Title

TECHNOLOGY ASSESSMENT OF SOLAR ENERGY SYSTEMS: PART I: AN ANALYSIS OF LIFE CYCLE COSTS OF SOLAR FACILITIES. PART II: MINERALS CRITICAL TO THE DEVELOPMENT OF FUTURE ENERGY TECHNOLOGIES IN HIGH AND LOW SOLAR SCENARIOS

Permalink

https://escholarship.org/uc/item/7jb8x3nc

Authors

Sathaye, J.
Ruderman, H.

Publication Date

1981-09-01

LBL-13324
UC-59b

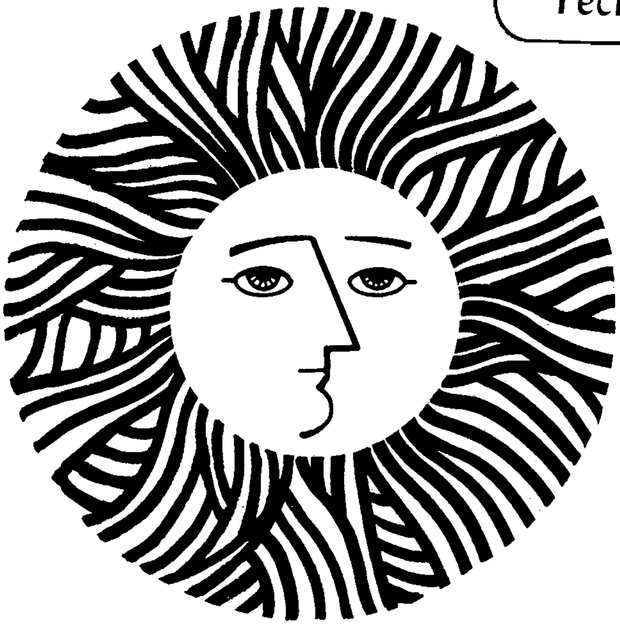
Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT
DIVISION

TECHNOLOGY ASSESSMENT OF SOLAR ENERGY SYSTEMS: PART I: AN ANALYSIS OF LIFE CYCLE COSTS OF SOLAR FACILITIES. PART II: MINERALS CRITICAL TO THE DEVELOPMENT OF FUTURE ENERGY TECHNOLOGIES IN HIGH AND LOW SOLAR SCENARIOS

Jayant Sathaye and Henry Ruderman

September 1981



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

Technology Assessment of Solar Energy Systems:

PART I: AN ANALYSIS OF LIFE CYCLE COSTS OF SOLAR FACILITIES

PART II: MINERