significant proportion of total demand, then potential for supply disruption or cartelization is present. The nature of the material as well as the dominant nation identified, then becomes a part of the criticality judgement. This criterion usually assumes more importance in assessing raw materials, since bulk material production among industrial nations tends to disperse over time.

Present Costs in \$/KW. This threshold is set at \$50.00 per KW of constructed capacity. This value is calculated as MT required x \$ per MT/system capacity in KW. Values for material in excess of the \$50.00 threshold deserve close examination. It should be emphasized that these figures represent present bulk material cost--not the present cost of fabricated components. The fabrication cost of many materials can very substantially exceed the materials cost per se. Stated costs also are representative of the prevailing art for producing the materials--often in low volumes in the case of new materials. For many newer materials, those production costs can be expected to be lowered over time.

Total cost of the system attributable to these materials becomes sensitive to changes in price or required volume of the materials in question. Materials price forecasts, fabrication cost determinations, design review and possible materials substitutions might be considered.

Net Percent Imported. The threshold value is set at 50 percent and is based on current levels of net U.S. imports. If the maximum volume of material required by the system is very small compared to total U.S. demand in the same time frame, there is probably little cause for concern regardless of the U.S. import level. For many materials - particularly raw materials - for which the U.S. is dependent on imports, that dependency is likely to grow in future years. This is a matter of general economic concern and not necessarily related to any specific system under consideration. In other words, we would be concerned only if the system design and its construction scenario might substantially exacerbate an already recognized U.S. import dependency for certain materials.

Raw Materials Screening. With respect to the screening of raw materials levels of current reserves and resources estimates are introduced as screening parameters, in addition to those identified in the bulk material discussion. In general, where the U.S. is reserve/resource deficient, it is also import dependent. The focus of concern in these cases is levels of world reserves and resources and whether the system construction would substantially contribute to world resource deficiency or to substantially greater U.S. import dependency. The complete list of raw material screening parameters is given below.

- World production growth rate (per year) required to meet SPS and all other projected demands

- Maximum percent demand (in any given year) of the SPS as a portion of total world demand
- Percent of U.S. reserves consumed by the SPS and all other projected demand
- Percent of U.S. resources consumed by the SPS and all other projected demand
- Percent of world material production attributable to a single foreign source
- Percent of world reserves consumed by the SPS and all other projected demand
- Percent of world resources consumed by the SPS and all other projected demand
- Material purchase cost contribution to SPS power installed, $/KW
- Net percent of U.S. material consumption that is imported (from all foreign sources).

The previous discussions of parameters under "Bulk Materials Screening" adequately describe those parameters which are common to both bulk and raw materials, with the exception of "World Production Growth Rate", and "Percent from One Nation, Non-U.S.", where the raw material threshold values are different. Therefore those discussions will not be repeated here. World Production Growth Rate and the new U.S. and world reserve and resource parameters are discussed below.

World Production Growth Rate. The threshold value here is 7 percent rather than the 10 percent value used for bulk materials. Extractive operations usually require longer lead times and are very capital intensive. Sustained annual growth rates of 5 percent are not too unusual but 7 percent would be.

Percent from One Nation, Non-U.S. The threshold value here is 60 percent rather than the 35 percent value used for bulk materials. Developed resources tend to be more concentrated in specific locations than bulk material production facilities. However, the opportunity to exploit undeveloped resources in alternative locations generally exists. Consequently, the higher threshold value is used.

U.S. Reserves and Resources Consumed and World Reserves and Resources Consumed. The threshold values used are 400 percent, 300 percent, 200 percent and 200 percent, respectively. For the 50-year time span considered, these threshold values are quite conservative (see Appendix B). One could argue for many materials that they might even comfortably be doubled. In analyzing U.S. reserves and resources, sensitivity to doubling those values would be minimal, since we are usually either highly foreign source dependent - or hardly at all.

SPS construction would measureably increase U.S. dependence for only a very few materials. These few materials however are important to SPS. In only one case would SPS significantly consume a world reserve/-resource in potentially short supply--namely silver ores.

CMAP Screening

CMAP was used to screen the materials requirements of both the Silicon and Gallium Arsenide reference design concepts. The development of (1986-2000) and operational (2000-2029) phases were screened separately because materials demand as a function of time is substantially different for the two phases. The CMAP printout results are presented in Tables 3-10:

Table No.	System/Phase	Material Type
3	Silicon/Development	Bulk
4	Silicon/Development	Raw
5	Silicon/Operational	Bulk
6	Silicon/Operational	Raw
7	GaAs/Development	Bulk
8	GaSa/Development	Raw
9	GaSa/Operational	Bulk
10	GaSa/Operational	Raw

TABLE 3. BULK MATERIAL REQUIREMENTS FOR SOLAR POWER SATELLITE DEVELOPMENT (SILICON)

SOLAR SCENARIO:
INTRODUCTION YEAR- 1990
CUMULATIVE CAPACITY 2000- 5. GW

FACTORS	BULK MATERIAL USAGE MT.	PERCENT SUPPLY AS BY-PROD	PRODTN GROWTH RATE 1986 +	MAX % SYSTEM 1 YEAR WORLD	% FROM ONE NATION NON-US	PRESENT COSTS IN $/KW	NET % IMPORT
THRESHOLD LEVELS--		50.	10.%	10.	35.	50.	50.
ALUMINUM	152157.	0.	7.	0.	13.	36.	9.
ALUMINUM OXIDE	707.	0.	7.	0.	13.	0.	9.
AMMONIA	8791.	0.	3.	0.	5.	0.	1.
ARGON	20589.	100.*	4.	1.	25.	1.	0.
ARSENIC	4.	100.*	3.	0.	23.	0.	39.
ARSENIC TRIOXIDE	6.	100.*	3.	0.	23.	0.	39.
BORON OXIDE	4274.	20.	3.	0.	39.*	0.	0.
CARBON DIOXIDE	921.	100.*	3.	0.	5.	0.	0.
CAUSTIC SODA	23718.	0.	3.	0.	5.	1.	1.
CEMENT	186200.	0.	3.	0.	18.	2.	4.
CHLORINE	6554.	0.	3.	0.	5.	0.	1.
COAL, BITUMINOUS	827.	0.	2.	0.	20.	0.	10.
COKE	579880.	0.	3.	0.	10.	10.	1.
COPPER	8630.	1.	6.	0.	13.	3.	12.
ELECTRICITY (KWH)	38893.E+6	0.	7.	0.	0.	233.*	0.
ELECTRODES	12898.	0.	3.	0.	10.	4.	1.
FERROMANGANESE	16538.	0.	3.	0.	22.	1.	98.*
FERROSILICON	1503.	0.	3.	0.	10.	0.	35.
FERROUS SCRAP, PURCHASED	368843.	0.	3.	0.	10.	6.	0.
FLUORSPAR	10965.	0.	5.	0.	19.	0.	79.*
GALLIUM	4.	100.*	5.	4.	40.*	1.	55.*
GALLIUM ARSENIDE (DEP)	7.	0.	5.	4.	10.	1.	0.
GLASS, BOROSILIC	33650.	0.	4.	6.	5.	5.	1.
GRAPHITE FIBER, SYNTHETIC	7555.	0.	19.*	36.*	35.*	86.*	0.
HELIUM	3.	100.*	3.	0.	5.	0.	0.
HYDROCHLORIC ACID	246365.	92.*	3.	1.	5.	10.	2.
HYDROGEN	110161.	40.	6.	0.	10.	13.	0.
LIME	98194.	0.	3.	0.	20.	1.	2.
LIQUID FUELS	69212.	0.	3.	0.	18.	2.	39.

Note: + = Beginning in 1986

* = Threshold exceeded

MT = Metric tons

TABLE 3. BULK MATERIAL REQUIREMENTS FOR SOLAR POWER SATELLITE DEVELOPMENT (SILICON) (CONTINUED)

SOLAR SCENARIO:
INTRODUCTION YEAR- 1990
CUMULATIVE CAPACITY 2000- 5. GW

FACTORS	BULK MATERIAL USAGE MT.	PERCENT SUPPLY AS BY-PROD	PRODTN GROWTH RATE 1986 +	MAX % SYSTEM 1 YEAR WORLD	% FROM ONE NATION NON-US	PRESENT COSTS IN $/KW	NET % IMPORT
THRESHOLD LEVELS--		50.	10.%	10.	35.	50.	50.
MAGNESIUM	342.	1.	6.	0.	27.	0.	0.
MERCURY	89.	2.	1.	0.	18.	0.	62.*
MOLYBDENUM	2.	42.	5.	0.	17.	0.	0.
NATURAL GAS REFINED	540572.	0.	5.	0.	23.	10.	5.
NITRIC ACID	19.	0.	3.	0.	32.	0.	1.
OXYGEN, GASEOUS	2374318.	0.	4.	1.	21.	9.	0.
OXYGEN, LIQUID	2374236.	0.	4.	3.	21.	9.	0.
PETROLEUM COKE	111080.	100.*	3.	0.	15.	2.	0.
PITCH-IN-TAR	52107.	0.	3.	2.	5.	0.	5.
POLYACRYLONITE FIBER	16999.	0.	3.	0.	18.	6.	3.
POLYSULFONE	4979.	0.	7.	2.	5.	4.	5.
SAND & GRAVEL	393899.	0.	4.	0.	10.	0.	0.
SILICA FIBER	2733.	0.	26.*	94.*	0.	164.*	4.
SILICON (MET)	62020.	0.	3.	1.	12.	13.	11.
SILICON (SEG)	13813.	0.	20.*	5.	10.	166.*	0.
SILVER	37.	70.*	4.	0.	14.	1.	50.*
SODIUM CARBONATE	765.	0.	0.	0.	10.	0.	0.
STAINLESS STEEL	7621.	0.	4.	0.	30.	2.	15.
STEAM	9751851.	1.	3.	0.	10.	8.	0.
STEEL & IRON	1495812.	1.	3.	0.	16.	99.*	7.
STONE, CRUSHED & SIZED	758100.	0.	3.	0.	3.	0.	0.
SULFUR	41160.	31.	3.	0.	14.	1.	0.
SULFURIC ACID	122169.	20.	3.	0.	14.	1.	0.
TITANIUM	1104.	0.	6.	0.	39.*	2.	8.
TUNGSTEN	646.	10.	3.	0.	7.	4.	54.*
ZINC	8.	25.	2.	0.	20.	0.	59.*
.BENZENE.	8145.	0.	5.	0.	16.	0.	1.
.PROPYLENE.	22432.	25.	5.	0.	14.	1.	0.
(MISC. BULK MATERIALS)	86173.						

Note: + = Beginning in 1986

* = Threshold exceeded

MT = Metric tons

TABLE 4. RAW MATERIAL REQUIREMENTS FOR SOLAR POWER SATELLITE DEVELOPMENT (SILICON)

SOLAR SCENARIO:
INTRODUCTION YEAR- 1990
CUMULATIVE CAPACITY 2000- 5. GW

FACTORS	RAW MATERIAL USAGE (1000MT)	%PRD GROW RATE FROM 1986+	MAX% SYST ONE YEAR WRLD	%US RESERV CONSUM BY 2000	%US RESOUR CONSUM BY 2000	%FRM ONE NAT NON-US	%WORLD RESERV CONSUM BY 2000	%WORLD RESOUR CONSUM BY 2000	PRSNT COSTS IN $/KW	NET% IMPT
THRESHOLD LEVELS--		7.	10.	400.	300.	60.	300.	200.	50.	50.
BAUXITE	717.	5.	0.	2692.*	364.*	31.	15.	10.	2.	91.*
BAUXITE, BY PROD	190.	5.	0.	2691.*	364.*	31.	15.	10.	0.	91.*
BORON OXIDE	4.	3.	0.	23.	6.	39.	17.	4.	0.	0.
CHROMITE	6.	3.	0.	100.	620.*	28.	117.	2.	0.	89.*
CLAYS	27.	2.	0.	0.	0.	12.	0.	0.	0.	0.
COAL, BITUMINOUS	19536.	2.	0.	5.	1.	7.	9.	1.	60.*	0.
COPPER BYPROD.	0.	4.	0.	73.	17.	13.	67.	16.	0.	12.
COPPER ORE	1233.	4.	0.	73.	17.	13.	67.	16.	0.	12.
FLUORSPAR ORE	33.	5.	0.	1004.*	168.	19.	255.	140.	0.	79.*
GYPSUM, CRUDE	9.	2.	0.	175.	0.	10.	115.	0.	0.	35.
IRON ORE	2423.	5.	0.	29.	5.	27.	16.	5.	1.	29.
LIMESTONE	787.	3.	0.	0.	0.	20.	0.	0.	5.	2.
MANGANESE ORE	36.	3.	0.	100.	8.	22.	15.	8.	1.	98.*
MERCURY ORE	3.	0.	0.	337.	152.	18.	118.	35.	0.	62.*
MOLYBDENUM ORE	1.	5.	0.	36.	8.	17.	43.	12.	1.	0.
NATURAL GAS	1289.	5.	0.	258.	60.	23.	97.	10.	24.	5.
NICKEL ORE	64.	2.	0.	3533.*	9.	33.	48.	20.	0.	70.*
PETROLEUM	7688.	2.	0.	565.*	185.	18.	104.	34.	112.*	39.
RUTILE (CONC.)	2.	5.	0.	165.	54.	98.*	11.	9.	0.	98.*
SALT	178.	6.	0.	0.	0.	18.	0.	0.	1.	7.
SAND & GRAVEL	266.	4.	0.	0.	0.	6.	0.	0.	0.	0.
SILVER ORE	53.	4.	0.	277.	73.	14.	208.	56.	0.	50.*
SODA ASH (NAT.)	3.	5.	0.	1.	0.	2.	1.	0.	0.	0.
STONE	758.	3.	0.	0.	0.	3.	0.	0.	0.	0.
SULFUR ORE	41.	3.	0.	189.	61.	14.	109.	34.	0.	0.
TIMBER, LUMBER	64.	1.	0.	0.	0.	12.	0.	0.	2.	18.
TUNGSTEN ORE	108.	3.	1.	254.	73.	21.	77.	27.	1.	54.*
WATER, SEAWATER	247.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ZINC ORE	0.	3.	0.	166.	100.	20.	125.	81.	0.	59.*

Note: + = Beginning in 1986

* = Threshold exceeded

MT = Metric tons

TABLE 5. BULK MATERIAL REQUIREMENTS FOR SOLAR POWER SATELLITE OPERATIONAL SYSTEM (SILICON)

SOLAR SCENARIO:
INTRODUCTION YEAR- 2000
CUMULATIVE CAPACITY 2029- 295. GW

FACTORS	BULK MATERIAL USAGE MT.	PERCENT SUPPLY AS BY-PROD	PRODTN GROWTH RATE 1995 +	MAX % SYSTEM 1 YEAR WORLD	% FROM ONE NATION NON-US	PRESENT COSTS IN $/KW	NET % IMPORT
THRESHOLD LEVELS--		50.	10.%	10.	35.	50.	50.
ALUMINUM	8478587.	0.	7.	0.	13.	34.	9.
ALUMINUM OXIDE	23877.	0.	7.	0.	13.	0.	9.
AMMONIA	270773.	0.	3.	0.	5.	0.	1.
ARGON	551553.	100.*	5.	1.	25.	0.	0.
ARSENIC	238.	100.*	3.	0.	23.	0.	39.
ARSENIC TRIOXIDE	334.	100.*	3.	0.	23.	0.	39.
BORON OXIDE	144398.	20.	3.	0.	39.*	0.	0.
CARBON DIOXIDE	54338.	100.*	3.	0.	5.	0.	0.
CAUSTIC SODA	1323000.	0.	3.	0.	5.	1.	1.
CEMENT	10985800.	0.	3.	0.	18.	2.	4.
CHLORINE	167629.	0.	3.	0.	5.	0.	1.
COAL, BITUMINOUS	48702.	0.	2.	0.	20.	0.	10.
COKE	34196511.	0.	3.	0.	10.	10.	1.
COPPER	405507.	1.	6.	0.	13.	2.	12.
ELECTRICITY (KWH)	1391.E+9	0.	7.	0.	0.	141.*	0.
ELECTRODES	472628.	0.	4.	1.	10.	3.	1.
FERROMANGANESE	974056.	0.	3.	0.	22.	1.	98.*
FERROSILICON	88551.	0.	3.	0.	10.	0.	35.
FERROUS SCRAP, PURCHASED	21677632.	0.	3.	0.	10.	6.	0.
FLUORSPAR	644614.	0.	5.	0.	19.	0.	79.*
GALLIUM	224.	100.*	7.	13.*	40.*	1.	55.*
GALLIUM ARSENIDE (DEP)	413.	0.	8.	14.*	10.	1.	0.
GLASS, BOROSILIC	1136989.	0.	6.	12.*	5.	3.	1.
GRAPHITE FIBER, SYNTHETIC	225650.	0.	30.*	52.*	35.*	44.	0.
HELIUM	21.	100.*	3.	0.	5.	0.	0.
HYDROCHLORIC ACID	8398592.	92.*	4.	1.	5.	6.	2.
HYDROGEN	3886409.	40.	6.	0.	10.	8.	0.
LIME	5737983.	0.	3.	0.	20.	1.	2.
LIQUID FUELS	3274403.	0.	3.	0.	18.	1.	39.

Note: + = Beginning in 1995

* = Threshold exceeded

MT = Metric tons

TABLE 5. BULK MATERIAL REQUIREMENTS FOR SOLAR POWER SATELLITE OPERATIONAL SYSTEM (SILICON) (CONTINUED)

SOLAR SCENARIO:
INTRODUCTION YEAR- 2000
CUMULATIVE CAPACITY 2029- 295. GW

FACTORS	BULK MATERIAL USAGE MT.	PERCENT SUPPLY AS BY-PROD	PRODTN GROWTH RATE 1995 +	MAX % SYSTEM 1 YEAR WORLD	% FROM ONE NATION NON-US	PRESENT COSTS IN $/KW	NET % IMPORT
THRESHOLD LEVELS--		50.	10.%	10.	35.	50.	50.
MAGNESIUM	2268.	1.	6.	0.	27.	0.	0.
MERCURY	5251.	2.	1.	2.	18.	0.	62.*
MOLYBDENUM	118.	42.	5.	0.	17.	0.	0.
NATURAL GAS REFINED	19222171.	0.	5.	0.	23.	6.	5.
NITRIC ACID	143.	0.	3.	0.	32.	0.	1.
OXYGEN, GASEOUS	86757637.	0.	5.	3.	21.	6.	0.
OXYGEN, LIQUID	86754070.	0.	5.	7.	21.	5.	0.
PETROLEUM COKE	5209156.	100.*	3.	0.	15.	1.	0.
PITCH-IN-TAR	2780508.	0.	4.	6.	5.	0.	5.
POLYACRYLONITE FIBER	507712.	0.	3.	0.	18.	3.	3.
POLYSULFONE	150049.	0.	8.	5.	5.	2.	5.
SAND & GRAVEL	22810692.	0.	4.	0.	10.	0.	0.
SILICA FIBER	18131.	0.	46.*	88.*	0.	18.	4.
SILICON (MET)	2093584.	0.	3.	1.	12.	8.	11.
SILICON (SEG)	466277.	0.	22.*	11.*	10.	95.*	0.
SILVER	2183.	70.*	4.	0.	14.	1.	50.*
SODIUM CARBONATE	42598.	0.	0.	0.	10.	0.	0.
STAINLESS STEEL	337657.	0.	4.	0.	30.	2.	15.
STEAM	399.E+6	1.	3.	0.	10.	6.	0.
STEEL & IRON	88212855.	1.	3.	0.	16.	99.*	7.
STONE, CRUSHED & SIZED	44727900.	0.	3.	0.	3.	0.	0.
SULFUR	1419127.	31.	3.	0.	14.	0.	0.
SULFURIC ACID	4212811.	20.	3.	0.	14.	1.	0.
TITANIUM	7316.	0.	6.	0.	39.*	0.	8.
TUNGSTEN	38114.	10.	3.	2.	7.	4.	54.*
ZINC	480.	25.	2.	0.	20.	0.	59.*
.BENZENE.	245480.	0.	5.	0.	16.	0.	1.
.PROPYLENE.	670353.	25.	5.	0.	14.	0.	0.
(MISC. BULK MATERIALS)	4947962.						

Note: + = Beginning in 1995

* = Threshold exceeded

MT = Metric tons

TABLE 6. RAW MATERIAL REQUIREMENTS FOR SOLAR POWER SATELLITE OPERATIONAL SYSTEM (SILICON)

SOLAR SCENARIO:
INTRODUCTION YEAR- 2000
CUMULATIVE CAPACITY 2029- 295. GW

FACTORS	RAW MATERIAL USAGE (1000MT)	%PRD GROW RATE FROM 1995+	MAX% SYST ONE YEAR WRLD	%US RESERV CONSUM BY 2029	%US RESOUR CONSUM BY 2029	%FRM ONE NAT NON-US	%WORLD RESERV CONSUM BY 2029	%WORLD RESOUR CONSUM BY 2029	PRSNT COSTS IN $/KW	NET% IMPT
THRESHOLD LEVELS--		7.	10.	400.	300.	60.	300.	200.	50.	50.
BAUXITE	39903.	5.	0.	19125.*	2588.*	31.	89.	58.	2.	91.*
BAUXITE, BY PROD	11213.	5.	0.	19055.*	2579.*	31.	89.	58.	0.	91.*
BORON OXIDE	144.	3.	0.	120.	30.	39.	64.	16.	0.	0.
CHROMITE	259.	3.	0.	100.	3852.*	28.	399.*	6.	0.	89.*
CLAYS	1582.	2.	0.	0.	0.	12.	0.	0.	0.	0.
COAL, BITUMINOUS	771721.	2.	1.	25.	3.	7.	26.	2.	40.	0.
COPPER BYPROD.	1.	4.	0.	299.	68.	13.	316.*	77.	0.	12.
COPPER ORE	57931.	4.	0.	299.	68.	13.	316.*	77.	0.	12.
FLUORSPAR ORE	1960.	5.	0.	6814.*	1143.*	19.	1402.*	769.*	0.	79.*
GYPSUM, CRUDE	527.	2.	0.	618.*	0.	10.	373.*	0.	0.	35.
IRON ORE	142905.	5.	0.	131.	21.	27.	84.	27.	1.	29.
LIMESTONE	46143.	3.	0.	0.	0.	20.	0.	0.	5.	2.
MANGANESE ORE	2143.	3.	0.	100.	25.	22.	52.	26.	1.	98.*
MERCURY ORE	181.	1.	2.	643.*	291.	18.	280.	83.	0.	62.*
MOLYBDENUM ORE	39.	5.	0.	198.	43.	17.	225.	65.	1.	0.
NATURAL GAS	47425.	5.	0.	698.*	163.	23.	501.*	50.	15.	5.
NICKEL ORE	2836.	2.	0.	11578.*	30.	33.	160.	67.	0.	70.*
PETROLEUM	329090.	2.	0.	2327.*	761.*	18.	343.*	113.	81.*	39.
RUTILE (CONC.)	16.	5.	0.	605.*	199.	98.*	53.	42.	0.	98.*
SALT	6767.	6.	0.	0.	0.	18.	0.	0.	1.	7.
SAND & GRAVEL	9252.	4.	0.	0.	0.	6.	0.	0.	0.	0.
SILVER ORE	3122.	4.	0.	921.*	244.	14.	990.*	266.*	0.	50.*
SODA ASH (NAT.)	112.	5.	0.	4.	2.	2.	3.	1.	0.	0.
STONE	44728.	3.	0.	0.	0.	3.	0.	0.	0.	0.
SULFUR ORE	1419.	3.	0.	726.*	236.	14.	417.*	131.	0.	0.
TIMBER, LUMBER	2146.	1.	0.	0.	0.	12.	0.	0.	1.	18.
TUNGSTEN ORE	6365.	3.	2.	1441.*	414.*	21.	275.	96.	1.	54.*
WATER, SEAWATER	1635.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ZINC ORE	11.	3.	0.	672.*	403.*	20.	436.*	282.*	0.	59.*

Note: + = Beginning in 1995

* = Threshold exceeded

MT = Metric tons

TABLE 7. BULK MATERIAL REQUIREMENTS FOR SOLAR POWER SATELLITE DEVELOPMENT (GA/AS)

SOLAR SCENARIO:
INTRODUCTION YEAR- 1990
CUMULATIVE CAPACITY 2000- 5. GW

FACTORS	BULK MATERIAL USAGE MT.	PERCENT SUPPLY AS BY-PROD	PRODTN GROWTH RATE 1986 +	MAX % SYSTEM 1 YEAR WORLD	% FROM ONE NATION NON-US	PRESENT COSTS IN $/KW	NET % IMPORT
THRESHOLD LEVELS--		50.	10.%	10.	35.	50.	50.
ALUMINUM	150729.	0.	7.	0.	13.	35.	9.
AMMONIA	6602.	0.	3.	0.	5.	0.	1.
ARGON	4899.	100.*	4.	0.	25.	0.	0.
ARSENIC	979.	100.*	3.	1.	23.	20.	39.
ARSENIC TRIOXIDE	1370.	100.*	3.	1.	23.	0.	39.
CARBON DIOXIDE	223141.	100.*	3.	1.	5.	2.	0.
CAUSTIC SODA	31788.	0.	3.	0.	5.	1.	1.
CEMENT	186200.	0.	3.	0.	18.	2.	4.
CHLORINE	14411.	0.	3.	0.	5.	0.	1.
COAL, BITUMINOUS	826.	0.	2.	0.	20.	0.	10.
COKE	580239.	0.	3.	0.	10.	10.	1.
COPPER	5030.	1.	6.	0.	13.	2.	12.
ELECTRICITY (KWH)	5100.E+6	0.	7.	0.	0.	31.	0.
ELECTRODES	1569.	0.	3.	0.	10.	1.	1.
FERROMANGANESE	16525.	0.	3.	0.	22.	1.	98.*
FERROSILICON	1502.	0.	3.	0.	10.	0.	35.
FERROUS SCRAP, PURCHASED	368102.	0.	3.	0.	10.	6.	0.
FLUORSPAR	13536.	0.	5.	0.	19.	0.	79.*
GALLIUM	921.	100.*	23.*	90.*	40.*	147.*	55.*
GALLIUM ARSENIDE (DEP)	1696.	0.	24.*	90.*	10.	237.*	0.
GRAPHITE FIBER, SYNTHETIC	4675.	0.	18.*	26.*	35.*	53.*	0.
HELIUM	2.	100.*	3.	0.	5.	0.	0.
HYDROCHLORIC ACID	3348.	92.*	3.	0.	5.	0.	2.
HYDROFLUORIC ACID	1147.	0.	3.	0.	15.	0.	0.
HYDROGEN	61448.	40.	6.	0.	10.	7.	0.
KAPTON	3313.	0.	9.	23.*	0.	44.	5.
LIME	107666.	0.	3.	0.	20.	1.	2.
LIQUID FUELS	64650.	0.	3.	0.	18.	2.	39.
MAGNESIUM	265.	1.	6.	0.	27.	0.	0.

Note: + = Beginning in 1986

* = Threshold exceeded

MT = Metric tons

TABLE 7. BULK MATERIAL REQUIREMENTS FOR SOLAR POWER SATELLITE DEVELOPMENT (GA/AS) (CONTINUED)

SOLAR SCENARIO:
INTRODUCTION YEAR- 1990
CUMULATIVE CAPACITY 2000- 5. GW

FACTORS	BULK MATERIAL USAGE MT.	PERCENT SUPPLY AS BY-PROD	PRODTN GROWTH RATE 1986 +	MAX % SYSTEM 1 YEAR WORLD	% FROM ONE NATION NON-US	PRESENT COSTS IN $/KW	NET % IMPORT
THRESHOLD LEVELS--		50.	10.%	10.	35.	50.	50.
MERCURY	89.	2.	1.	0.	18.	0.	62.*
NATURAL GAS REFINED	265539.	0.	5.	0.	23.	5.	5.
NITRIC ACID	3610.	0.	3.	0.	32.	0.	1.
OXYGEN, GASEOUS	1270811.	0.	4.	1.	21.	5.	0.
OXYGEN, LIQUID	1270743.	0.	4.	1.	21.	5.	0.
PETROLEUM COKE	66971.	100.*	3.	0.	15.	1.	0.
PITCH-IN-TAR	46014.	0.	3.	1.	5.	0.	5.
POLYACRYLONITE FIBER	10520.	0.	3.	0.	18.	3.	3.
POLYSULFONE	3072.	0.	7.	2.	5.	3.	5.
SAND & GRAVEL	392055.	0.	4.	0.	10.	0.	0.
SAPPHIRE	4213.	0.	27.*	55.*	25.	674.*	0.
SILICA FIBER	2118.	0.	23.*	92.*	0.	127.*	4.
SILVER	928.	70.*	4.	2.	14.	36.	50.*
SODIUM CARBONATE	4678.	0.	0.	0.	10.	0.	0.
STAINLESS STEEL	6511.	0.	4.	0.	30.	2.	15.
STEAM	6788256.	1.	3.	0.	10.	6.	0.
STEEL & IRON	1495806.	1.	3.	0.	16.	99.*	7.
STONE, CRUSHED & SIZED	758100.	0.	3.	0.	3.	0.	0.
SULFUR	6085.	31.	3.	0.	14.	0.	0.
SULFURIC ACID	18962.	20.	3.	0.	14.	0.	0.
TEFLON	1441.	0.	7.	1.	10.	2.	8.
TITANIUM	856.	0.	6.	0.	39.*	1.	8.
TUNGSTEN	646.	10.	3.	0.	7.	4.	54.*
ZINC	204.	25.	2.	0.	20.	0.	59.*
.BENZENE.	10694.	0.	5.	0.	16.	1.	1.
.PROPYLENE.	13879.	25.	5.	0.	14.	1.	0.
(MISC. BULK MATERIALS)	92054.						

Note: + = Beginning in 1986

* = Threshold exceeded

MT = Metric tons

TABLE 8. RAW MATERIAL REQUIREMENTS FOR SOLAR POWER SATELLITE DEVELOPMENT (GA/AS)

SOLAR SCENARIO:
INTRODUCTION YEAR- 1990
CUMULATIVE CAPACITY 2000- 5. GW

FACTORS	RAW MATERIAL USAGE (1000MT)	%PRD GROW RATE FROM 1986+	MAX% SYST ONE YEAR WRLD	%US RESERV CONSUM BY 2000	%US RESOUR CONSUM BY 2000	%FRM ONE NAT NON-US	%WORLD RESERV CONSUM BY 2000	%WORLD RESOUR CONSUM BY 2000	PRSNT COSTS IN $/KW	NET% IMPT
THRESHOLD LEVELS—		7.	10.	400.	300.	60.	300.	200.	50.	50.
BAUXITE	708.	5.	0.	2692.*	364.*	31.	15.	10.	2.	91.*
BAUXITE, BY PROD	46046.	6.	7.	2804.*	379.*	31.	15.	10.	0.	91.*
CHROMITE	5.	3.	0.	100.	620.*	28.	117.	2.	0.	89.*
CLAYS	27.	2.	0.	0.	0.	12.	0.	0.	0.	0.-
COAL, BITUMINOUS	5967.	2.	0.	5.	1.	7.	9.	1.	18.	0.
COPPER BYPROD.	3.	4.	0.	73.	17.	13.	67.	16.	0.	12.
COPPER ORE	719.	4.	0.	73.	17.	13.	67.	16.	0.	12.
FLUORSPAR ORE	41.	5.	0.	1004.*	168.	19.	255.	140.	0.	79.*
GYPSUM, CRUDE	9.	2.	0.	175.	0.	10.	115.	0.	0.	35.
IRON ORE	2423.	5.	0.	29.	5.	27.	16.	5.	1.	29.
LIMESTONE	819.	3.	0.	0.	0.	20.	0.	0.	5.	2.
MANGANESE ORE	36.	3.	0.	100.	8.	22.	15.	8.	1.	98.*
MERCURY ORE	3.	0.	0.	337.	152.	18.	118.	35.	0.	62.*
NATURAL GAS	723.	5.	0.	258.	60.	23.	97.	10.	14.	5.
NICKEL ORE	55.	2.	0.	3533.*	9.	33.	48.	20.	0.	70.*
PETROLEUM	5822.	2.	0.	565.*	185.	18.	104.	34.	85.*	39.
RUTILE (CONC.)	2.	5.	0.	165.	54.	98.*	11.	9.	0.	98.*
SALT	83.	6.	0.	0.	0.	18.	0.	0.	0.	7.
SAND & GRAVEL	11.	4.	0.	0.	0.	6.	0.	0.	0.	0.
SILVER ORE	1327.	4.	2.	279.	74.	14.	209.	56.	1.	50.*
SODA ASH (NAT.)	0.	5.	0.	1.	0.	2.	1.	0.	0.	0.
STONE	758.	3.	0.	0.	0.	3.	0.	0.	0.	0.
SULFUR ORE	6.	3.	0.	189.	61.	14.	109.	34.	0.	0.
TUNGSTEN ORE	108.	3.	1.	254.	73.	21.	77.	27.	1.	54.*
WATER, SEAWATER	191.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ZINC ORE	5.	3.	0.	166.	100.	20.	125.	81.	0.	59.*

Note: + = Beginning in 1986

* = Threshold exceeded

MT = Metric tons

TABLE 9. BULK MATERIAL REQUIREMENTS FOR SOLAR POWER SATELLITE OPERATIONAL SYSTEM (GA/AS)

SOLAR SCENARIO:
INTRODUCTION YEAR- 2000
CUMULATIVE CAPACITY 2029- 295. GW

FACTORS	BULK MATERIAL USAGE MT.	PERCENT SUPPLY AS BY-PROD	PRODTN GROWTH RATE 1995 +	MAX % SYSTEM 1 YEAR WORLD	% FROM ONE NATION NON-US	PRESENT COSTS IN $/KW	NET % IMPORT
THRESHOLD LEVELS--		50.	10.%	10.	35.	50.	50.
ALUMINUM	8591759.	0.	7.	0.	13.	34.	9.
AMMONIA	374085.	0.	3.	0.	5.	0.	1.
ARGON	137687.	100.*	4.	0.	25.	0.	0.
ARSENIC	46094.	100.*	4.	3.	23.	16.	39.
ARSENIC TRIOXIDE	64532.	100.*	3.	3.	23.	0.	39.
CARBON DIOXIDE	10510513.	100.*	4.	2.	5.	2.	0.
CAUSTIC SODA	1730575.	0.	3.	0.	5.	1.	1.
CEMENT	10985800.	0.	3.	0.	18.	2.	4.
CHLORINE	681361.	0.	3.	0.	5.	0.	1.
COAL, BITUMINOUS	48707.	0.	2.	0.	20.	0.	10.
COKE	34231786.	0.	3.	0.	10.	10.	1.
COPPER	285206.	1.	6.	0.	13.	2.	12.
ELECTRICITY (KWH)	268.E+9	0.	7.	0.	0.	27.	0.
ELECTRODES	90580.	0.	3.	0.	10.	1.	1.
FERROMANGANESE	974166.	0.	3.	0.	22.	1.	98.*
FERROSILICON	88561.	0.	3.	0.	10.	0.	35.
FERROUS SCRAP, PURCHASED	21669697.	0.	3.	0.	10.	6.	0.
FLUORSPAR	766910.	0.	5.	0.	19.	0.	79.*
GALLIUM	43378.	100.*	85.*	97.*	40.*	118.*	55.*
GALLIUM ARSENIDE (DEP)	79886.	0.	87.*	97.*	10.	190.*	0.
GRAPHITE FIBER, SYNTHETIC	272163.	0.	32.*	57.*	35.*	53.*	0.
HELIUM	11.	100.*	3.	0.	5.	0.	0.
HYDROCHLORIC ACID	196432.	92.*	3.	0.	5.	0.	2.
HYDROFLUORIC ACID	54149.	0.	3.	0.	15.	0.	0.
HYDROGEN	2398332.	40.	6.	0.	10.	5.	0.
KAPTON	160421.	0.	20.*	50.*	0.	36.	5.
LIME	6319792.	0.	3.	0.	20.	1.	2.
LIQUID FUELS	3795948.	0.	3.	0.	18.	2.	39.
MAGNESIUM	1134.	1.	6.	0.	27.	0.	0.

Note: + = Beginning in 1995

* = Threshold exceeded

MT = Metric tons

TABLE 9. BULK MATERIAL REQUIREMENTS FOR SOLAR POWER SATELLITE OPERATIONAL SYSTEM (GA/AS) (CONTINUED)

SOLAR SCENARIO:
INTRODUCTION YEAR- 2000
CUMULATIVE CAPACITY 2029- 295. GW

FACTORS	BULK MATERIAL USAGE MT.	PERCENT SUPPLY AS BY-PROD	PRODTN GROWTH RATE 1995 +	MAX % SYSTEM 1 YEAR WORLD	% FROM ONE NATION NON-US	PRESENT COSTS IN $/KW	NET % IMPORT
THRESHOLD LEVELS--		50.	10.%	10.	35.	50.	50.
MERCURY	5251.	2.	1.	2.	18.	0.	62.*
NATURAL GAS REFINED	11207935.	0.	5.	0.	23.	4.	5.
NITRIC ACID	174060.	0.	3.	0.	32.	0.	1.
OXYGEN, GASEOUS	55850565.	0.	4.	2.	21.	4.	0.
OXYGEN, LIQUID	55847290.	0.	5.	4.	21.	3.	0.
PETROLEUM COKE	3792213.	100.*	3.	0.	15.	1.	0.
PITCH-IN-TAR	2623435.	0.	4.	6.	5.	0.	5.
POLYACRYLONITE FIBER	612367.	0.	3.	1.	18.	3.	3.
POLYSULFONE	181248.	0.	8.	6.	5.	3.	5.
SAND & GRAVEL	22783760.	0.	4.	0.	10.	0.	0.
SAPPHIRE	199184.	0.	54.*	78.*	25.	540.*	0.
SILICA FIBER	9153.	0.	33.*	78.*	0.	9.	4.
SILVER	54752.	70.*	5.	6.	14.	36.	50.*
SODIUM CARBONATE	271913.	0.	0.	0.	10.	0.	0.
STAINLESS STEEL	312995.	0.	4.	0.	30.	1.	15.
STEAM	315.E+6	1.	3.	0.	10.	5.	0.
STEEL & IRON	88247973.	1.	3.	0.	16.	99.*	7.
STONE, CRUSHED & SIZED	44727900.	0.	3.	0.	3.	0.	0.
SULFUR	327322.	31.	3.	0.	14.	0.	0.
SULFURIC ACID	1014141.	20.	3.	0.	14.	0.	0.
TEFLON	68027.	0.	8.	3.	10.	2.	8.
TITANIUM	3658.	0.	6.	0.	39.*	0.	8.
TUNGSTEN	38114.	10.	3.	2.	7.	4.	54.*
ZINC	12045.	25.	2.	0.	20.	0.	59.*
.BENZENE.	571002.	0.	5.	0.	16.	0.	1.
.PROPYLENE.	808610.	25.	5.	0.	14.	1.	0.
(MISC. BULK MATERIALS)	5025022.						

Note: + = Beginning in 1995

* = Threshold exceeded

MT = Metric tons

TABLE 10. RAW MATERIAL REQUIREMENTS FOR SOLAR POWER SATELLITE OPERATIONAL SYSTEM (GA/AS)

SOLAR SCENARIO:
INTRODUCTION YEAR- 2000
CUMULATIVE CAPACITY 2029- 295. GW

FACTORS	RAW MATERIAL USAGE (1000MT)	%PRD GROW RATE FROM 1995+	MAX% SYST ONE YEAR WRLD	%US RESERV CONSUM BY 2029	%US RESOUR CONSUM BY 2029	%FRM ONE NAT NON-US	%WORLD RESERV CONSUM BY 2029	%WORLD RESOUR CONSUM BY 2029	PRSNT COSTS IN $/KW	NET% IMPT
THRESHOLD LEVELS--		7.	10.	400.	300.	60.	300.	200.	50.	50.
BAUXITE	40381.	5.	0.	19126.*	2588.*	31.	89.	58.	2.	91.*
BAUXITE, BY PROD	2168905.	9.*	20.*	24369.*	3298.*	31.	97.	64.	0.	91.*
CHROMITE	240.	3.	0.	100.	3851.*	28.	399.*	6.	0.	89.*
CLAYS	1582.	2.	0.	0.	0.	12.	0.	0.	0.	0.
COAL, BITUMINOUS	325342.	2.	0.	25.	3.	7.	26.	2.	17.	0.
COPPER BYPROD.	148.	4.	0.	299.	68.	13.	316.*	77.	0.	12.
COPPER ORE	40745.	4.	0.	299.	68.	13.	316.*	77.	0.	12.
FLUORSPAR ORE	2331.	5.	0.	6817.*	1144.*	19.	1403.*	769.*	0.	79.*
GYPSUM, CRUDE	527.	2.	0.	618.*	0.	10.	373.*	0.	0.	35.
IRON ORE	142962.	5.	0.	131.	21.	27.	84.	27.	1.	29.
LIMESTONE	48095.	3.	0.	0.	0.	20.	0.	0.	5.	2.
MANGANESE ORE	2143.	3.	0.	100.	25.	22.	52.	26.	1.	98.*
MERCURY ORE	181.	1.	2.	643.*	291.	18.	280.	83.	0.	62.*
NATURAL GAS	31082.	5.	0.	697.*	163.	23.	501.*	50.	10.	5.
NICKEL ORE	2629.	2.	0.	11577.*	30.	33.	160.	67.	0.	70.*
PETROLEUM	323051.	2.	0.	2327.*	761.*	18.	343.*	113.	80.*	39.
RUTILE (CONC.)	8.	5.	0.	605.*	199.	98.*	53.	42.	0.	98.*
SALT	4371.	6.	0.	0.	0.	18.	0.	0.	0.	7.
SAND & GRAVEL	626.	4.	0.	0.	0.	6.	0.	0.	0.	0.
SILVER ORE	78295.	5.	6.	1033.*	274.	14.	1018.*	273.*	1.	50.*
SODA ASH (NAT.)	9.	5.	0.	4.	2.	2.	3.	1.	0.	0.
STONE	44728.	3.	0.	0.	0.	3.	0.	0.	0.	0.
SULFUR ORE	327.	3.	0.	725.*	236.	14.	417.*	131.	0.	0.
TUNGSTEN ORE	6365.	3.	2.	1441.*	414.*	21.	275.	96.	1.	54.*
WATER, SEAWATER	818.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ZINC ORE	267.	3.	0.	672.*	403.*	20.	436.*	282.*	0.	59.*

Note: + = Beginning in 1995

* = Threshold exceeded

MT = Metric tons

V - ANALYSIS OF RESULTS

By-Product/Co-Product Problems

Our screening criterion is a threshold value of 50 percent for any material whose production is reliant on being a co-product or by-product of another material. Table 11 indicates the bulk materials that are "flagged"as meeting this criterion.

By-Products/Co-Products of No Concern

Those materials that are flagged but present no real problem include

Argon is a co-product of production of oxygen by air liquefication/separation. No supply problems are anticipated since oxygen demand will remain high. The SPS itself would be a high oxygen demander.

Carbon Dioxide is rarely produced as a primary material. It is a by-product of many industrial chemical processes. Its potential for recovery is almost unlimited.

Helium is recovered as a co-product from certain helium rich natural gas deposits through low temperature liquefaction. If necessary it could also be recovered as a co-product of oxygen production by air liquefaction -- but at much higher cost. At the level of SPS demand for helium, we would anticipate no problems.

Hydrochloric Acid is a by-product of several chemical processes. In general, it is a "glut" on the market. No problems are anticipated.

TABLE 11. PERCENT SUPPLIED AS BY-PRODUCT/COPRODUCT
THRESHOLD VALUE 50 PERCENT

Code*	Material	By Product-Coproduct of	Percentage	SPS System Si and/or GaAs
A	Gallium	Alumina/Aluminum, zinc	100	Mostly Ga/AS
B	Arsenic	Copper, lead, zinc	100	Mostly Ga/As
B	Arsenic Trioxide	Copper, lead, zinc	100	Mostly Ga/As
B	Silver	Copper, lead, zinc	70	Mostly Ga/As
D	Hydrogen	Many processes	40	Both
C	Argon	Air liquifaction	100	Both
C	Carbon dioxide	Many processes	100	Both
C	HCl	Many processes	92	Both
C	Helium	Natural gas	100	Both
C	Petroleum coke	Petroleum based fuels	100	Both

* Code	Interpretation
A	Serious concern
B	Possible concern
C	No concern
D	Not flagged, but of concern

Petroleum Coke is a by-product of the refining of petroleum of liquid fuels. Availability in the amounts required for SPS presents no problem. Possible future inadequacy of petroleum-based fuels might present a far larger problem than petroleum coke per se.

By-Products/Co-Products of Possible Concern

Silver is most often a by-product of the production of copper, lead, and zinc, and silver prices can often be a deciding factor in the exploitation of some of those ore bodies.

Silver recovery directly from silver ores per se represents perhaps only 30 percent of total silver production. Trends toward on-site leaching of copper ores (rather than conventional milling) could reduce by-product silver recovery and therefore silver production does represent a possible problem. However, silver production is very responsive to price and recent higher silver market prices will go a long way toward increasing primary silver production as well as increasing secondary recovery of silver.

Arsenic and Arsenic Trioxide are included as materials of possible concern because of the special circumstances surrounding domestic capacity. Both materials are in plentiful supply worldwide, however, there is only one U. S. supplier, and that operation has had severe environmental and safety problems. It currently is operating under court-ordered 5-year variance from Washington State air pollution standards. Arsenic and several of its compounds are also listed in OSHA's Number I carcinogen group.

In addition to the above, the future market outlook for arsenic is not strong. A future business decision to close U.S. smelter operations would not come as a surprise.

It should also be noted that U.S. production of very high purity arsenic (99.999) is quite limited. Current U.S. production by a single supplier is only about 5 metric tons per year.

By-Products/Co-Products of Serious Concern

Gallium is most commonly recovered as a by-product of the production of alumina from bauxite. The alumina is then processed into aluminum. Average gallium content in bauxite is about 0.005 percent. Current processing techniques recover about 40 percent of the gallium. Unfortunately, few bauxite processors currently recover gallium. The Ga/As version of SPS would require at least 1470 MT of gallium per year which would require processing of 73,500,000 MT of bauxite.* World demand for bauxite in 2000 is expected to be about 271,000,000 MT. Hence, adequate quantities of bauxite will be processed worldwide to recover the needed gallium, if sufficient market and price incentives are present.

The major question would then become "where will the bauxite be processed to alumina?" Over one-third of U.S. alumina consumption is currently imported and that proportion will almost certainly rise over the coming decades.

By-Product/Co-Product - Not "Flagged" But of Possible Concern

Hydrogen is usually either a process by-product used captively, or it is manufactured captively for particular chemical processes. Probably over 98 percent of hydrogen produced is so consumed. Hydrogen is readily manufactured by several processes, most commonly from natural gas and steam as feedstock. It is also often (perhaps 40 percent of production) a byproduct recovered for its chemical values in downstream production. Petroleum refining is a primary example.

Liquid hydrogen production for sale probably reprsents no more than about 1/2 percent of total U.S. hydrogen production--or perhaps

*New technology could possibly recover 80 percent of by-product gallium which would reduce bauxite requirement by 50 percent.

about 40,000 metric tons in 1976. Hence, total U.S. hydrogen production is not a reliable guide for SPS requirements. SPS requirements of 80,000 to 130,000 MT/year would represent a very large share of expected U.S. production of non-captive liquid hydrogen in year 2000 of about 185,000 metric tons.

Production Capacity/System Market Demand Problems

In the assessment of SPS, these two factors tend to coexist with one another. This results from some of the specific "exotic" or new material demands of the present SPS reference design. These materials are in limited commercial supply at present, and SPS would demand substantial shares of them relative to other expected market demands.

The worst case is represented by the system "introduction" year 2000 when two 5-GW systems would be built. We assume capacity build-up would begin in 1995.

Following is a tabulation (Table 12) of those materials presenting the most serious production capacity/market impact problems in year 2000.

The following paragraphs further elaborate on the tabular data presented.

Gallium presents the most severe problem. As discussed earlier under by-product problems, there is probably enough gallium in the amount of bauxite expected to be processed in year 2000 to reasonably accommodate SPS demand. However, the rate-of-growth needed in productive by-product recovery processes would be huge. In the current economics of alumina/aluminum production, by-product gallium recovery is not a significant contributor to economic viability even at today's very high gallium prices. The use of gallium, particularly in gallium arsenide electronic applications (non-solar) is expected to grow perhaps 6 percent to 7 percent in future years. However, an SPS demand of 1470 MT/yr would completely dominate the market (97 percent of demand in year

TABLE 12. CAPACITY/MARKET FACTORS OF CONCERN

Code*	Material	Percent World Production Growth Rate Required (Threshold 10 Percent)		Maximum Percent System Demand One Year World (Threshold 10 Percent)	
		GaAs System	Silicon System	GaAs System	Silicon System
A	Gallium	85	7	97	13
A	Gallium arsenide	87	8	97	14
A	Graphite fiber	32	30	57	52
A	Sapphire	54	-	78	-
A	Silicon (SEG)	-	22	-	11
B	Glass (Borosilicate)	-	6	-	12
B	Hydrogen	6	6	0	0
B	Kapton	20	-	50	-
B	Natural gas (methane)	5	5	0	0
B	Oxygen	5	5	4	7
B	Silica fiber	33	46	78	88

* Code	Interpretation
A	Serious concern
B	Possible concern

2000). It would seem clear then, that only if that market were completely assured, would the necessary gallium world-wide production capacity be forthcoming.

These observations are made in the absence of consideration of the possible use of gallium arsenide as an economic terrestially-based solar cell. If this potential were to be realized within the next 10 to 15 years, then growth of gallium production for SPS might be more readily accommodated. This eventuality, however, would mean even more demand for gallium and perhaps start to extend recovery operations toward marginal gallium concentrations and consequent higher prices.

Gallium Arsenide. Crystal growth of GaAs from melt is a crude art. Epitaxial growth is considerably more advanced, but still a very slow process. Less is known about epitaxial growth of GaAs on sapphire substrates.

Consequently, the timing of the development of true production processes for these materials in the quantities needed by SPS (about 2700 Mt/yr) is very speculative. We can assume that the development process may take at least 5 to 15 years. Therefore, starting in 1985 at best (or more likely 1995), large increments of capacity would need to be built for a market that would be dominated by SPS. This could only be accomplished under a system of assured markets.

Sapphire. Most synthetic sapphire is produced today as slices from single crystal boules, but ribbon growing is rapidly developing. The production level in 1976 was probably about 10 metric tons, and today perhaps about 25 to 30 MT. Electronic applications are the major market drivers. At an estimated growth rate of about 20 percent/year, about 800 MT would be produced in year 2000.

Therefore, similar to the case of Gallium/gallium arsenide, very large increments of capacity would need to be added for a market dominated by SPS.

The U.S. is currently an exporter of synthetic sapphire, but the raw material (99.999 percent pure ground crystal) is almost all imported from Switzerland and France. Domestic production of the raw material was discontinued a few years ago, but could possibly be reestablished if the market continues its growth.

Silicon (SEG). U.S. consumption of semiconductor grade silicon (SEG) in 1976 was about 700 MT. Today, consumption might be about 1000 to 1200 MT, and applications are very largely electronic in nature.

Technology for production of silicon crystal by ribbon growing techniques is rapidly advancing. Despite a projected annual growth rate of 20 percent/year, substantial additional capacity for silicon SEG would be required for SPS. If the projected growth rate for silicon SEG is realized, the capacity problem might not be nearly so severe as for gallium and sapphire. However, SPS would still consume 11 percent of world production--an uncomfortable market position.

Production capacity for metallurgical grade silicon (Silicon MG) as a raw material should present no problem.

Graphite Fiber. World consumption of graphite fiber in 1976 was about 215 MT. Based on potential substantial use by the automobile industry, it is projected to grow by about 15 percent/year to about 6,160 MT by year 2000. SPS demands in 2000 would require additional capacity growth of over 30 percent/year beginning in 1995. SPS would also be very market dominant, requiring over 50 percent of world capacity.

It is also likely that SPS would require very high modulus graphite fiber. High modulus fiber is very costly, representing a tiny fraction of today's production and, therefore, graphite fiber capacity to be added for SPS consumption would probably be very specialized. The market would need to be completely assured to bring forth this higher level of very special fiber.

Raw material complications might be present if rayon were designated as the graphite fiber precursor. The rayon fiber currently used to manufacture high modulus graphite fiber is also "special".

Current production capacity for that rayon fiber is less than half the annual requirements for SPS. Given present rayon market trends, current capacity for that special precursor fiber is very unlikely to be increased without an assured market.

If polyacrylonitrile (PAN) fiber were used as the graphite fiber precursor, no raw material problems would be anticipated.

Borosilicate Glass. This glass with special thermal properties is exemplified by Pyrex. Assuming normal market growth, (about 3 percent to 4 percent per year) world production by year 2000 might be near 70,000 MT. To produce SPS requirements (38,542 MT in 2000) would require a 6 percent annual growth from year 1995, and SPS would consume about 12 percent of world requirements. From a capacity growth and market domination point of view this situation is marginal.

Problems of producing and assembling the glass in the required 50 and 75 micron thicknesses also present a very substantial set of technical complexities. Costs per unit of weight would be far in excess of the values assigned to the bulk material per se.

Natural Gas (Methane)/Hydrogen/Oxygen

These are basically the transportation fuels of SPS. Each presents a somewhat different problem.

Methane in the CMAP data base is currently treated as natural gas. The methane (CH_4) component of natural gas varies widely. The critical question of supply (beyond the general concern for natural gas supply) becomes one of purity. Some domestic deposits (Alaska) produce a sulfur free methane purity of 99.5 percent. Other U.S. and world deposits may be as low as 70-80 percent methane.

A requirement of 651,599 MT of liquid methane annually for SPS space vehicle operations is quite small compared to an expected world production of over 3 billion metric tons of natural gas in year 2000. However, the general outlook for natural gas (national priorities and price) is cause for speculation. Also, liquid methane is not a conventional or common commodity of commerce.

Through distillation separations, liquefied natural gas (LNG) from many U.S. and world sources could be used as a source of liquid methane of nearly any required purity. Methane could also be produced from coal or biomass. These latter two options would require substantial capital investments.

Hydrogen. Despite very large world production of hydrogen, liquid hydrogen is not a common market commodity. NASA has been among the largest consumers. As discussed under "by-product problems", SPS could easily consume 50 percent of expected liquid hydrogen production in year 2000. This presents obvious problems of capacity and market share.

Oxygen. About 30 percent of total oxygen production is presently liquified, hence, the liquid product is not uncommon. SPS vehicle requirements of over 2.7 million MT annually would however represent nearly 7 percent of liquid oxygen world production in year 2000. It is therefore possible that dedicated liquification facilities might need to be considered.

Kapton. The raw material base for Kapton (benzene, chlorine, durene, etc.) presents no unique problems. However, Kapton is a proprietary product whose production capacity would need to be increased substantially. Beginning in 1995, the production base would need to be increased 20 percent/year and in 2000, SPS would consume 50 percent of total capacity.

This proprietary product situation is almost unique (Teflon is the other) in the SPS materials assessment. The material presents a capacity and market share problem with the current added dimensions of single source. It is not necessarily a serious problem, but it is "different".

Silica Fiber. The heat shielding insulation (ceramics) of reusable space vehicles is assumed to be similar to the insulation on the current shuttle. A large proportion of those insulating tiles are based on a special silica fiber. One firm produces the silica fiber; another produces the tiles. Tile production is quite sophisticated. The annual quantities required by SPS are not large, but production capacity would have to grow 46 percent/year beginning in 1995 and SPS would completely dominate the market. Again, a typical capacity/market domination situation would prevail.

Resource Depletion Problem

The screening program flags those raw materials where total world consumption of those resources by year 2029 (including SPS) is expected to exceed 200 percent of the currently identified resource base. Resources for nearly all materials are continually being identified worldwide and the history of the identified world resource base indicates that a 200 percent increase in the identified world resource base over the next 50 years is a reasonably conservative assumption.

Those raw materials demanded by SPS that indicate resource consumption, including SPS, of over 200 percent by 2029 are shown in Table 13. The 1978 identified resource base is shown as well as the annual requirements of SPS related to that base.

TABLE 13. WORLD RESOURCES - PERCENT CONSUMED BY 2029 AND SPS DEMAND

	Percent World Resource Consumption Year 2029		1978 Ore Resource Base	Total SPS 300 GW Consumption by Year 2029	
	Si	Ga As	1000 MT	Si 1000 MT	GaAs 1000 MT
Fluorspar Ore	769	769	456,000	1993	2373
Silver ore	266	273	7,050,000	3175	79,622
Zinc ore	282	282	53,600,000	11	272

The consumption of the fluorspar ore and zinc ore resource base by SPS represents only a tiny fraction of world demand for those ores and make no measureable impact on the rate of resource depletion. There are also reasonably viable substitutes for each material, hence these should not be viewed as critical materials.

The gallium arsenide reference design however would consume something over 1 percent of the world's currently identified silver ore resources and increase the depletion rate from 266 percent to 273 percent. While not terribly significant from a resource depletion point-of-view, we would expect a continued rise in silver prices as more marginal resources are exploited.

Import Dependency Problems

The criticality of import dependency relative to SPS is a function of the current U.S. levels of import, the future U.S. material demand outlook, and SPS demand as a proportion of that total U.S. demand. In the latter case we should probably view SPS import demand as "critical" only if it might significantly exacerbate an already existing high level of domestic dependency on imports for many other uses.

While the import dependency threshold (50 percent) is measured against todays U.S. import levels, we can probably safely assume that some bulk materials and nearly all raw material dependencies will become even greater by year 2000.

Tables 14 and 15 present the import dependency factor for both reference systems. They indicate the SPS annual requirements in metric tons for bulk materials, and 1000 MT for raw materials. If those numbers represent a high proportion of year 2000 U.S. consumption for specific materials, this would indicate situations where SPS could significantly increase dependency.

In general, the GaAs reference design option presents the more severe import dependency problems. These relate to significantly higher use of gallium, arsenic, and silver.

TABLE 14. RAW MATERIAL IMPORT DEPENDENCY FACTORS
PERCENT U.S. IMPORTS 1976
(Threshhold Value - 50 Percent)

Code	***Material	% Current Dependency U.S.	**Estimated U.S. Annual Consumption Year 2000 1000 MT	Silicon Option SPS Annual Demand Year 2000 1000 MT	GaAs Option SPS Annual Demand Year 2000 1000 MT
A	Bauxite By Product (Ga)	91	85,800*	380	3,500
B	Mercury Ore	62	55.9	6.0	6.0
B	Silver Ore	50	10,200	106	2,654
C	Bauxite	91	85,500*	1,352	1,352
C	Chromite	89	3,330	8.8	8.1
C	Fluorspar Ore	79	11,900	66.4	79.1
C	Manganese Ore	98	4,390	72.6	72.6

* Does not imply that the U.S. will process this much bauxite. Import of alumina processed from bauxite at foreign lcoations has been growing. About 1/3 of U.S. alumina consumption is currently imported.

**Without SPS

***Code	Interpretation
A	Serious concern
B	Possible concern
C	No concern

TABLE 15. BULK MATERIAL IMPORT DEPENDENCY FACTORS OF CONCERN. PERCENT U.S. IMPORTS 1976

(Threshhold Value 50 Percent)

Code*	Material	% Current Dependency U.S.	Estimated U.S. Annual Consumption Year 2000 MT	Silicon Option SPS Annual Demand Year 2000 MT	GaAs Option SPS Annual Demand Year 2000 Mt
A	Gallium	55	32.0	7.5	1,462
B	Arsenic	39	23,800	8	1,562
B	Arsenic Trioxide	39	38,100	11	2,187
B	Mercury	62	2,000	178	178
B	Silver	50	9,640	74	1,856
B	Tungsten	54	23,500	1,292	1,292
C	Ferromanganese	98	2,510,000	33,000	33,000
C	Fluorspar	79	3,910,000	22,000	26,000
C	Sapphire (ground) (crystal)	100	800	0	6,752
C	Zinc	59	2,490,000	16	4,069

* Code	Interpretation
A	Serious concern
B	Possible concern
C	No concern

Both options would require a high proportion (9%) of expected U.S. mercury consumption in year 2000. Both options would also represent 5% of U.S. tungsten consumption.

Material Cost Problems

The CMAP screening threshold for material cost is set at $50.00 per KW of installed capacity. This would represent about 5 percent of the total cost for an "average" $1,000.00 per KW conventional power generating system.

It should be borne in mind that the values produced by the CMAP program are the current values of the unfabricated bulk materials. The present program also assumes no waste, and therefore the values represent a floor value for materials.

The costs are additive only if one selects the final materials specified for the system. For example, materials cost for GFRTP would be the cost of graphite fiber plus the cost of polysulfone. Conversely, the cost of aluminum would already incorporate the cost of caustic soda used in its manufacture.

The bulk materials that exceed the threshold value are shown in Table 16.

Electricity. Consumption of electricity by the silicon option is nearly 5 times that of the gallium arsenide option.* This is due to the very large energy requirements to produce silicon (SEG). Battelle's very preliminary estimate for energy consumption to produce silicon SEG is about 2,300,000 Kwh per metric ton and this does not consider any detailed accounting for process and fabrication losses.

Further, electricity costs are likely to inflate faster than the economy as a whole.

The literature on energy consumption to produce single crystal silicon shows very wide variation in estimates. Since this value may be

*However, this may be due to differing assumption as to the state-of-the-art production processes.

TABLE 16. BULK AND RAW MATERIALS VALUES EXCEEDING $50.00 PER KW INSTALLED

Criticality	Material	300 GW GaAs System	300 GW Si System
A	Electricity	-	$143.00
A	Gallium	$118.00	-
A	Gallium Arsenide	190.00	-
A	Graphite Fiber (syn)	53.00	44.00
A	Sapphire (syn)	542.00	-
A	Silicon (SEG)	-	96.00
B	Petroleum	80.00	82.00
B	Steel	99.00	99.00

Criticality

A - Serious concern

B - Some concern

C - No concern

very critical to evaluation of the SPS silicon option it seems imperative that the issue be reviewed in depth, and some common agreement reached on current values as well as the future outlook for reduction of those energy requirements.

Gallium. The price of Gallium probably does not bear strong relationship to its cost of production. As a minor material consitiuent in electronic devices, it is not highly price elastic, and its use is based on unique or superior performance properties. It is probably priced therefore at what the market will bear. The recovery process is tedious and quality control for purity is undoubtedly costly, but it would seem very likely that recovery on the scale required by SPS could reduce costs and prices significantly.

On the other hand, to scale up gallium recovery to the level required for SPS would require assurance of market, since non-solar cell uses for gallium are apt to remain small. The future price for gallium is probably "negotiable" depending upon the quantities to be contracted.

Gallium Arsenide. The manufacture of single crystal gallium arsenide is still a relatively crude art. Consistant quality control and production rates are major problems. Even when efficient production processes are developed, the price of the material is obviously going to be very dependent on the price of gallium.

Even with the very thin layers of gallium arsenide projected in the SPS reference designs, the material is a major cost driver.

The current price of gallium is about \$800,000/MT. High purity arsenic (99.999) is about \$100,000/MT. Epitaxially grown layers of GaAs are estimated at \$700/Kg. This may be quite low. Single crystal GaAs produced from ingot is priced at about \$30,000/Kg. The cost of epitaxially grown layers needs further investigation.

Graphite Fiber, Synthetic. The current "average" price for graphite fiber used in reasonable commercial quantities is about \$26.00/lb (\$57,200/MT). If the price can be brought down to \$5.00 to \$10.00 per lb, large scale use in the automobile industry is forecast.

An automotive high volume commercial fiber would not be the very high modulus fiber currently used in some aerospace defense applications. Prices on high modulus grades are currently 10 to 20 times the "average" price used in the CMAP data base.

At present, a particular fiber grade has not been specified for SPS. Until further determination is made, we can only guess that the current graphite fiber cost contribution to SPS may be some 10 to 20 times higher than currently shown by CMAP. Undoubtedly significant cost reductions could be made even for the very high modulus fibers - in the volume contemplated by SPS.

Sapphire. In the bulk form of boules, sapphire costs about $800 per Kg. If boules are sliced to wafers, the cost is apt to be at least twice that; the thinner the wafer, the higher the cost per Kg. Ribbon grown sapphire, which is relatively new, would appear to offer definite cost advantages if SPS specified thicknesses and widths can be achieved.

Synthetic sapphire production is very energy intensive and therefore is never apt to be costed lower than "hundreds of dollars" per Kg. Pending further investigating sapphire appears as one of the highest cost contributions to SPS.

Single Crystal Silicon (SEG). A current price for "bulk" semi-conductor grade silicon is around $600.00 per Kg. Production of 50 micron wafers from single crystal ingot would entail very substantial process losses. A far more promising approach will probably involve ribbon growing processes--of which there are several under development.

High purity single crystal silicon is extremely energy intensive, and barring some radical technical innovation, it is apt to remain so. Production processes for high purity polycrystalline silicon as well as single crystal silicon are under intense technical development at present. Without thorough review, any price projection would be very hazardous. In the case of SPS, the production and fabrication of 50 micron thicknesses of single crystal silicon present many technical complexities.

As a "bulk" material we would expect the relative price of single crystal silicon to decline. However, the technical complexities and consequently the costs of processing and fabricating 50 micron thick single crystal silicon material remain a very uncertain area.

Steel. The cost contribution of steel to the SPS system stems almost entirely from the nearly 3,000,000 metric tons of steel per year required for the rectenna installations to accommodate two 5 GW satellites per year. That steel would probably be specified in basic mill structural shapes and therefore further fabrication costs would be minimal.

It would seem likely--that as a bulk material-the cost of steel is likely to inflate relatively faster than many of the other cost sensitive materials on the threshold list. This would stem from the relative maturity of the manufacture of steel compared to the new technology, cost-reducible materials that dominate the threshold list.

Petroleum. The cost contribution of petroleum derives very dominantly from its use as an energy source and not from its use as a chemical feedstock. Many industries rely on oil as their source of process heat and mechanical power.

Similar to the cost contribution of electricity, petroleum costs are apt to inflate faster than the other materials costs.

Percent World Supply From One Nation, Non-U.S

This category of concern looks at the potential dominance of any one non-U.S. nation as a world supplier of bulk or raw material. For bulk materials, the threshold value is 35 percent. For raw materials the threshold is 60 percent.

Table 17 shows the bulk and raw materials exceeding these thresholds.

TABLE 17. PERCENT OF WORLD SUPPLY FROM ONE NON-U.S. NATION

	Material	Dominant World Supplier	Percent World Supply
C	Gallium	Switzerland	40
C	Graphite fiber	Japan	35
C	Titanium	USSR	39
C	Rutile (conc)	Australia	98

A - serious concern

B - possible concern

C - no concern.

Gallium. The predominant world supplier of gallium is one aluminum company in Switzerland. If gallium is to be produced in substantial quantities, that production would occur in a diverse number of countries that are the world's bauxite suppliers. It is very unlikely that any one nation would dominate gallium supply. A possible, but unlikely, threat of cartelization could exist.

Graphite Fiber. Japan is a large world supplier of graphite fiber based upon proprietary technology. Similarly the U.K. is a major world supplier. U.S. production is also very substantial, and in response to U.S. demand, could be expanded almost without limit.

Titanium. The dominant non-U.S. world producer is the USSR. This poses no real threat in that U.S. supply could be expanded substantially. U.S. imports, largely from Japan, are estimated at about 8 percent of consumption. Further the SPS requirements for titanium are very small compared to total U.S. consumption.

Rutile (conc). Rutile concentrate is the principal raw material for manufacturing titanium. Australia is by far the dominant world supplier. Other world sources of synthetic rutile derived from ilmenite are developing and these include the U.S. Further, since titanium demand by SPS is quite small, rutile requirements are also very small.

VI - SPS CRITICAL MATERIALS SUMMARY

Assessment of SPS material requirements produced a number of potential material supply problems. The more serious problems are those associated with the solar cell materials (gallium, gallium arsenide, sapphire, and solar grade silicon), and the graphite fiber required for the satellite structure and space construction facilities. In general, the gallium arsenide SPS option exhibits more serious problems than the silicon option, possibly because gallium arsenide technology is not as well developed as that for silicon.

Table 18 summarizes potential material problems that have been identified. Problems of serious concern are denoted by an "A" in the table, and those of lesser but possible concern are denoted by a "B". Within each of the two rating groups, materials are listed in order of decreasing criticality in terms of the number of different categories in which a problem exists (e.g., a material that exhibits a problem in two categories is judged more critical than a material with a problem in only one category). Materials with problems in the same number of categories are listed alphabetically.

The problems associated with each of the materials in the table are described in the following discussions.

Material Problems of Serious Concern

Gallium represents nearly 50 percent of the material required to produce the gallium arsenide active layer of the solar cells specified in the Gallium Arsenide option for SPS. SPS would require a minimum of 1470 MT/year of gallium. Current world production is about 16 to 17 MT/year.

A primary concern is that, with very rare exception, gallium does not naturally occur in concentrated ore deposits as do many other elements. Well over 70 percent of current world gallium production is recovered as a by-product of the production of alumina from bauxite. "Average" concentration of gallium in bauxite is considered to be about

TABLE 18. SUMMARY OF ASSESSMENT RESULTS

PARAMETER	PERCENT SUPPLIED AS BY-PRODUCT	WORLD PRODUCTION GROWTH RATE	SPS PERCENT OF DEMAND	NET PERCENT IMPORTED	PERCENT WORLD RESOURCE CONSUMPTION	COST $/KW
THRESHOLD VALUE *	50%	10%	10%	50%	200%	$50/KW
Gallium	A	A	A	A		
Graphite Fiber		A	A			A
Sapphire		A	A			A
Silicon SEG		A	A			A
Gallium Arsenide		A	A			A
Electricity						A
Arsenic/Arsenic Trioxide	B			B		
Kapton		B	B			
Oxygen (liq)		B	B			
Silica Fiber		B	B			
Silver	B			B		
Silver ore				B	B	
Glass, borosil.			B			
Hydrogen (liq)		B				
Mercury				B		
Mercury ore				B		
Methane		B				
Petroleum						B
Steel						B
Tungsten				B		

Note: "A" signifies problem of serious concern
"B" signifies problem of possible concern

*Parameter value above which a potential problem exists. Materials in this table exceeded these values where an "A" or "B" is recorded.

50 parts per million. However, very few alumina producers currently recover by-product gallium. If sufficient market demand and price incentives were present, many others most probably would.

The very dominant current use of gallium involves gallium arsenide in electronic applications. This use might grow at 6 to 7 percent per year. An SPS solar cell annual demand of 1470 MT in year 2000 would completely dominate the market (97 percent) and require a world annual production growth rate of 85 percent beginning in 1995 to the year 2000. These are clearly formidable hurdles unless demand and price can be completely assured.

While world-wide processing of bauxite to alumina could potentially easily accommodate this level of demand by a margin of 5 to 10 times, that processing step will increasingly occur in non U.S. locations. Currently the U.S. is over 90 percent dependent on foreign bauxite or alumina and will become more so in the future. This, of course, means increasing dependency on foreign supply of gallium (currently estimated at about 55 percent) and an increasing potential for cartellization.

The current price of gallium is about $800,000/MT. Gallium price is probably relatively inelastic in present markets. Given sufficient lead time for installation of new capacity and assured high levels of demand, that price level in large quantities is probably very negotiable-downward. Because of its very low concentration in ore bodies, it is unlikely that gallium will ever be priced at less than "hundreds of thousands of dollars" per metric ton. Therefore, its price will continue to represent a very significant contribution to the overall cost of SPS.

A mitigating strategy to decrease foreign dependency for gallium might involve increasing domestic supply from non-bauxite sources. Increased domestic supply from zinc ores and possibly from coal are being investigated.

Graphite Fiber. Graphite fiber reinforced thermoplastic (GFRTP) is specified as the structural support material for both SPS options. The composition is tentatively specified as 60 percent graphite fiber and 40 percent polysulfone thermoplastic.

World consumption of graphite fiber in 1976 was about 215 MT. Based on potential substantial use by the automobile industry, it is projected to grow by about 15 percent/year to about 6,160 MT by year 2000. SPS demand in 2000 of 12,700 to 15,300 MT/yr of GFRTP would require capacity growth of graphite fiber capacity by over 30 percent/year beginning in 1995. SPS wouild also be very market dominant, requiring over 50 percent of world capacity.

It is also likely that SPS would require very high modulus graphite fiber. High modulus fiber is very costly, and represents a tiny fraction of today's production. Therefore, graphite fiber capacity to be added for SPS consumption would probably be very specialized. The market would need to be completely assured to bring forth this high level of very special fiber.

Material complications might be present if rayon were designated as the graphite fiber precursor. The rayon fiber currently used to manufacture high modulus graphite fiber is also "special". Current production capacity for that rayon fiber is less than half the annual requirements for SPS. Given present rayon market trends, current capacity for that special precursor fiber is very unlikely to be increased without an assured market.

If polyacrylonitrile (PAN) fiber were used as the graphite fiber precursor, no raw material problems would be anticipated.

The current "average" price for graphite fiber purchased in reasonable commercial quantities is about \$26.00/lb (\$57,200/MT). If that price can be brought down to \$5.00 to \$10.00 per lb, large scale use in the automobile industry is forecast.

An automotive grade high volume commercial fiber would not be the very high modulus fiber currently used in some aerospace/defense applications. Prices on high modulus grades are currently 10 to 20 times the "average" price used in the CMAP data base.

At present, a particular fiber grade has not been specified for SPS. Until further determination is made, we can only guess that the current graphite fiber cost contribution to SPS may be some 10 to 20 times higher than currently shown by CMAP. Undoubtedly significant cost reductions could be made even for the very high modulus fibers -- in the volume contemplated by SPS.

The major problems with graphite fiber then involve matters of manufacturing capacity and price. SPS designers should be aware of the implications of fiber specification on both these factors.

Regardless of fiber specifications, long lead time will be required to build the needed capacity. Some combination of advance procurement and assured markets will probably be needed.

Sapphire is specified as the substrate and cover for the GaAs solar cells. Sapphire is composed of crystalline Al_2O_3, hence no basic raw material problems exist.

Most synthetic sapphire is produced today as slices from single crystal boules, but ribbon growing technology is rapidly developing. The production level for synthetic sapphire in 1976 was probably about 10 metric tons, and today perhaps about 25 to 30 MT. Electronic applications are the major market drivers. At an estimated growth rate of about 20 percent/year, about 800 MT would be produced in year 2000. Therefore, very large increments of capacity would need to be added - about 54 percent growth per year beginning in 1995. SPS demand would also be very market dominant, requiring about 78 percent of world output.

In the bulk form of boules, sapphire costs about $800 per kg. If boules are sliced to wafers, the cost is much greater; the thinner the wafer, the higher the cost per kg. Ribbon grown sapphire, which is relatively new, would appear to offer definite cost advantages if SPS specified thicknesses and areas can be achieved.

Synthetic sapphire production is very energy intensive and therefore is never apt to be costed lower than "hundreds of dollars" per kg. Pending further investigating sapphire appears as one of the highest cost contributions to the GaAs option for SPS.

The U.S. is currently an exporter of synthetic sapphire single crystal, but the raw material (99.999 percent pure ground crystal) is almost all imported form Switzerland and France. Domestic production of the raw material was discontinued a few years ago, but could possibly be reestablished if the market continues its growth.

Mitigating strategies must involve rapid expansion of production capacity perhaps utilizing mechanisms such as advance procurement and assured market. Ribbon growing technology should be encouraged as a cost reducing measure.

Serious consideration should also be given to examining possibilities for substitution of other substrates for sapphire.

Single Crystal Silicon (SEG). Single crystal silicon between two layers of borosilicate glass is specified as the active layer of the silicon option solar array. Silicon crystals are essentially derived form SiO_2, hence no raw material problems exist.

U.S. consumption of semiconductor grade silicon (SEG) in 1976 was about 700 MT. Today, consumption might be about 1000 to 1200 MT, and applications are very largely electronic in nature.

Despite a projected annual growth rate of 20 percent/year, substantial additional capacity for silicon SEG would be required for SPS. Even if that projected growth rate for silicon SEG is realized, SPS would still consume 11 percent of world production--an uncomfortable market position.

A current price for "bulk" semi-conductor grade silicon (single crystal) is around $600.00 per Kg. Production of 50 micron wafers from single crystal ingot would entail very substantial process losses. A far more promising approach will probably involve ribbon growing processes--of which there are several under development.

High purity single crystal silicon is extremely energy intensive, and barring some radical technical innovation, it is apt to remain so. Production processes for high purity polycrystalline silicon amorphous silicon, as well as single crystal silicon are under intense technical development at present. Without thorough review, any price projection would be very hazardous. In the case of SPS, the production and fabrication of 50 micron thicknesses of single crystal silicon present many technical complexities.

As a "bulk" material we would expect the relative price of single crystal silicon to decline. However, the technical complexities and consequently the costs of processing and fabricating 50 micron thick single crystal silicon material remain a very uncertain area.

Mitigating strategies for SPS should probably involve encouragement of single crystal ribbon growing technology. Because of the high efficiency/low mass requirements of SPS, lower cost polycrystalline or amorphous silicon active layers may not present practical alternatives. The silicon "industry" and silicon technology is expanding rapidly, hence SPS management may need to do little to encourage capacity increases. Other than encouragement of lower cost single crystal technology, the SPS stance might logically be "wait and see".

Gallium Arsenide grown on a sapphire substrate is specified as the active layer of the solar array of the GaAs option.

Crystal growth of GaSa from melt is still a crude art. Epitaxial growth is considerably more advanced, but still a very slow process. Less is known about epitaxial growth of GaAs on sapphire substrates.

Consequently, the timing of the development of true production processes for these materials in the quantities needed by SPS (about 2700 MT/yr) is very speculative. We can assume that the development process may take at least 5 to 15 years. Therefore, starting in 1995 large increments of capacity (85 percent increase annually) would need to be built for a market that would be 97 percent dominated by SPS. This could only be accomplished under a system of assured markets.

Even with the very thin layers of gallium arsenide projected in the SPS reference designs, the material is a major cost driver. The current price of gallium is about $800,000/MT. High purity arsenic (99.999) is about $100,000/MT. Epitaxially grown layers of GaAs are estimated at $700/Kg. Our estimate may be quite low. Single crystal GaAs produced form ingot is priced at about $30,000/Kg.

If the gallium arsenide option for SPS is selected, SPS strategy (beyond the problems of gallium supply), should probably include enhancement of thin film GaAs technology. Much technology will need to be developed for deposition and handling of very thin films (5 microns) of GaAs on very thin substrates such as 20 micron sapphire. GaAs technology for terrestial solar cells is under very active development, but this technology will not be highly sensitive to mass.

There will not likely be a GaAs "materials industry" as such. It is not yet clear whether active layers might preferably be deposited from the elements Ga and As, the arsenide, or from chemical vapor depositon precursors such as trimethyl gallium -- AsH_3.

Electricity. The consumption of electricity to produce solar cell materials is a significant contributing factor in the high cost of those materials. It also is a major contributor to the energy debt incurred in implementing photovoltaic (PV) systems -- a debt that must be repaid during a system's initial operational period before a net gain can be realized. In the case of the SPS a minimum of five to six months satellite operation would be required just to repay the energy consumed in producing its solar cell materials.

Present definitions of SPS solar cell production processes yield significantly higher electrical consumption for silicon cells than for gallium arsenide cells. However, this is probably due to the fact that the silicon process represents present or near term state-of-the-art while the gallium arsenide process is a projection of a more advanced state-of-the-art. Electrical consumption is a problem with both systems and is directly related to the problem of high solar materials costs. The viability of both system depends on the success of research on and development of more efficient production processes.

Material Problems of Possible Concern

Arsenic and Arsenic Trioxide are materials used in the production of gallium arsenide for that SPS option. The primary cause for concern is the environmental hazard that the production of these materials represents. Arsenic and several of its compounds are listed in OSHA's Number I carcinogenic group. The only U.S. arsenic production facility is continuing its operation only by virtue of a court-ordered 5-year variance from Washington State air pollution standards. There is an abundant supply of the raw material from copper ores but product demand is not strong. In addition, the current annual production of the high purity (99.999%) arsenic is less than 1 percent of the SPS annual requirement.

From the standpoint of the SPS the key question is: Will other demands for arsenic lead to production process improvements that will assure continued and even expanded production of the material? If not, then actions and investments may be required as part of a gallium arsenide SPS program to resolve the problem. In any event production capacity of high purity arsenic will have to be greatly expanded.

Kapton. Kapton is used as a covering material for gallium arsenide solar cells in the gallium arsenide option. The only concern is that it is a proprietary product obtainable from a single source (Dupont), and the SPS would require a significant (100%) growth rate in projected production·capacity in the late 1990's. The combined effect of the unfavorable market positon and used for major industry expansion need to be assessed further.

Oxygen. Liquid oxygen is the oxidizer that would be used to burn fuels in all SPS chemical rocket stages used in the SPS space transportation system. When the SPS begins its operational phase in the year 2000 it would require over 2.7 million MT annually, representing about 7 percent of projected total world production. While the market percentage is not excessive, this requirement does represent a heavy demand for a cryogenic material that is difficult and expensive to store and transport. Dedicated on-site production facilities might be required. Further investigation of liquid oxygen supply requirements and their implications is needed.

Silica Fiber. Reusable launch vehicles required to transport SPS materials and personnel to low Earth orbit require heat shielding insulation to survive reentry. The present Space Shuttle utilizes silica tiles made from a special silica fiber as its primary heat shielding system. The SPS cargo on personnel launch vehicles are assumed to use this same heat shielding material. Current production of the required silica fiber is very limited (only 5 Shuttles are currently planned). Production capacity would have to be increased significantly in the late 1990's to produce the fleet of vehicles for the SPS. The growth rate required would be 46 percent per year for several years. Presently there is a single supplier of this special material used only in the reentry heat shielding application. This is an unfavorable market condition.

The severity of the silica problem is unclear. The silica approach to reentry vehicle heat shielding is very new (and as yet untried). Technology developments and operational experience in the 1980's could lead to a significantly altered system or even to a totally different system in the 1990's. It is clear that whatever system is used the SPS would likely cause a material production capacity problem that would have to be dealt with.

Silver/Silver Ore. Silver represents a problem from several standpoints. Silver recovery directly from silver ore (much of which is imported) represents only 30 percent of total silver production. The Gallium Arsenide SPS design would require over 1 percent of the world's currently identified silver ore resources which are being depleted at a moderately significant rate. However, attractive silver prices continue to make by-product recovery of silver from copper, lead, and zinc ore economically desirable. In fact, by-product silver recovery can be a deciding factor in the exploitation of some of these ore bodies. On the other hand, trends toward on-site leaching of copper ores (rather than conventional milling) would reduce by-product silver recovery.

The net result of the above discussion is that the availability of adequate silver supplies in the year 2000 and beyond is somewhat in question. Assurance of an adequate supply would most likely come as a result of very high market prices. Thus it may be desirable to consider mitigating strategies to minimize the silver requirement such as design modifications and/or material substitution.

Borosilicate Glass is the cover/encapsulant material for the silicon solar cells in the silicon SPS option. This glass with special thermal properties is exemplified by Pyrex. Production of sufficient quantities of the material will generate problems in production capacity growth and from a market domination point of view. In the late 1990's, the SPS would require a 6 percent annual production growth rate, and would consume about 12 percent of world requirements. In addition, producing and assembling the glass in the required 50 and 75 micron thicknesses will introduce substantial production complexities that will greatly increase material costs. These conditions may necessitate action (e.g. market assurance) and investments as part of the SPS program to assure production capacity growth and acceptable material prices.

Liquid Hydrogen is a fuel for various rocket stages used in the SPS space transportation system. Despite very large world production of hydrogen, liquid hydrogen is not a common market commodity. Much gaseous hydrogen is used captively by its producers. Liquid hydrogen for sale represents only about 1/2 percent of total U.S. hydrogen production. NASA has been among its largest consumers.

SPS requirements of 80,000 to 130,000 MT per year would represent 50 percent or more of expected non-captive liquid hydrogen production in the year 2000. Since liquid hydrogen (like liquid oxygen) is a cryogenic material that is difficult and expensive to transport and store, dedicated on-site production facilities may be needed. Further assessment is needed.

Mercury/Mercury Ore. Mercury is commonly used in electrical apparatus (e.g., switches) because it is a unique liquid phase conductor of electricity. Manufacture of electrical apparatus is the single largest domestic market (45 percent) for mercury.

Both SPS options involve annual consumption of about 180 MT of mercury which would represent about 9 percent of U.S. consumption in year 2000. Because of its toxicologically hazardous nature, mercury consumption in the U.S. is expected to remain relatively flat at about 2000 MT annually. Consequently SPS demand should not present significant supply problems. However the U.S. is currently 62 percent dependent on foreign sources of mercury/mercury ore. The world and domestic supply of mercury is quite price elastic, and under favorable price conditions, U.S. domestic supply could be significantly increased. While no major problems are anticipated, current U.S. dependence on a single domestic mercury producer is some cause for concern and should be closely monitored.

Methane. The rocket boosters that will launch elements of the SPS into orbit will require large quantities (650,000 MT annually) of high purity liquid methane fuel which is not presently in demand*. There are three potential sources for that fuel: (1) naturally occurring deposits (e.g. 99.5 percent pure methane is currently being recovered from natural gas wells in Alaska); distillation/separation from liquified natural gas (LNG), which may be available from various sources; and, (3) gasification of coal (and/or possibly biomass). For high purity natural gas and LNG there is a high degree of uncertainty as to how much of these fuels can be expected to be available in the year 2000, where the major sources of supply will be located, and how much it will cost. If these supplies are inadequate, then the coal gasification option will have to be pursued and significant investments will be required to create this totally new supply.

Petroleum. Petroleum products are required as energy sources and as chemical feedstocks for many SPS materials. The primary concern

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*Methane is normally the primary constituent of natural gas, although, content may vary from approximately 70 percent to near 100 percent. Most present uses of natural gas do not demand high purity methane -- however, high purity deposits are being depleted as part of the overall world consumption of natural gas.

arises form its use as an energy source for process heat and mechanical power, where it represents a significant contribution to material costs ($80/KW power installed). Similar to the cost contribution of electricity, petroleum costs are likely to inflate faster than the other material costs. From the SPS viewpoint it may be desirable to encourage DOE efforts to expand industrial use of alternative energy sources.

Steel is the primary structural material for the SPS rectenna. Nearly 3,000,000 MT of steel per year will be required to support the installation of two 5 GW rectennas per year. This extremely large requirement and the cost of steel ($100/KW power installed) is a significant factor in overall SPS costs. Furthermore, since steel manufacturing is a mature industry, the situation is not likely to improve substantially and steel prices may be expected to inflate faster than many other materials on the SPS list. Therefore it may prove desirable to minimize the steel requirement through rectenna redesign and/or material substitution where possible.

Tungsten. Both SPS options currently specify use of about 1300 MT/year of tungsten in heating elements for the klystrons. This would represent about 5 percent of U.S. tungsten consumption in year 2000. From 1976 to 2000 primary tungsten consumption in the U.S. should increase about 5 percent/year from a 1977 base of about 15,600 MT/year.

Tungsten is sometimes a co-product or by-product of molybdenum, copper, tin, bismuth, gold and silver production. Co-product/by-product tungsten represents perhaps 10 percent of world supply. In the U.S., by-product/co-product production is nearer 30 percent. Domestically, the ore occurs often with molybdenum. (In the far-eastern countries, it often occurs with tin.) Tungsten is a strategic material and as such it commands attention. Steel industry demand for molybdenum should help to maintain co-product tungsten production in the U.S.

Currently the U.S. imports over 50 percent of its tungsten requirements. Canada is a principal U.S. source, but the very dominant producer and world exporter of tungsten is the People's Republic of China.

SPS consumption of tungsten would not seem to present "critical" dimensions, but its use should probably be minimized if suitable substitution alternatives exist.

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APPENDIX A

This appendix presents the materials assessment data base as it was used for the SPS study. Table A-1 contains the bulk materials screening data on materials availability, cost, consumption, and import dependency. Table A-2 is the raw materials screening data--similar to that for bulk materials (Table 1), but also containing current estimates of U.S. and World reserves and resources. Table A-3 contains the engineering material to bulk material conversions, and Table A-4 summarizes bulk material production processes. Quantities shown in Table A-4 are those needed to produce one metric ton (MT) of the desired material.

This data base represents an updating and upgrading of that used in previous materials assessment studies (References 1-3). These changes include:

- Additions required for SPS:
  - engineering materials
  - bulk materials
  - raw materials
- Conversion of data base from gross imports to net imports
- Updating various data parameters to 1976 actual values as published by U.S. Bureau of Mines. (Previous data were 1976 estimates of consumption, reserves, imports, etc.)
- Bulk material prices were updated to January 1, 1979
- Incorporation of intermediate bulk materials into the bulk to raw conversion data
- A number of recalculations and corrections.

TABLE A-1. BULK MATERIAL DATA SUMMARY

MATERIAL NAME	% SUPPLIED AS BY-PRODUCT	WORLD CONSUMPTION 1976 MT	WORLD CONSUMPTION 2000 MT	% FROM LARGEST NON US COUNTRY	PRICE $/MT	NET PERCENT IMPORTED	U.S. CONSUMPTION 1976 MT	U.S. CONSUMPTION 2000 MT
ABS RESINS	0	717.K	3.64M	19	1.25K	1.0	400.K	2.03M
ACETYLENE	0	815.K	1.82M	5.0	890.	0	222.K	495.K
ACRYLIC	0	829.K	4.2M	5.0	1.23K	1.0	226.K	1.15M
ALKYD RESIN	0	1.21M	6.13M	5.0	968.	1.0	330.K	1.67M
ALUMINUM	0	12.5M	60.2M	13	1.17K	9.0	4.64M	19.M
ALUMINUM OXIDE	0	25.M	120.M	13	220.	9.0	9.28M	38.M
ARGON	100	439.K	1.21M	25	240.	0	239.K	599.K
ARSENIC	100	24.7K	50.7K	23	100.K	39	22.1K	23.8K
ARSENIC TRIOXIDE	100	39.6K	81.1K	23	255.	39	35.4K	38.1K
ARSINE, 99.999%	0	3.	320.	10	143.K	0	2.	160.
ASBESTOS	0	5.05M	9.56M	31	550.	85	658.K	1.01M
ASPHALT	0	109.M	204.M	5.0	14.3	0	24.9M	55.5M
BORON OXIDE	20	1.43M	3.01M	39	350.	0	327.K	994.K
BORON, 99.9995%	0	.	.13	0	50.M	0	.	.1
BROMINE	10	297.K	1.03M	9.0	550.	0	169.K	499.K
CADMIUM	100	17.1K	37.K	17	5.29K	64	5.38K	11.5K
CADMIUN SULFIDE	0	3.3K	8.4K	10	24.K	0	900.	2.3K
CALCIUM	0	67.9	219.	20	3.97K	0	18.5	59.7
CARBON BLACK	0	3.5M	5.M	12	440.	0	1.41M	2.02M
CARBON DIOXIDE	100	6.86M	15.3M	5.0	46.	0	1.87M	4.17M
CAUSTIC SODA	0	35.M	78.2M	5.0	154.	1.0	9.55M	21.3M
CEMENT	0	694.M	1.44G	18	44.	4.0	67.2M	200.M
CHLORINE	0	51.M	114.M	5.0	149.	1.0	13.9M	31.M
CHLOROFORM	0	488.K	1.1M	5.0	440.	1.0	133.K	300.K
CHROMIUM	0	2.58M	5.45M	28	6.59K	89	480.K	1.13M
COAL, BITUMINOUS	0	3.19G	4.86G	20	23.	10	541.M	1.41G
COBALT	100	26.K	65.K	42	44.1K	98	9.K	20.3K
COKE	0	200.M	448.M	10	90.	1.0	54.6M	122.M
COPPER	1.0	7.45M	27.2M	13	1.57K	12	2.03M	5.44M
COTTON FIBERS	0	3.M	5.85M	16	885.	1.0	1.4M	3.6M
CUPROUS CHLORIDE	0	7.3K	16.K	20	2.7K	20	2.K	4.4K
DIBORANE	0	16.1	52.1	5.0	1.9M	0.	4.4	14.2
ELECTRICITY (KWH)	0	6.79T	31.8T	0	.03	0	1.85T	8.65T
ELECTRODES	0	771.K	1.72M	10	1.68K	1.0	210.K	468.K
EPOXY RESIN	0	419.K	2.12M	5.0	1.67K	1.0	114.K	578.K
ETHYLENE GLYCOL	0	5.25M	26.6M	5.0	539.	1.0	1.43M	7.25M
ETHYLENE PROPYLENE	0	190.K	963.K	13	1.1K	1.0	11.K	558.K

$K = 10^3$, $M = 10^6$, $G = 10^9$, and $T = 10^{12}$.

MT = Metric tons

TABLE A-1. BULK MATERIAL DATA SUMMARY
(CONTINUED)

11/20/79

MATERIAL NAME	% SUPPLIED AS BY-PRODUCT	WORLD CONSUMPTION 1976 MT	WORLD CONSUMPTION 2000 MT	% FROM LARGEST NON US COUNTRY	PRICE $/MT	NET PERCENT IMPORTED	U.S. CONSUMPTION 1976 MT	U.S. CONSUMPTION 2000 MT
FERROUS SCRAP, PURCHASED	0	138.M	307.M	10	85.	0	37.5M	83.6M
FLUORINE	8.0	2.03M	6.51M	19	1.3K	79	432.K	1.71M
FLUORSPAR	0	4.61M	14.8M	19	125.	79	982.K	3.91M
GALLIUM	100	16.8	47.	40	800.K	55	8.88	32.
GALLIUM ARSENIDE (DEP)	0	26.	84.3	10	700.K	0	14.	45.4
GALLIUM ARSENIDE (INGOT)	0	11.1	57.8	10	3.M	0	8.9	35.5
GALLIUM ARSENIDE (WAFER)	0	5.	26.	10	7.M	0	4.	16.
GERMANE, 99.9%	0	.04	.16	5.0	350.K	0	.03	.08
GERMANIUM	100	79.4	127.	29	316.K	16	21.3	36.7
GLASS, BOROSILIC	0	117.K	262.K	5.0	735.	1.0	32.K	71.4K
GLASS, FIBER	0	771.K	7.22M	5.0	1.35K	2.0	210.K	1.97M
GLASS, SODA LIME	0	68.3M	117.M	5.0	340.	1.0	18.6M	32.M
GOLD	47	1.2K	2.01K	58	6.43M	76	145.	528.
GRAPHITE FIBER, SYNTHETIC	0	215.	6.16K	35	57.2K	0	118.	3.38K
GRAPHITE, MFGD.	0	1.2M	2.67M	10	8.7K	1.0	326.K	727.K
GYPSUM, CALCINED	5.0	64.6M	113.M	10	28.	35	16.3M	31.6M
HELIUM	100	10.6K	23.7K	5.0	4.37K	0	2.9K	6.47K
HYDROCHLORIC ACID	92	8.33M	18.6M	5.0	200.	2.0	2.27M	5.06M
HYDROFLUORIC ACID	0	947.K	2.11M	15	981.	0	258.K	575.K
HYDROGEN	40	22.M	90.M	10	600.	0	7.9M	37.M
HYDROGEN SULFIDE, 99.999%	0	.	.01	10	195.K	0	.	.
INDIUM	100	46.5	103.	20	338.K	24	37.6	47.3
INDIUM-TIN OXIDE	0	15.	24.	10	320.K	0	9.	12.
KAPTON	0	1.K	5.06K	0	66.K	5.0	273.	1.38K
KRAFT FIBERS	0	60.M	120.M	10	425.	15	28.M	60.M
LEAD	13	3.35M	10.6M	12	838.	15	1.38M	2.2M
LIME	0	105.M	217.M	20	34.	2.0	18.6M	39.3M
LINSEED OIL	0	1.5M	2.M	5.0	1.03K	1.0	230.K	290.K
LIQUID FUELS	0	2.72G	5.4G	18	123.	39	631.M	1.47G
LITHIUM	4.0	7.5K	27.K	2.0	32.K	0	2.64K	13.1K
LUMBER,SOFTWOOD	0	300.M	780.M	20	188.	12	70.M	180.M
MAGNESIUM	1.0	229.K	889.K	27	2.23K	0	94.3K	358.K
MERCURY	2.0	8.4K	10.2K	18	4.5K	62	2.36K	2.K
METHANOL	0	6.M	19.4M	10	146.	0	2.71M	8.75M
MOLYBDENUM	42	86.8K	266.K	17	11.7K	0	27.1K	87.5K

K = 10^3, M = 10^6, G = 10^9, and T = 10^{12}.

MT = Metric tons

TABLE A-1. BULK MATERIAL DATA SUMMARY
(CONTINUED)

11/20/79

MATERIAL NAME	% SUPPLIED AS BY-PRODUCT	WORLD CONSUMPTION 1976 MT	WORLD CONSUMPTION 2000 MT	% FROM LARGEST NON US COUNTRY	PRICE $/MT	NET PERCENT IMPORTED	U.S. CONSUMPTION 1976 MT	U.S. CONSUMPTION 2000 MT
NATURAL GAS REFINED	0	1.01G	3.04G	23	94.	5.0	406.M	551.M
NEOPRENE (POLYCHOROPRENE)	0	404.K	899.K	5.0	1.32K	6.0	110.K	245.K
NICKEL	7.0	804.K	1.81M	33	4.59K	70	198.K	499.K
NITRIC ACID	0	46.8M	104.M	32	116.	1.0	7.17M	16.M
NYLON RESINS	0	341.K	1.73M	20	2.55K	2.0	100.K	507.K
OXYGEN, GASEOUS	0	35.5M	93.8M	21	20.	0	10.1M	39.3M
OXYGEN, LIQUID	0	15.2M	40.2M	21	18	0	4.32M	16.9M
PALLADIUM	100	76.6	188.	47	2.17M	90	27.3	49.2
PETROLEUM COKE	100	55.7M	110.M	15	84.	0	12.9M	30.M
PHENOLIC RESIN	0	2.18M	11.1M	13	1.03K	1.0	593.K	3.01M
PHOSPHATE ROCK	0	107.M	414.M	22	22.	0	31.1M	62.6M
PHOSPHINE 99.999%	0	2.5	240.	10	187.K	0	1.5	120.
PHOSPHOROUS	0	14.3M	55.4M	22	1.21K	0	4.17M	8.39M
PIG IRON	0	487.M	1.05G	22	210.	0	78.9M	148.M
PITCH-IN-TAR	0	757.K	1.45M	5.0	33.1	5.0	349.K	890.K
PLATINUM	100	87.8	180.	47	10.7M	90	31.3	44.8
POLYACRYLONITE FIBER	0	1.72M	3.84M	18	1.63K	3.0	285.K	636.K
POLYCARBONATE RESIN	0	100.K	507.K	10	2.49K	1.0	51.K	259.K
POLYESTER RESIN	0	1.6M	8.11M	5.0	792.	1.0	436.K	2.2M
POLYETHYLENE (LDPE+HDPE)	0	11.M	20.5M	14	693.	1.0	4.04M	20.5M
POLYPROPYLENE	0	2.81M	14.2M	18	726.	0	1.15M	5.83M
POLYSULFONE	0	18.4K	93.3K	5.0	4.4K	5.0	5.K	25.4K
POLYURETHANE RIGID FOAM	0	635.K	3.22M	5.0	3.85K	1.0	173.K	877.K
POLYVINYL FLUORIDE	0	10.5K	53.2K	5.0	19.8K	5.0	4.68K	23.7K
PORCELAIN	0	543.K	1.21M	5.0	2.2K	0	148.K	330.K
PROPYLENE GLYCOL	0	870.K	4.41M	5.0	561.	5.0	237.K	1.2M
PVC PLASTIC	0	8.36M	42.4M	19	594.	1.0	2.11M	10.7M
RUBBER, SBR	0	3.19M	16.2M	14	748.	4.0	1.23M	6.24M
SALT	0	166.M	686.M	18	49.	7.0	43.1M	124.M
SAND & GRAVEL	0	6.49G	15.7G	10	2.18	0	800.M	1.9G
SAPPHIRE	0	20.	1.6K	25	800.K	0	10.	800.
SELENIUM	100	1.26K	3.49K	37	39.7K	59	448.	1.41K
SILANE	0	30.	2.7K	10	130.K	0	17.	1.35K
SILICA FIBER	0	41.9	83.8	0	300.K	4.0	1.9	3.8
SILICA VITREOUS, 99.99%	0	1.8K	4.K	10	106.K	0	500.	1.1K
SILICON MONOXIDE	0	18.	40.	20	120.K	30	5.	11.
SILICON (MET)	0	2.21M	4.72M	12	1.07K	11	548.K	1.09M
SILICON (SEG)	0	1.4K	111.K	10	60.K	0	700.	55.6K
SILICONES	0	266.K	591.K	5.0	6.27K	1.0	72.4K	161.K
SILVER	70	9.48K	26.1K	14	196.K	50	5.3K	9.64K

$K = 10^3$, $M = 10^6$, $G = 10^9$, and $T = 10^{12}$.

MT = Metric tons

TABLE A-1. BULK MATERIAL DATA SUMMARY
(CONTINUED)

11/20/79

MATERIAL NAME	% SUPPLIED AS BY-PRODUCT	WORLD CONSUMPTION 1976 MT	WORLD CONSUMPTION 2000 MT	% FROM LARGEST NON US COUNTRY	PRICE $/MT	NET PERCENT IMPORTED	U.S. CONSUMPTION 1976 MT	U.S. CONSUMPTION 2000 MT
SODIUM CARBONATE	0	18.5M	11.5M	10	64.	0	1.57M	0.
SODIUM DICHROMATE	0	477.K	1.06M	5.0	815.	1.0	130.K	290.K
STAINLESS STEEL	0	6.45M	16.5M	30	1.37K	15	1.03M	2.09M
STEAM	1.0	2.57G	5.72G	10	4.25	0	700.M	
SULFURIC ACID	20	144.M	308.M	14	55.	0	30.M	64.4M
TANTALUM	100	1.36K	4.17K	24	143.K	96	602.	2.4K
TEFLON	0	11.8K	59.8K	10	6.82K	8.0	7.08K	35.9K
TELLURIUM	100	260.	349.	21	44.1K	53	173.	231.
TIN	1.0	226.K	410.K	28	16.4K	85	65.4K	81.3K
TITANIUM	0	57.1K	213.K	39	7.23K	8.0	21.1K	63.5K
TRICHLOROSILANE	0	8.45K	92.K	10	1.98K	0	4.65K	45.8K
TRIMETHYL AL., 99.9999%	0	.25	1.	5.0	5.M	0	.15	.5
TRIMETHYL GA., 99.9995%	0	.08	.32	5.0	8.M	0	.05	.16
TRIMETHYL INDIUM, 99.998%	0	.04	.16	5.0	35.M	0	.03	.08
TUNG OIL	0	45.K	45.1K	45	2.2K	70	15.K	15.1K
TUNGSTEN	10	40.7K	80.2K	7.0	32.4K	54	7.81K	23.5K
WATER, FRESH	0	1.6T	2.86T	5.0	4.25	0	437.G	778.G
ZINC	25	5.86M	10.5M	20	760.	59	1.03M	2.49M
ZINC FLUOROBORATE	0	3.5	8.	25	2.85K	0	1.	2.2
.BENZENE.	0	9.13M	29.4M	16	239.	1.0	4.9M	15.8M
.BUTADIENE.	40	3.32M	10.7M	14	451.	16	1.73M	5.59M
.ETHYLENE.	0	37.4M	12.1M	13	286.	0	10.2K	32.9M
.O-XYLENE.	0	2.37M	5.33M	12	248.	0	388.K	865.K
.PROPYLENE.	25	16.7M	53.9M	14	220.	0	4.55M	14.7M

K = 10^3, M = 10^6, G = 10^9, and T = 10^{12}.

MT = Metric tons

TABLE A-2. RAW MATERIAL DATA SUMMARY

11/20/79

MATERIAL NAME	WORLD CONSUMP 1976 MT	WORLD CONSUMP 2000 MT	PRICE $/MT	RAW RESERVES WORLD MT	RAW RESOURCES WORLD MT	% LARGEST COUNTRY	% RESERVES TOP 3 COUNTRIES	NET PERCENT IMPORTED	U.S. CONSUMP 1976 MT	U.S. CONSUMP 2000 MT	RAW RESERVES U.S. MT	RAW RESOURCES U.S. MT
AIR	50.7M	134.M	20.	1.0E+20	1.0E+20	21	36	0	14.4M	56.2M	1.0E+20	1.0E+20
ANTIMONY ORE	7.28M	14.5M	11.7	453.M	533.M	22	60	54	3.8M	4.73M	11.5M	12.4M
ASBESTOS ORE	84.2M	159.M	5.46	1.45G	2.25G	31	81	85	11.M	16.8M	60.5M	106.M
BARITE	4.95M	10.3M	26.	181.M	1.81G	7.0	14	42	1.99M	2.44M	59.M	227.M
BAUXITE	77.6M	271.M	15.	24.9G	38.G	31	62	91	20.5M	85.5M	40.6M	300.M
BAUXITE, BY PROD	77.6M	271.M	0.	24.9G	38.G	31	62	91	20.5M	85.5M	40.6M	300.M
BORON OXIDE	1.43M	3.02M	130.	300.M	1.2G	39	62	0	327.K	995.K	63.M	250.M
BUTANE	135.M	227.M	35.	5.4G	54.G	23	78	5.0	36.7M	61.9M	520.M	5.2G
CHROMITE	8.61M	16.M	59.	245.M	16.3G	28	97	89	912.K	3.33M	.	7.23M
CLAYS	563.M	962.M	22	1.0E+20	1.0E+20	12	39	0	45.7M	164.M	1.0E+20	1.0E+20
COAL BYPROD.	3.19G	4.86G	.	1.07T	11.5T	7.0	47	0	541.M	1.41G	397.6G	3.6T
COAL BYPROD.#2	3.19G	4.86G	0.	1.07T	11.5T	7.0	47	0	541.M	1.41G	397.G	3.6T
COAL, BITUMINOUS	3.19G	4.86G	15.4	1.07T	11.5T	7.0	47	0	541.M	1.41G	397.G	3.6T
COPPER BYPROD.	1.06G	2.88G	0.	65.2G	267.G	13	32	12	235.M	544.M	12.1G	53.1G
COPPER BYPROD.#2	1.06G	2.88G	0.	65.2G	267.G	13	32	12	235.M	544.M	12.1G	53.1G
COPPER ORE	1.06G	2.88G	1.96	65.2G	267.G	13	32	12	235.M	544.M	12.1G	53.1G
COTTON	13.2M	19.1M	885.	1.0E+20	1.0E+20	16	35	1.0	1.6M	2.M	1.0E+20	1.0E+20
CU ANODE SLIMES	1.06G	2.88G	0.	65.2G	267.G	13	32	12	235.M	544.M	12.1G	53.1G
FELDSPAR	2.58M	7.26M	25.	907.M	1.0E+20	8.0	3.0	0	666.K	1.81M	544.M	1.0E+20
FLAX SEED	2.5M	3.3M	160.	1.0E+20	1.0E+20	25	35	20	350.K	380.K	1.0E+20	1.0E+20
FLUORSPAR ORE	14.M	45.M	0.	250.M	456.M	19	43	79	2.98M	11.9M	15.4M	91.8M
GOLD ORE	140.M	211.M	15.9	4.4G	6.87G	58	79	76	15.3M	55.3M	400.M	748.M
GYPSUM, CRUDE	64.6M	113.M	5.28	1.81G	1.0E+20	10	35	35	16.3M	31.6M	317.M	1.0E+20
IRON ORE	895.M	2.83G	2.	259.G	813.G	27	67	29	127.M	325.M	17.3G	110.G
LEAD ORE	63.1M	130.M	5.49	2.33G	5.65G	12	33	15	13.5M	26.2M	486.M	2.04G
LIMESTONE	302.M	625.M	31.6	1.0E+20	1.0E+20	20	40	2.0	53.6M	113.M	1.0E+20	1.0E+20
LITHIUM ORE	810.K	3.86M	143.	96.4M	273.M	24	78	0	377.K	1.87M	52.7M	120.M
MANGANESE ORE	24.8M	46.4M	126.	5.44G	10.8G	22	91	98	2.81M	4.39M	0.	1.03G
MERCURY ORE	290.K	320.K	33.8	6.19M	20.8M	18	63	62	81.3K	55.9K	484.K	1.07M
MILK BYPRODUCTS	100.M	200.M	220.	1.0E+20	1.0E+20	20	20	1.0	52.M	100.M	1.0E+20	1.0E+20
MOLYBDENUM ORE	28.9M	88.6M	7.04K	2.99G	10.4G	17	46	0	9.04M	29.2M	1.15G	5.31G
NATURAL GAS	1.01G	3.04G	94.	45.7G	457.G	23	50	5.0	406.M	551.M	4.41G	18.9G
NICKEL ORE	80.4M	144.M	15.8	5.44G	13.G	33	69	70	19.8M	34.9M	18.1M	7.G
PETROLEUM	2.88G	5.11G	73.	89.6G	272.G	18	45	39	667.M	1.55G	4.45G	13.6G
PETROLEUM BYPROD	2.88G	5.11G	73.	89.6G	272.G	18	45	39	667.M	1.55G	4.45G	13.6G
PHOSPHATE ROCK	101.M	414.M	22.	25.8G	76.1G	14	77	0	31.1M	62.6M	3.55G	6.35G
PROPANE	78.5M	132.M	35.	3.16G	31.6G	23	78	5.0	21.4M	36.1M	305.M	3.05G
RUTTLE (CONC.)	399.K	1.15M	396.	160.M	200.M	98	91	98	256.K	521.K	5.44M	16.5M
SALT	166.M	686.M	30.	1.0E+20	1.0E+20	18	10	7.0	43.1M	124.M	1.0E+20	1.0E+20
SAND & GRAVEL	6.49G	15.7G	2.18	1.0E+20	1.0E+20	6.0	10	0	800.M	1.9G	1.0E+20	1.0E+20

K = 10^3, M = 10^6, G = 10^9, and T = 10^{12}.

MT = Metric tons

TABLE A-2. RAW MATERIAL DATA SUMMARY
(CONTINUED)

11/20/79

MATERIAL NAME	WORLD CONSUMP 1976 MT	WORLD CONSUMP 2000 MT	PRICE $/MT	RAW RESERVES WORLD MT	RAW RESOURCES WORLD MT	% LARGEST COUNTRY	% RESERVES TOP 3 COUNTRIES	NET PERCENT IMPORTED	U.S. CONSUMP 1976 MT	U.S. CONSUMP 2000 MT	RAW RESERVES U.S. MT	RAW RESOURCES U.S. MT
SILVER ORE	13.6M	37.3M	4.85	271.M	1.01G	14	52	50	5.7M	10.2M	67.1M	253.M
SODA ASH (NAT.)	4.85M	14.M	60.	31.G	92.G	2.0	.40	0	4.7M	14.2M	30.G	46.G
SODIUM NITRATE	536.K	1.2M	110.	1.0E+20	1.0E+20	16	10	1.0	146.K	326.K	1.0E+20	1.0E+20
SOYBEAN	62.M	120.M	180.	1.0E+20	1.0E+20	12	25	0	31.M	80.M	1.0E+20	1.0E+20
STONE	7.G	13.4G	2.63	1.0E+20	1.0E+20	3.0	10	0	818.M	2.27G	1.0E+20	1.0E+20
SULFUR ORE	52.2M	112.M	45.8	1.73G	5.49G	14	33	0	10.9M	23.4M	208.M	640.M
TANTALUM ORE	310.K	2.9M	125.	47.2M	209.M	39	83	96	482.K	1.67M	.	1.23M
TIMBER, LUMBER	1.4G	1.9G	140.	1.0E+20	1.0E+20	12	20	18	210.M	340.M	1.0E+20	1.0E+20
TIN ORE	22.6M	35.1M	421.	1.02G	3.76G	28	50	85	5.18M	6.5M	4.M	19.8M
TUNG NUTS	105.K	1.15G	880.	1.0E+20	1.0E+20	70	35	80	13.K	20.K	1.0E+20	1.0E+20
TUNGSTEN ORE	5.09M	9.89M	24.4	225.M	646.M	21	75	54	868.K	2.8M	15.6M	54.3M
WATER, FRESH	1.6T	2.86T	.16	2.22T	5.32T	5.0	20	0	437.G	778.G	606.G	1.45T
WATER, SEAWATER	10.T	11.T	0.	1.0E+20	1.0E+20	0	0	0	10.T	11.T	1.0E+20	1.0E+20
WHEAT	340.M	710.M	130.	1.0E+20	1.0E+20	10	25	0	23.M	30.M	1.0E+20	1.0E+20
ZINC BYPROD.	117.M	224.M	0.	3.17G	4.9G	20	43	59	24.2M	55.3M	544.M	907.M
ZINC BYPROD.#2	117.M	224.M	0.	3.17G	4.9G	20	43	59	24.2M	55.3M	544.M	907.M
ZINC BYPROD.#3	117.M	224.M	0.	3.17G	4.9G	20	43	59	24.2M	55.3M	544.M	907.M
ZINC ORE	117.M	224.M	12.7	3.17G	4.9G	20	43	59	24.2M	55.3M	544.M	907.M

K = 10^3, M = 10^6, G = 10^9, and T = 10^{12}.

MT = Metric tons

TABLE A-3. ENGINEERING TO BULK CONVERSIONS

ENGINEERING MATERIAL : ALUMINUM BRONZE D

BULK MATERIALS	NAME	PERCENT
	ALUMINUM	7.00
	COPPER	91.00
	STEEL & IRON	2.00

ENGINEERING MATERIAL : ALUMINUM, 6061

BULK MATERIALS	NAME	PERCENT
	ALUMINUM	97.80
	COPPER	.25
	FERROCHROME	.35
	MAGNESIUM	1.00
	SILICON (MET)	.60

ENGINEERING MATERIAL : ALUMINUM, 6063

BULK MATERIALS	NAME	PERCENT
	ALUMINUM	98.90
	MAGNESIUM	7.00
	SILICON (MET)	4.00

ENGINEERING MATERIAL : ANTIMONY LEAD, 5%

BULK MATERIALS	NAME	PERCENT
	ANTIMONY	5.00
	LEAD	95.00

ENGINEERING MATERIAL : ANTIMONY TIN SOLDER

BULK MATERIALS	NAME	PERCENT
	ANTIMONY	5.00
	TIN	95.00

ENGINEERING MATERIAL : ANTMONIAL LEAD

BULK MATERIALS	NAME	PERCENT
	ANTIMONY	5.00
	LEAD	95.00

ENGINEERING MATERIAL : BRASS

BULK MATERIALS	NAME	PERCENT
	COPPER	70.00
	ZINC	32.00

TABLE A-3. ENGINEERING TO BULK CONVERSIONS
(CONTINUED)

ENGINEERING MATERIAL : CALCIUM LEAD

BULK MATERIALS	NAME	PERCENT
	LEAD	99.70
	LIME	.30

ENGINEERING MATERIAL : CALCIUM LEAD, .3%

BULK MATERIALS	NAME	PERCENT
	CALCIUM	.30
	LEAD	97.00

ENGINEERING MATERIAL : CARBON STEEL

BULK MATERIALS	NAME	PERCENT
	FERROMANGANESE	.60
	STEEL & IRON	99.40

ENGINEERING MATERIAL : CARBON-CARBON

BULK MATERIALS	NAME	PERCENT
	GRAPHITE FIBER, SYNTHETIC	176.00

ENGINEERING MATERIAL : CAST IRON

BULK MATERIALS	NAME	PERCENT
	FERROMANGANESE	.80
	SILICON (MET)	2.50
	STEEL & IRON	96.70

ENGINEERING MATERIAL : CONCRETE

BULK MATERIALS	NAME	PERCENT
	CEMENT	14.00
	SAND & GRAVEL	29.00
	STONE, CRUSHED & SIZED	57.00

ENGINEERING MATERIAL : COPPER NICKEL 10 %

BULK MATERIALS	NAME	PERCENT
	COPPER	88.70
	NICKEL	10.00
	STEEL & IRON	1.30

ENGINEERING MATERIAL : EPOXY GLASS LAM

BULK MATERIALS	NAME	PERCENT
	EPOXY RESIN	35.00
	GLASS, FIBER	65.00

TABLE A-3. ENGINEERING TO BULK CONVERSIONS (CONTINUED)

ENGINEERING MATERIAL : FLAT BLACK ALKYD PAINT

BULK MATERIALS	NAME	PERCENT
	ALKYD RESIN	13.00
	CARBON BLACK	62.00
	PAINT THINNER	25.00

ENGINEERING MATERIAL : FRP POLYESTER

BULK MATERIALS	NAME	PERCENT
	GLASS, FIBER	30.00
	POLYESTER RESIN	70.00

ENGINEERING MATERIAL : FRP POLYESTER

BULK MATERIALS	NAME	PERCENT
	GLASS, FIBER	47.00
	POLYESTER RESIN	53.00

ENGINEERING MATERIAL : GFRTP

BULK MATERIALS	NAME	PERCENT
	GRAPHITE FIBER, SYNTHETIC	60.00
	POLYSULFONE	40.00

ENGINEERING MATERIAL : LEADED RED BRASS

BULK MATERIALS	NAME	PERCENT
	COPPER	85.00
	LEAD	5.00
	TIN	5.00
	ZINC	5.00

ENGINEERING MATERIAL : LEADED TIN BRONZE

BULK MATERIALS	NAME	PERCENT
	COPPER	88.00
	LEAD	2.00
	TIN	6.00
	ZINC	5.00

ENGINEERING MATERIAL : MASONITE

BULK MATERIALS	NAME	PERCENT
	COTTON FIBERS	35.00
	KRAFT FIBERS	15.00
	PHENOLIC RESIN	50.00

TABLE A-3. ENGINEERING TO BULK CONVERSIONS (CONTINUED)

ENGINEERING MATERIAL : MICARTA

BULK MATERIALS	NAME	PERCENT
	COTTON FIBERS	35.00
	KRAFT FIBERS	15.00
	PHENOLIC RESIN	50.00

ENGINEERING MATERIAL : NICHROME

BULK MATERIALS	NAME	PERCENT
	CHROMIUM	20.00
	NICKEL	78.00
	SILICON (MET)	2.00

ENGINEERING MATERIAL : PLYWOOD

BULK MATERIALS	NAME	PERCENT
	LUMBER,SOFTWOOD	98.00
	/*NONAME*/	2.00

ENGINEERING MATERIAL : R-22

BULK MATERIALS	NAME	PERCENT
	TEFLON	100.00

ENGINEERING MATERIAL : SILICA TILE

BULK MATERIALS	NAME	PERCENT
	SILICA FIBER	900.00

ENGINEERING MATERIAL : SILICON STEEL

BULK MATERIALS	NAME	PERCENT
	SILICON (MET)	3.00
	STEEL & IRON	97.00

ENGINEERING MATERIAL : SOLDER, 50-50

BULK MATERIALS	NAME	PERCENT
	LEAD	50.00
	TIN	50.00

TABLE A-3. ENGINEERING TO BULK CONVERSIONS (CONTINUED)

ENGINEERING MATERIAL : SOLDER, 60-40

BULK MATERIALS	NAME	PERCENT
	LEAD	37.00
	TIN	63.00

ENGINEERING MATERIAL : STAINLESS STEEL, 304

BULK MATERIALS	NAME	PERCENT
	CHROMIUM	27.00
	NICKEL	10.00
	STEEL & IRON	63.00

ENGINEERING MATERIAL : STAINLESS STEEL, 316

BULK MATERIALS	NAME	PERCENT
	CHROMIUM	24.00
	MOLYBDENUM	3.00
	NICKEL	12.00
	STEEL & IRON	61.00

ENGINEERING MATERIAL : STAINLESS STEEL, 416

BULK MATERIALS	NAME	PERCENT
	CHROMIUM	19.00
	STEEL & IRON	81.00
	SULFUR	2.00

ENGINEERING MATERIAL : TIN BRONZE

BULK MATERIALS	NAME	PERCENT
	COPPER	89.00
	TIN	11.00

ENGINEERING MATERIAL : TRANSITE

BULK MATERIALS	NAME	PERCENT
	ASBESTOS	25.00
	CEMENT	75.00

ENGINEERING MATERIAL : VARNISH

BULK MATERIALS	NAME	PERCENT
	ALKYD RESIN	100.00
	LINSEED OIL	50.00
	TUNG OIL	150.00

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES

BULK MATERIAL : ABS RESINS

RAW MATERIALS	NAME	AMOUNT(MT)
	COAL, BITUMINOUS	.0240
	NATURAL GAS	.0300

BULK MATERIALS	NAME	AMOUNT(MT)
	ALUMINUM CHLORIDE	.0050
	AMMONIA	.1460
	ELECTRICITY (KWH)	217.0000
	LIQUID FUELS	.0160
	.BENZENE.	.5220
	.BUTADIENE.	.1400
	.ETHYLENE.	.1940
	.PROPYLENE.	.3620

BULK MATERIAL : ACETYLENE

RAW MATERIALS	NAME	AMOUNT(MT)
	NATURAL GAS	6.8770

BULK MATERIALS	NAME	AMOUNT(MT)
	ELECTRICITY (KWH)	155.0000
	STEAM	29.0000

BULK MATERIAL : ACRYLIC

RAW MATERIALS	NAME	AMOUNT(MT)
	COAL, BITUMINOUS	1.3620
	NATURAL GAS	.1290

BULK MATERIALS	NAME	AMOUNT(MT)
	AMMONIA	.5000
	ELECTRICITY (KWH)	1188.0000
	LIQUID FUELS	1.4520
	.PROPYLENE.	1.2370

BULK MATERIAL : ALKYD RESIN

BULK MATERIALS	NAME	AMOUNT(MT)
	CAUSTIC SODA	.1940
	ELECTRICITY (KWH)	72.0000
	METHANOL	.2020
	OXYGEN, GASEOUS	.4140
	STEAM	.6150
	.ETHYLENE.	.0950
	.O-XYLENE.	.7600
	(MISC. BULK MATERIALS)	.2220

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : ALUMINUM

	NAME	AMOUNT(MT)
RAW MATERIALS	BAUXITE	4.7000
	COAL, BITUMINOUS	.0200
	NATURAL GAS	.2576
BULK MATERIALS	ALUMINUM FLUORIDE	.0200
	CAUSTIC SODA	.1500
	CRYOLITE	.0350
	ELECTRICITY (KWH)	17940.0000
	FLUORSPAR	.0030
	LIME	.1000
	PETROLEUM COKE	.4250
	PITCH-IN-TAR	.3000
	STEAM	9.8720
	(MISC. BULK MATERIALS)	.0050

BULK MATERIAL : ALUMINUM OXIDE

	NAME	AMOUNT(MT)
RAW MATERIALS	BAUXITE	2.2500
BULK MATERIALS	CAUSTIC SODA	.0880
	ELECTRICITY (KWH)	220.0000
	LIQUID FUELS	.1210
	STEAM	2.0000

BULK MATERIAL : AMMONIA

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	.8531
BULK MATERIALS	ELECTRICITY (KWH)	15.0000
	(MISC. BULK MATERIALS)	.0044

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : ANTIMONY

	NAME	AMOUNT(MT)
RAW MATERIALS	ANTIMONY ORE	105.0000
	IRON ORE	.0800
	LIMESTONE	1.2300
	NATURAL GAS	.1522
	SAND & GRAVEL	.3200

	NAME	AMOUNT(MT)
BULK MATERIALS	CAUSTIC SODA	3.3400
	COKE	.5600
	ELECTRICITY (KWH)	170.0600
	ELECTRODES	.0020
	LIQUID FUELS	.0070
	SODIUM CARBONATE	.0260
	STEEL & IRON	.0070
	(MISC. BULK MATERIALS)	.0120

BULK MATERIAL : ANTIMONY TRIOXIDE

	NAME	AMOUNT(MT)
BULK MATERIALS	ANTIMONY	.8400

BULK MATERIAL : ARGON

	NAME	AMOUNT(MT)
BULK MATERIALS	ELECTRICITY (KWH)	428.0000
	HYDROGEN	.0015

BULK MATERIAL : ARSENIC

	NAME	AMOUNT(MT)
RAW MATERIALS	COAL, BITUMINOUS	.3400

	NAME	AMOUNT(MT)
BULK MATERIALS	ARSENIC TRIOXIDE	1.4000

BULK MATERIAL : ARSENIC TRIOXIDE

	NAME	AMOUNT(MT)
RAW MATERIALS	COPPER BYPROD.	2.3000
	NATURAL GAS	.1170

	NAME	AMOUNT(MT)
BULK MATERIALS	ELECTRICITY (KWH)	121.0000

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES
(CONTINUED)

BULK MATERIAL : ARSINE, 99.999%

BULK MATERIALS	NAME	AMOUNT(MT)
	SULFURIC ACID	2.1400
	ZINC ARSENIDE	2.4700

BULK MATERIAL : BORON OXIDE

RAW MATERIALS	NAME	AMOUNT(MT)
	BORON OXIDE	1.0000

BULK MATERIAL : BORON TRIFLUORIDE ETHERAT

BULK MATERIALS	NAME	AMOUNT(MT)
	BORAX	.6700
	DIETHYL ETHER	.5200
	HYDROFLUORIC ACID	.4300
	SULFURIC ACID	.3500

BULK MATERIAL : BORON, 99.9995%

BULK MATERIALS	NAME	AMOUNT(MT)
	BORON OXIDE	5.3500
	CHLORINE	14.7000
	ELECTRICITY (KWH)	1100000.0000
	ELECTRODES	4.2000
	HYDROGEN	.3730
	PETROLEUM COKE	3.2100

BULK MATERIAL : BROMINE

RAW MATERIALS	NAME	AMOUNT(MT)
	WATER, SEAWATER	1000.0000

BULK MATERIALS	NAME	AMOUNT(MT)
	CHLORINE	.5000
	ELECTRICITY (KWH)	153.0000
	STEAM	.5600

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : CADMIUM

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	.0370
	ZINC BYPROD.	400.0000
BULK MATERIALS	CAUSTIC SODA	.0630
	ELECTRICITY (KWH)	221.0000
	SODIUM DICHROMATE	.0150
	SULFURIC ACID	8.2000
	ZINC	1.0200

BULK MATERIAL : CADMIUN SULFIDE

	NAME	AMOUNT(MT)
BULK MATERIALS	CADMIUM	.8000
	SULFUR	.2300

BULK MATERIAL : CALCIUM

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	1.9500
BULK MATERIALS	ELECTRICITY (KWH)	25.0000
	FERROSILICON	1.4000
	LIME	1.5600

BULK MATERIAL : CARBON BLACK

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	5.1710

BULK MATERIAL : CAUSTIC SODA

	NAME	AMOUNT(MT)
RAW MATERIALS	SALT	1.5000
BULK MATERIALS	ELECTRICITY (KWH)	2750.0000
	SODIUM CARBONATE	.0250
	STEAM	10.0000
	SULFURIC ACID	.1000

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : CEMENT

	NAME	AMOUNT(MT)
RAW MATERIALS	CLAYS	.1440
	COAL, BITUMINOUS	.0908
	GYPSUM, CRUDE	.0480
	LIMESTONE	1.3700
	NATURAL GAS	.0700
	SAND & GRAVEL	.0570

	NAME	AMOUNT(MT)
BULK MATERIALS	ELECTRICITY (KWH)	131.0000
	LIQUID FUELS	.0240
	STEEL & IRON	.0010

BULK MATERIAL : CESIUM

BULK MATERIAL : CHLORINE

	NAME	AMOUNT(MT)
RAW MATERIALS	SALT	1.8300

	NAME	AMOUNT(MT)
BULK MATERIALS	ELECTRICITY (KWH)	3310.0000
	ELECTRODES	.0005
	SODIUM CARBONATE	.0029
	STEAM	11.4250
	SULFURIC ACID	.0010

BULK MATERIAL : CHLOROFORM

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	.1750

	NAME	AMOUNT(MT)
BULK MATERIALS	CHLORINE	1.7800

BULK MATERIAL : COKE

	NAME	AMOUNT(MT)
RAW MATERIALS	COAL, BITUMINOUS	1.4500

	NAME	AMOUNT(MT)
BULK MATERIALS	ELECTRICITY (KWH)	36.4000
	STEAM	.5000
	(MISC. BULK MATERIALS)	.0010

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : COPPER

RAW MATERIALS	NAME	AMOUNT(MT)
	COAL, BITUMINOUS	.0033
	COPPER ORE	142.8600
	NATURAL GAS	.6670

BULK MATERIALS	NAME	AMOUNT(MT)
	ELECTRICITY (KWH)	5000.0000
	LIQUID FUELS	.4790
	STEAM	.1835
	STEEL & IRON	.3865
	SULFURIC ACID	.0165
	(MISC. BULK MATERIALS)	.3620

BULK MATERIAL : CUPROUS CHLORIDE

BULK MATERIALS	NAME	AMOUNT(MT)
	CHLORINE	.3600
	COPPER	.6500

BULK MATERIAL : DIBORANE

BULK MATERIALS	NAME	AMOUNT(MT)
	BORON TRIFLUORIDE ETHERAT	8.8000
	SODIUM BOROHYDRIDE	2.3000

BULK MATERIAL : DIMETHYL ALUM. CHLORIDE

BULK MATERIALS	NAME	AMOUNT(MT)
	ALUMINUM	.6000
	METHYL CHLORIDE	1.6700

BULK MATERIAL : ELECTRICITY (KWH)

RAW MATERIALS	NAME	AMOUNT(MT)
	COAL, BITUMINOUS	.0004

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : ELECTRODES

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	.6720
BULK MATERIALS	ELECTRICITY (KWH)	7750.0000
	PETROLEUM COKE	1.5000
	PITCH-IN-TAR	.5000

BULK MATERIAL : EPOXY RESIN

	NAME	AMOUNT(MT)
RAW MATERIALS	COAL, BITUMINOUS	.0330
	NATURAL GAS	.0410
BULK MATERIALS	CAUSTIC SODA	.6650
	CHLORINE	1.2390
	ELECTRICITY (KWH)	300.0000
	LIQUID FUELS	.0220
	.BENZENE.	.7240
	.PROPYLENE.	.7880

BULK MATERIAL : ETHYLENE GLYCOL

	NAME	AMOUNT(MT)
BULK MATERIALS	.ETHYLENE.	.9000

BULK MATERIAL : ETHYLENE PROPYLENE

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	.8140
BULK MATERIALS	DUYCLOPINTADIENE	.0530
	ELECTRICITY (KWH)	653.0000
	SULFURIC ACID	.0370
	.ETHYLENE.	.6460
	.PROPYLENE.	.4550
	(MISC. BULK MATERIALS)	.0870

BULK:
BULK MATERIAL : EVA

	NAME	AMOUNT(MT)
BULK MATERIALS	ELECTRICITY (KWH)	35.0000
	STEAM	.2640
	.ETHYLENE.	1.0270

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES
(CONTINUED)

BULK MATERIAL : FERROCHROME

	NAME	AMOUNT(MT)
RAW MATERIALS		
	CHROMITE	2.5000
	SILICA PEBBLE	.2130
BULK MATERIALS		
	COKE	.3750
	ELECTRODES	.0220
	(MISC. BULK MATERIALS)	.1210

BULK MATERIAL : FERROMANGANESE

	NAME	AMOUNT(MT)
RAW MATERIALS		
	LIMESTONE	.3000
	MANGANESE ORE	2.2000
BULK MATERIALS		
	COKE	.5000
	ELECTRICITY (KWH)	3064.0000
	FERROUS SCRAP, PURCHASED	.1500
	(MISC. BULK MATERIALS)	.2190

BULK MATERIAL : FERROSILICON

	NAME	AMOUNT(MT)
RAW MATERIALS		
	NATURAL GAS	.0640
	SILICA PEBBLE	1.1500
BULK MATERIALS		
	COAL, BITUMINOUS	.5500
	COKE	.0900
	ELECTRICITY (KWH)	5934.0000
	FERROUS SCRAP, PURCHASED	.5500
	PETROLEUM COKE	.0300
	PITCH-IN-TAR	.0070
	(MISC. BULK MATERIALS)	.1380

BULK MATERIAL : FLUORINE

	NAME	AMOUNT(MT)
RAW MATERIALS		
	NATURAL GAS	.2440
BULK MATERIALS		
	ELECTRICITY (KWH)	3738.0000
	FLUORSPAR	2.5000
	STEAM	1.9500
	SULFURIC ACID	3.1700

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : FLUORSPAR

	NAME	AMOUNT(MT)
RAW MATERIALS	FLUORSPAR ORE	3.0400
	NATURAL GAS	.0400

	NAME	AMOUNT(MT)
BULK MATERIALS	ELECTRICITY (KWH)	297.0000
	LIQUID FUELS	.0044
	STEEL & IRON	.0032
	(MISC. BULK MATERIALS)	.0300

BULK MATERIAL : GALLIUM

	NAME	AMOUNT(MT)
RAW MATERIALS	BAUXITE, BY PROD	50000.0000

	NAME	AMOUNT(MT)
BULK MATERIALS	CARBON DIOXIDE	242.3000
	CAUSTIC SODA	9.1000
	ELECTRICITY (KWH)	151170.0000
	HYDROCHLORIC ACID	.1000
	NITRIC ACID	.0800
	STEAM	.0820

BULK MATERIAL : GALLIUM ARSENIDE (DEP)

	NAME	AMOUNT(MT)
BULK MATERIALS	ARSENIC	.5770
	GALLIUM	.5430

BULK MATERIAL : GALLIUM ARSENIDE (INGOT)

	NAME	AMOUNT(MT)
BULK MATERIALS	ARSENIC	.5770
	ELECTRICITY (KWH)	200000.0000
	GALLIUM	.5430

BULK MATERIAL : GALLIUM ARSENIDE (WAFER)

	NAME	AMOUNT(MT)
BULK MATERIALS	GALLIUM ARSENIDE (INGOT)	2.2200

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES
(CONTINUED)

BULK MATERIAL : GALLIUM TRICHLORIDE

	NAME	AMOUNT(MT)
BULK MATERIALS		
	CHLORINE	.6400
	GALLIUM	.4200

BULK MATERIAL : GERMANE, 99.9%

	NAME	AMOUNT(MT)
RAW MATERIALS		
	WATER, FRESH	3.5700
BULK MATERIALS	NAME	AMOUNT(MT)
	GERMANIUM TETRACHLORIDE	3.5400
	SODIUM BOROHYDRIDE	2.5000

BULK MATERIAL : GERMANIUM

	NAME	AMOUNT(MT)
RAW MATERIALS		
	PROPANE	1.6700
	ZINC ORE	2500000.0000
BULK MATERIALS	NAME	AMOUNT(MT)
	CAUSTIC SODA	.0500
	CHLORINE	.6600
	ELECTRICITY (KWH)	185808.0000
	HYDROCHLORIC ACID	32.8000
	HYDROGEN	.0870

BULK MATERIAL : GERMANIUM TETRACHLORIDE

	NAME	AMOUNT(MT)
BULK MATERIALS		
	CHLORINE	.7000
	GERMANIUM	.3600

BULK MATERIAL : GLASS, BOROSILIC

	NAME	AMOUNT(MT)
RAW MATERIALS		
	NATURAL GAS	.1700
	SAND & GRAVEL	.8530
	SODA ASH (NAT.)	.0900
BULK MATERIALS	NAME	AMOUNT(MT)
	ALUMINUM OXIDE	.0210
	BORON OXIDE	.1270
	ELECTRICITY (KWH)	330.0000
	LIQUID FUELS	.0430
	(MISC. BULK MATERIALS)	.0152

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : GLASS, FIBER

	NAME	AMOUNT(MT)
RAW MATERIALS	BORON OXIDE	.1050
	NATURAL GAS	.7930
	SAND & GRAVEL	.5680

	NAME	AMOUNT(MT)
BULK MATERIALS	ALUMINUM OXIDE	.1470
	ELECTRICITY (KWH)	885.0000
	LIME	.1580
	LIQUID FUELS	.1360
	SODIUM CARBONATE	.0360
	(MISC. BULK MATERIALS)	.0530

BULK MATERIAL : GLASS, SODA LIME

	NAME	AMOUNT(MT)
RAW MATERIALS	FELDSPAR	.0922
	LIMESTONE	.1999
	NATURAL GAS	.1700
	SAND & GRAVEL	.6510
	SODA ASH (NAT.)	.0867

	NAME	AMOUNT(MT)
BULK MATERIALS	ELECTRICITY (KWH)	330.0000
	LIQUID FUELS	.0430
	SODIUM CARBONATE	.1300
	(MISC. BULK MATERIALS)	.0152

BULK MATERIAL : GOLD

	NAME	AMOUNT(MT)
RAW MATERIALS	GOLD ORE	116280.0000
	SODA ASH (NAT.)	32.3000

	NAME	AMOUNT(MT)
BULK MATERIALS	CHLORINE	202.0000
	ELECTRICITY (KWH)	3000000.0000
	LIME	525.0000
	LIQUID FUELS	727.0000
	STEAM	60.9000
	STEEL & IRON	54.7000
	SULFURIC ACID	9.4000
	ZINC	11.0000
	(MISC. BULK MATERIALS)	205.9000

BULK MATERIAL : GRAPHITE FIBER, SYNTHETIC

	NAME	AMOUNT(MT)
BULK MATERIALS	POLYACRYLONITE FIBER	2.2500

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES
(CONTINUED)

BULK MATERIAL : GRAPHITE, MFGD.

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	.2400
BULK MATERIALS	ELECTRICITY (KWH)	7000.0000
	PETROLEUM COKE	.8500
	PITCH-IN-TAR	.2600

BULK MATERIAL : GYPSUM, CALCINED

	NAME	AMOUNT(MT)
RAW MATERIALS	COAL, BITUMINOUS	.0020
	GYPSUM, CRUDE	1.0620
	NATURAL GAS	.0229
BULK MATERIALS	ELECTRICITY (KWH)	34.3750
	LIQUID FUELS	.0035

BULK MATERIAL : HYDROCHLORIC ACID

	NAME	AMOUNT(MT)
RAW MATERIALS	SALT	.5250
BULK MATERIALS	SULFURIC ACID	.4750

BULK MATERIAL : HYDROFLUORIC ACID

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	.2190
BULK MATERIALS	ELECTRICITY (KWH)	383.0000
	FLUORSPAR	2.2500
	STEAM	1.7500
	SULFURIC ACID	2.8500

BULK MATERIAL : HYDROGEN

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	5.6250
BULK MATERIALS	ELECTRICITY (KWH)	354.4000
	STEAM	64.1800

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : HYDROGEN SULFIDE, 99.999%

BULK MATERIALS	NAME	AMOUNT(MT)
	STEEL & IRON	1.6400
	SULFUR	1.8800
	SULFURIC ACID	5.8000

BULK MATERIAL : INDIUM

RAW MATERIALS	NAME	AMOUNT(MT)
	NATURAL GAS	9.9500
	SALT	1.8400
	ZINC BYPROD.	4000.0000

BULK MATERIALS	NAME	AMOUNT(MT)
	ALUMINUM	.2600
	AMMONIA	.6500
	ELECTRICITY (KWH)	2087.0000
	SULFURIC ACID	21.2600

BULK MATERIAL : INDIUM TRICHLORIDE

BULK MATERIALS	NAME	AMOUNT(MT)
	CHLORINE	.5100
	INDIUM	.5500

BULK MATERIAL : INDIUM-TIN OXIDE

BULK MATERIALS	NAME	AMOUNT(MT)
	INDIUM	.8000
	NITRIC ACID	1.4000
	TIN	.0430

BULK MATERIAL : KAPTON

RAW MATERIALS	NAME	AMOUNT(MT)
	PETROLEUM	44.6250

BULK MATERIALS	NAME	AMOUNT(MT)
	CHLORINE	1.2290
	HYDROGEN	.0470
	NITRIC ACID	1.0630
	SULFURIC ACID	1.4460
	.BENZENE.	1.7110

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : LEAD

RAW MATERIALS	NAME	AMOUNT(MT)
	IRON ORE	.0700
	LEAD ORE	21.0000
	LIMESTONE	.1200
	NATURAL GAS	.1610
	SAND & GRAVEL	.0900
	SULFUR ORE	.0020

BULK MATERIALS	NAME	AMOUNT(MT)
	CALCIUM	.0010
	CAUSTIC SODA	.0010
	COKE	.2550
	ELECTRICITY (KWH)	1003.0000
	LIQUID FUELS	.0220
	MAGNESIUM	.0020
	SODIUM CARBONATE	.0100
	STEEL & IRON	.0190
	(MISC. BULK MATERIALS)	.0120

BULK MATERIAL : LIME

RAW MATERIALS	NAME	AMOUNT(MT)
	COAL, BITUMINOUS	.1557
	LIMESTONE	2.8800
	NATURAL GAS	.0790

BULK MATERIALS	NAME	AMOUNT(MT)
	ELECTRICITY (KWH)	63.2800
	LIQUID FUELS	.0160
	(MISC. BULK MATERIALS)	.0005

BULK MATERIAL : LIQUID FUELS

RAW MATERIALS	NAME	AMOUNT(MT)
	PETROLEUM	1.0570

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : LITHIUM

	NAME	AMOUNT(MT)
RAW MATERIALS	COAL, BITUMINOUS	24.0000
	LIMESTONE	113.0000
	LITHIUM ORE	159.0000
BULK MATERIALS	ELECTRICITY (KWH)	71042.0000
	FERROSILICON	.0610
	LIQUID FUELS	1.0000
	STEAM	18.5180
	STEEL & IRON	.2670
	SULFURIC ACID	.5230
	(MISC. BULK MATERIALS)	.9680

BULK MATERIAL : LITHIUM HYDRIDE

	NAME	AMOUNT(MT)
BULK MATERIALS	HYDROGEN	.1300
	LITHIUM	.9200

BULK MATERIAL : MAGNESIUM

	NAME	AMOUNT(MT)
RAW MATERIALS	LIMESTONE	7.6000
	NATURAL GAS	3.4240
	WATER, SEAWATER	721.0000
BULK MATERIALS	CHLORINE	.4900
	ELECTRICITY (KWH)	19076.0000
	ELECTRODES	.1004
	LIQUID FUELS	.0062
	(MISC. BULK MATERIALS)	.0022

BULK MATERIAL : MERCURY

	NAME	AMOUNT(MT)
RAW MATERIALS	MERCURY ORE	34.4800
BULK MATERIALS	ELECTRICITY (KWH)	18630.0000
	LIME	.0900
	LIQUID FUELS	4.9400
	(MISC. BULK MATERIALS)	.0750

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : METHANOL

	NAME	AMOUNT(MT)
	NATURAL GAS	1.0120
BULK MATERIALS	NAME	AMOUNT(MT)
	CARBON DIOXIDE	.3820
	ELECTRICITY (KWH)	38.0500
	STEAM	.3120

BULK MATERIAL : METHYL BORATE

AMOUNT(MT)

	NAME	AMOUNT(MT)
	BORAX	3.6700
	METHANOL	3.7000
	SULFURIC ACID	1.8900

BULK MATERIAL : MOLYBDENUM

RAW MATERIAL

	NAME	AMOUNT(MT)
RAW MATERIALS	NAME	AMOUNT(MT)
	MOLYBDENUM ORE	333.0000
	NATURAL GAS	.6200
BULK MATERIALS	NAME	AMOUNT(MT)
	ELECTRICITY (KWH)	10500.0000
	HYDROGEN	.0700
	LIQUID FUELS	.1822
	STEEL & IRON	.1900
	(MISC. BULK MATERIALS)	.7405

BULK MATERIAL : NATURAL GAS REFINED

	NAME	AMOUNT(MT)
RAW MATERIALS	NAME	AMOUNT(MT)
	NATURAL GAS	1.0000

BULK MATERIAL : NEOPRENE (POLYCHOROPRENE)

	NAME	AMOUNT(MT)
BULK MATERIALS	NAME	AMOUNT(MT)
	HYDROCHLORIC ACID	.4570
	KAPTON	.6510

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : NICKEL

RAW MATERIALS	NAME	AMOUNT(MT)
	NATURAL GAS	1.1130
	NICKEL ORE	100.0000
	SAND & GRAVEL	10.3360

BULK MATERIALS	NAME	AMOUNT(MT)
	CHLORINE	.0065
	COKE	.1300
	ELECTRICITY (KWH)	7270.0000
	ELECTRODES	.7236
	LIME	.3180
	LIQUID FUELS	.2220
	OXYGEN, GASEOUS	3.7900
	SODIUM CARBONATE	.0300
	STEEL & IRON	.0874
	(MISC. BULK MATERIALS)	.2280

BULK MATERIAL : NITRIC ACID

BULK MATERIALS	NAME	AMOUNT(MT)
	AMMONIA	.2900
	ELECTRICITY (KWH)	385.0000

BULK MATERIAL : NYLON RESINS

RAW MATERIALS	NAME	AMOUNT(MT)
	COAL, BITUMINOUS	.0740
	NATURAL GAS	.0340

BULK MATERIALS	NAME	AMOUNT(MT)
	AMMONIA	.2070
	ELECTRICITY (KWH)	533.0000
	HYDROGEN	.1580
	LIQUID FUELS	.1070
	NITRIC ACID	1.4540
	.BENZENE.	1.0880
	(MISC. BULK MATERIALS)	.0011

BULK MATERIAL : ORTHO-PHOSPHOROUS ACID

RAW MATERIALS	NAME	AMOUNT(MT)
	WATER, FRESH	.6600

BULK MATERIALS	NAME	AMOUNT(MT)
	PHOSPHOROUS TRICHLORIDE	1.6800

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : OXYGEN, GASEOUS

BULK MATERIALS	NAME	AMOUNT(MT)
	ELECTRICITY (KWH)	244.0000

BULK MATERIAL : OXYGEN, LIQUID

BULK MATERIALS	NAME	AMOUNT(MT)
	ELECTRICITY (KWH)	937.0000
	OXYGEN, GASEOUS	1.0000

BULK MATERIAL : PALLADIUM

RAW MATERIALS	NAME	AMOUNT(MT)
	CU ANODE SLIMES	476190.0000

BULK MATERIALS	NAME	AMOUNT(MT)
	AMMONIA	.6400
	ELECTRICITY (KWH)	25.0000
	HYDROCHLORIC ACID	1.3740

BULK MATERIAL : PETROLEUM COKE

RAW MATERIALS	NAME	AMOUNT(MT)
	PETROLEUM	51.7000

BULK MATERIAL : PHENOLIC RESIN

RAW MATERIALS	NAME	AMOUNT(MT)
	COAL, BITUMINOUS	.1540
	NATURAL GAS	.0720

BULK MATERIALS	NAME	AMOUNT(MT)
	CARBON MONOXIDE	.6010
	ELECTRICITY (KWH)	798.0000
	HYDROGEN	.0860
	LIQUID FUELS	.0380
	STEAM	3.4500
	.BENZENE.	.8060
	.PROPYLENE.	.4330

BULK MATERIAL : PHOSPHINE 99.999%

BULK MATERIALS	NAME	AMOUNT(MT)
	ORTHO-PHOSPHOROUS ACID	10.0000

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : PHOSPHOROUS

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	.0470
	PHOSPHATE ROCK	10.3000
	SAND & GRAVEL	1.3600
BULK MATERIALS	COKE	1.6000
	ELECTRICITY (KWH)	15216.0000
	ELECTRODES	.0200

BULK MATERIAL : PHOSPHOROUS TRICHLORIDE

	NAME	AMOUNT(MT)
BULK MATERIALS	CHLORINE	.7800
	PHOSPHOROUS	.2300

BULK MATERIAL : PITCH-IN-TAR

	NAME	AMOUNT(MT)
RAW MATERIALS	COAL, BITUMINOUS	51.6000

BULK MATERIAL : POLYACRYLONITE FIBER

	NAME	AMOUNT(MT)
RAW MATERIALS	COAL, BITUMINOUS	1.3620
	NATURAL GAS	.1290
BULK MATERIALS	AMMONIA	.5000
	ELECTRICITY (KWH)	1188.0000
	LIQUID FUELS	1.4520
	.PROPYLENE.	1.2370

BULK MATERIAL : POLYCARBONATE RESIN

	NAME	AMOUNT(MT)
RAW MATERIALS	COAL, BITUMINOUS	.0330
	NATURAL GAS	.0410
BULK MATERIALS	CARBON MONOXIDE	.2660
	CHLORINE	.6670
	ELECTRICITY (KWH)	300.0000
	LIQUID FUELS	.0220
	.BENZENE.	1.9590
	.PROPYLENE.	1.0520

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES
(CONTINUED)

BULK MATERIAL : POLYESTER RESIN

	NAME	AMOUNT(MT)
RAW MATERIALS		
	COAL, BITUMINOUS	.0400
	NATURAL GAS	.0490
BULK MATERIALS		
	ELECTRICITY (KWH)	280.0000
	LIQUID FUELS	.0260
	STEAM	.9000
	.BENZENE.	.5330
	.ETHYLENE.	.1420
	.O-XYLENE.	.2710
	.PROPYLENE.	.2030
	(MISC. BULK MATERIALS)	.0040

BULK MATERIAL : POLYETHYLENE (LDPE+HDPE)

	NAME	AMOUNT(MT)
RAW MATERIALS		
	COAL, BITUMINOUS	.0840
	NATURAL GAS	.1040
BULK MATERIALS		
	ELECTRICITY (KWH)	1145.0000
	LIQUID FUELS	.0540
	.ETHYLENE.	1.0940

BULK MATERIAL : POLYPROPYLENE

	NAME	AMOUNT(MT)
RAW MATERIALS		
	COAL, BITUMINOUS	.0340
	NATURAL GAS	.0420
BULK MATERIALS		
	ELECTRICITY (KWH)	662.0000
	LIQUID FUELS	.0220
	.PROPYLENE.	1.0530

BULK MATERIAL : POLYSULFONE

	NAME	AMOUNT(MT)
BULK MATERIALS		
	CHLORINE	1.0610
	SULFURIC ACID	.4910
	.BENZENE.	1.6360
	.PROPYLENE.	.2820

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES
(CONTINUED)

BULK MATERIAL : POLYURETHANE RIGID FOAM

	NAME	AMOUNT(MT)
RAW MATERIALS		
	COAL, BITUMINOUS	.0010
	NATURAL GAS	.0040
BULK MATERIALS		
	CHLORINE	.0460
	DUYCLOPINTADIENE	.2540
	ELECTRICITY (KWH)	75.3600
	FLUORSPAR	.0080
	HYDROGEN	.0300
	METHANOL	.3580
	NITRIC ACID	.3480
	OXYGEN, GASEOUS	1.0850
	STEAM	.0060
	SULFURIC ACID	.4830
	.PROPYLENE.	.3800
	.TOLUENE.	.2540
	(MISC. BULK MATERIALS)	.0170

BULK MATERIAL : POLYVINYL FLUORIDE

	NAME	AMOUNT(MT)
RAW MATERIALS		
	COAL, BITUMINOUS	.2130
BULK MATERIALS		
	ACETYLENE	.6040
	ELECTRICITY (KWH)	164.0000
	FLUORSPAR	1.0440
	STEAM	.8120
	SULFURIC ACID	1.3230

BULK MATERIAL : PORCELAIN

	NAME	AMOUNT(MT)
RAW MATERIALS		
	CLAYS	.6950
	FELDSPAR	.3580
	NATURAL GAS	1.0500
BULK MATERIALS		
	ELECTRICITY (KWH)	25.0000

BULK MATERIAL : PROPYLENE GLYCOL

	NAME	AMOUNT(MT)
BULK MATERIALS		
	CHLORINE	1.2130
	LIME	.8320
	.PROPYLENE.	.7170

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES
(CONTINUED)

BULK MATERIAL : PVC PLASTIC

	NAME	AMOUNT(MT)
RAW MATERIALS		
	COAL, BITUMINOUS	.0540
	NATURAL GAS	.0670
BULK MATERIALS		
	CHLORINE	1.3900
	ELECTRICITY (KWH)	1830.0000
	LIQUID FUELS	.0350
	.ETHYLENE.	.5470

BULK MATERIAL : RUBBER, SBR

	NAME	AMOUNT(MT)
RAW MATERIALS		
	COAL, BITUMINOUS	.0380
	NATURAL GAS	.1040
BULK MATERIALS		
	CARBON BLACK	.3400
	ELECTRICITY (KWH)	183.6000
	.BENZENE.	.1400
	.BUTADIENE.	.3780
	.ETHYLENE.	.0520
	(MISC. BULK MATERIALS)	.1370

BULK MATERIAL : SILANE

	NAME	AMOUNT(MT)
BULK MATERIALS		
	LITHIUM HYDRIDE	1.2100
	SILICON TETRACHLORIDE	7.2500

BULK MATERIAL : SILICA FIBER

	NAME	AMOUNT(MT)
BULK MATERIALS		
	SAND & GRAVEL	3.0000

BULK MATERIAL : SILICA VITREOUS, 99.99%

	NAME	AMOUNT(MT)
RAW MATERIALS		
	QUARTZ	1.0000
BULK MATERIALS		
	HYDROCHLORIC ACID	.0100

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES
(CONTINUED)

BULK MATERIAL : SILICON MONOXIDE

	NAME	AMOUNT(MT)
RAW MATERIALS	QUARTZ	.7000
BULK MATERIALS	SILICON (SEG)	.3200

BULK MATERIAL : SILICON TETRACHLORIDE

	NAME	AMOUNT(MT)
BULK MATERIALS	HYDROCHLORIC ACID	.9000
	SILICON (MET)	.1700

BULK MATERIAL : SILICON (MET)

	NAME	AMOUNT(MT)
RAW MATERIALS	COAL, BITUMINOUS	1.2350
	SAND & GRAVEL	3.6570
	TIMBER, LUMBER	1.0250
BULK MATERIALS	ELECTRICITY (KWH)	13200.0000
	ELECTRODES	.1825
	PETROLEUM COKE	.4250

BULK MATERIAL : SILICON (SEG)

	NAME	AMOUNT(MT)
BULK MATERIALS	ELECTRICITY (KWH)	2304000.0000
	HYDROCHLORIC ACID	17.6000
	HYDROGEN	.1930
	SILICON (MET)	4.4900

BULK MATERIAL : SILICONES

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	.6730
BULK MATERIALS	CHLORINE	2.9650
	SILICON (MET)	.5850

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES
(CONTINUED)

BULK MATERIAL : SILVER

RAW MATERIALS	NAME	AMOUNT(MT)
	NATURAL GAS	8.2740
	SILVER ORE	1430.0000

BULK MATERIALS	NAME	AMOUNT(MT)
	ELECTRICITY (KWH)	164350.0000
	LIME	10.8300
	LIQUID FUELS	8.9000
	OXYGEN, LIQUID	.0140
	SODIUM CARBONATE	2.0700
	SODIUM CYANIDE	.4000
	STEAM	7.0200
	STEEL & IRON	1.5400
	SULFURIC ACID	4.8600
	ZINC	.2200
	(MISC. BULK MATERIALS)	2.3300

BULK MATERIAL : SODIUM BOROHYDRIDE

BULK MATERIALS	NAME	AMOUNT(MT)
	METHYL BORATE	3.1000
	SODIUM HYDRIDE	2.8000

BULK MATERIAL : SODIUM CARBONATE

RAW MATERIALS	NAME	AMOUNT(MT)
	COAL, BITUMINOUS	.4500
	LIMESTONE	1.2200
	SALT	1.5650

BULK MATERIALS	NAME	AMOUNT(MT)
	AMMONIA	.0025
	COKE	.1000
	ELECTRICITY (KWH)	47.0000
	(MISC. BULK MATERIALS)	.0005

BULK MATERIAL : SODIUM DICHROMATE

RAW MATERIALS	NAME	AMOUNT(MT)
	CHROMITE	1.4500
	NATURAL GAS	1.0500

BULK MATERIALS	NAME	AMOUNT(MT)
	ELECTRICITY (KWH)	551.0000
	LIME	.4500
	SODIUM CARBONATE	1.0000
	SULFURIC ACID	.5880

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : STAINLESS STEEL

	NAME	AMOUNT(MT)
RAW MATERIALS		
	CHROMITE	.7680
	LIMESTONE	.0100
	NATURAL GAS	.0030
	NICKEL ORE	8.4000
BULK MATERIALS		
	ALUMINUM	.0010
	ELECTRICITY (KWH)	606.0000
	ELECTRODES	.0060
	FERROMANGANESE	.0110
	FERROSILICON	.0010
	FERROUS SCRAP, PURCHASED	.6620
	FLUORSPAR	.0050
	LIME	.0300
	OXYGEN, GASEOUS	.0110
	(MISC. BULK MATERIALS)	.0130

BULK MATERIAL : STEAM

	NAME	AMOUNT(MT)
RAW MATERIALS		
	COAL, BITUMINOUS	.1120

BULK MATERIAL : STEEL & IRON

	NAME	AMOUNT(MT)
RAW MATERIALS		
	IRON ORE	1.6200
	LIMESTONE	.1610
	NATURAL GAS	.0150
BULK MATERIALS		
	ALUMINUM	.0010
	COKE	.3820
	ELECTRICITY (KWH)	159.0000
	ELECTRODES	.0010
	FERROMANGANESE	.0110
	FERROSILICON	.0010
	FERROUS SCRAP, PURCHASED	.2410
	FLUORSPAR	.0070
	LIME	.0550
	LIQUID FUELS	.0190
	OXYGEN, LIQUID	.0710
	STEAM	.3840
	(MISC. BULK MATERIALS)	.0490

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : STONE, CRUSHED & SIZED

	NAME	AMOUNT(MT)
RAW MATERIALS	STONE	1.0000

	NAME	AMOUNT(MT)
BULK MATERIALS	ELECTRICITY (KWH)	1.8535
	LIQUID FUELS	.0008
	(MISC. BULK MATERIALS)	.0002

BULK MATERIAL : SULFUR

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	.1450
	SULFUR ORE	1.0000

	NAME	AMOUNT(MT)
BULK MATERIALS	ELECTRICITY (KWH)	3.3000

BULK MATERIAL : SULFURIC ACID

	NAME	AMOUNT(MT)
BULK MATERIALS	ELECTRICITY (KWH)	9.0000
	SULFUR	.3370

BULK MATERIAL : TANTALUM

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	.1560
	TANTALUM ORE	800.0000

	NAME	AMOUNT(MT)
BULK MATERIALS	ELECTRICITY (KWH)	636.0000
	HYDROCHLORIC ACID	1.3400
	HYDROFLUORIC ACID	2.0000
	METHANOL	.9000
	STEAM	2.1600
	(MISC. BULK MATERIALS)	7.7360

BULK MATERIAL : TEFLON

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	.6380

	NAME	AMOUNT(MT)
BULK MATERIALS	CHLORINE	4.2290
	HYDROFLUORIC ACID	.7960

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES (CONTINUED)

BULK MATERIAL : TIN

	NAME	AMOUNT(MT)
RAW MATERIALS	LIMESTONE	.0470
	TIN ORE	100.0000
BULK MATERIALS	COKE	.2850
	ELECTRICITY (KWH)	16733.0000
	LIQUID FUELS	.1210
	(MISC. BULK MATERIALS)	.1440

BULK MATERIAL : TITANIUM

	NAME	AMOUNT(MT)
RAW MATERIALS	LIMESTONE	.0061
	NATURAL GAS	.3502
	RUTILE (CONC.)	2.1740
BULK MATERIALS	ARGON	.0271
	CHLORINE	1.0000
	ELECTRICITY (KWH)	25855.0000
	HELIUM	.0029
	MAGNESIUM	.3100
	NITRIC ACID	.0171
	PETROLEUM COKE	.6000

BULK MATERIAL : TRICHLOROSILANE

	NAME	AMOUNT(MT)
BULK MATERIALS	HYDROCHLORIC ACID	4.8000
	SILICON (MET)	1.0600

BULK MATERIAL : TRIMETHLY AL., COMM.

	NAME	AMOUNT(MT)
BULK MATERIALS	DIMETHYL ALUM. CHLORIDE	2.5000
	SODIUM	.6200

BULK MATERIAL : TRIMETHYL AL., 99.9999%

	NAME	AMOUNT(MT)
BULK MATERIALS	TRIMETHLY AL., COMM.	1.0800

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES
(CONTINUED)

BULK MATERIAL : TRIMETHYL GA., 99.9995%

	NAME	AMOUNT(MT)
BULK MATERIALS	GALLIUM TRICHLORIDE	2.4600
	TRIMETHLY AL., COMM.	2.0000

BULK MATERIAL : TRIMETHYL INDIUM, 99.998%

	NAME	AMOUNT(MT)
BULK MATERIALS	INDIUM TRICHLORIDE	2.0700
	TRIMETHLY AL., COMM.	.6700

BULK MATERIAL : TUNGSTEN

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	1.4760
	SODA ASH (NAT.)	.2415
	TUNGSTEN ORE	167.0000
BULK MATERIALS	NAME	AMOUNT(MT)
	AMMONIA	.4400
	CAUSTIC SODA	1.2350
	ELECTRICITY (KWH)	4102.0000
	HYDROCHLORIC ACID	5.0400
	HYDROGEN	.0904
	LIME	.1095
	LIQUID FUELS	4.6080
	SODIUM CYANIDE	.0550
	STEEL & IRON	.3065
	(MISC. BULK MATERIALS)	.1870

BULK MATERIAL : ZINC

	NAME	AMOUNT(MT)
RAW MATERIALS	NATURAL GAS	.1350
	ZINC ORE	22.2000
BULK MATERIALS	NAME	AMOUNT(MT)
	ELECTRICITY (KWH)	5413.0000
	LIQUID FUELS	.0560
	STEEL & IRON	.0250
	SULFURIC ACID	.0840
	(MISC. BULK MATERIALS)	.0810

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES
(CONTINUED)

BULK MATERIAL : ZINC ARSENIDE

BULK MATERIALS	NAME	AMOUNT(MT)
	ARSENIC	.4400
	ZINC	.5800

BULK MATERIAL : ZINC FLUOROBORATE

BULK MATERIALS	NAME	AMOUNT(MT)
	BORAX	.8000
	HYDROFLUORIC ACID	.6700
	SULFURIC ACID	.2100
	ZINC	.2800

BULK MATERIAL : .BENZENE.

RAW MATERIALS	NAME	AMOUNT(MT)
	NATURAL GAS	.0350
	PETROLEUM	174.2200

BULK MATERIALS	NAME	AMOUNT(MT)
	ELECTRICITY (KWH)	15.6790

BULK MATERIAL : .BUTADIENE.

RAW MATERIALS	NAME	AMOUNT(MT)
	NATURAL GAS	.2950
	PETROLEUM	73.7460

BULK MATERIALS	NAME	AMOUNT(MT)
	ELECTRICITY (KWH)	15.4870

BULK MATERIAL : .ETHYLENE.

RAW MATERIALS	NAME	AMOUNT(MT)
	NATURAL GAS	.3100
	PETROLEUM	10.0120

BULK MATERIALS	NAME	AMOUNT(MT)
	ELECTRICITY (KWH)	15.4190

TABLE A-4. BULK MATERIAL PRODUCTION PROCESSES
(CONTINUED)

BULK MATERIAL : .O-XYLENE.

RAW MATERIALS	NAME	AMOUNT(MT)
	NATURAL GAS	.5850
	PETROLEUM	146.3300

BULK MATERIALS	NAME	AMOUNT(MT)
	ELECTRICITY (KWH)	30.7300

BULK MATERIAL : .PROPYLENE.

RAW MATERIALS	NAME	AMOUNT(MT)
	NATURAL GAS	.3030
	PETROLEUM	20.2100

BULK MATERIALS	NAME	AMOUNT(MT)
	ELECTRICITY (KWH)	15.3600

APPENDIX A REFERENCES

(See also Primary Report References)

(1) Litchfield, J.W., Watts, R. L., et al., "A Methodolgy for Identifying Materials Constraints to Implementation of Solar Energy Technologies", Battelle Pacific Northwest Laboratories, Richland, WA, July, 1978.

(2) Watts, R. L., Gurwell, W. E., et al, "Some Potential Material Supply Constraints in the Deployment of Photovoltaic Solar Electric Systems", Battelle Pacific Northwest Laboratories, Richland, Washington, September, 1978.

(3) Watts, R. L., Gurwell, W. E., et al, "Some Potential Material Supply Constraints in Solar Systems for Heating and Cooling of Buildings and Process Heat", Battelle Pacific Northwest Laboratories, Richland, Washington, September, 1978.

APPENDIX B

DISCUSSION OF RESERVES AND RESOURCES

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 B-1).

This diagram illustrates changing qualities of resources in terms of increasing geologic assurance and increasing economic feasibility. In this two-dimensional diagram, reserves are represented by the shaded area. In this context, reserves are defined as 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 of exploration.

U.S. government estimates of available resources and reserves historically have been very conservative. For example, consider the case of bauxite (aluminum ore). Selected U.S. Bureau of Mines estimates over the 1945-1977 time span are listed below and shown graphically in Figure B-2:

1945 -	1×10^9 tons
1955 -	3×10^9
1965	6×10^9
1975	17×10^9
1977	24×10^9

Over a 32 year time span, this represents a 2400% increase in reserve estimates.

Similarly bauxite resource estimates in 1963 and 1975 were:

1963	14.5×10^9 tons
1975	40×10^9

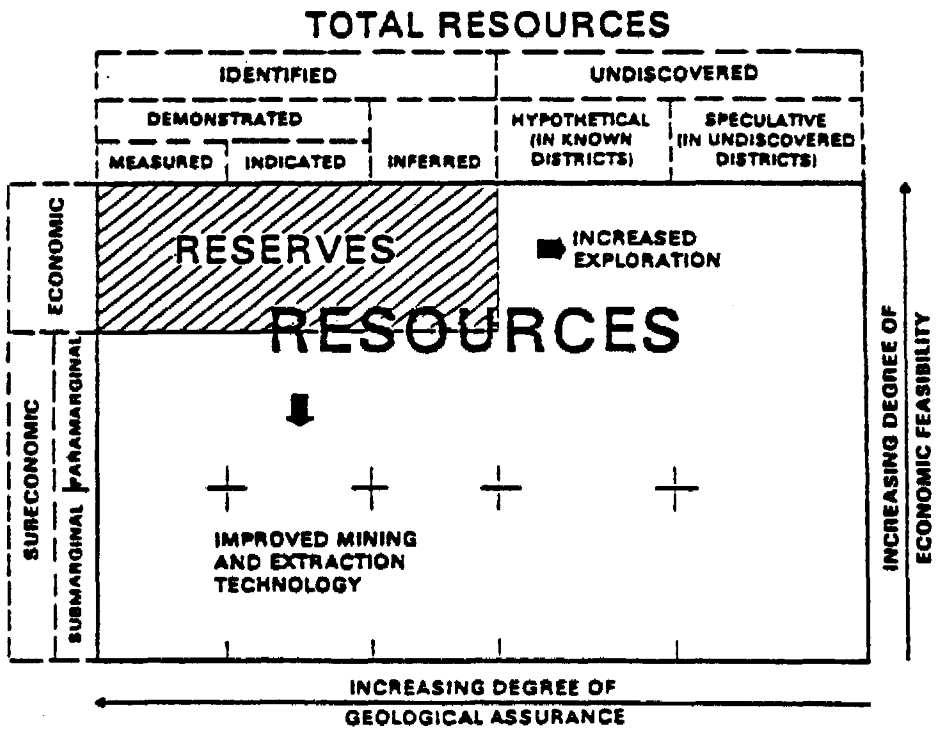

Figure B-1. CLASSIFICATION OF MINERAL RESOURCES*

*Commodity Data Summaries 1977. Bureau of Mines, U.S. Department of Interior, Washington, D.C., 1977

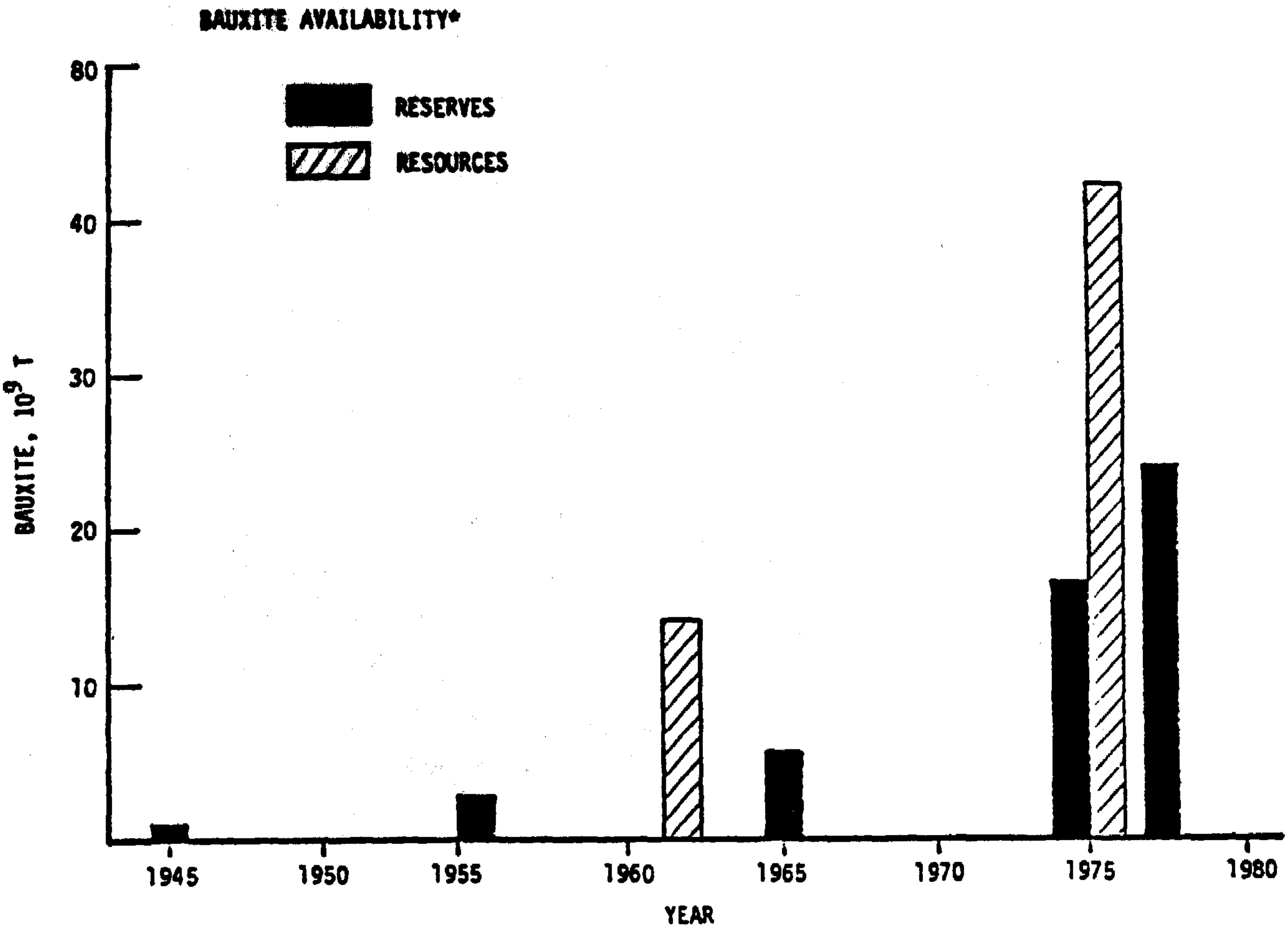

FIGURE B-2. BAUXITE AVAILABILITY*

*Commodity Data Summaries, Bureau of Mines, U.S. Department of Interior, Washington, D.C. (various years).

Mineral Facts and Problems (Bicentennial Edition), Bureau of Mines Bulletin 667, U.S. Department of Interior, Washington, D.C., 1975.

This represents over 275% increase in resource estimates over a 12-year span (see also Figure B-2). For comparison of availability with consumption, the 1975 consumption of bauxite was only 0.3×10^9 MT (U.S. Bureau of Mines estimate), a very small fraction of reserves and resources for what is a recyclable commodity.

These increases are due to major new discoveries, technological advances in recovery processes permitting inclusion of lower grade bauxite ores and upward movement in prices for aluminum, e.g., $0.22/lb in current dollars in 1954 to $0.40/lb in 1975 to $0.60+/lb today. In constant 1973 prices, the increase is more like 10% to 15% over the 25-year time span.

Even estimates of petroleum reserves and resources are being vastly increased under todays new ground rules on prices. 1978 study by the International Institute for Applied Systems Analysis in Austria estimates 2.1 trillion barrels of world oil resources recoverable at $20/barrel in 1976 dollars*--a 95 year supply at present world rates of production.

Assessment of the criticality of materials from a reserves and resources standpoint must allow for the conservative nature of availability estimates. For this reason, materials assessment threshold values for these parameters have been set at high levels: 400 percent for U.S. reserves, 300 percent for U.S. resources, and 200 percent for world resources. In most cases even these values are conservative.

*U.S. GOVERNMENT PRINTING OFFICE : 1980 O-310-912/181

*Fortune, September 24, 1979, page 86.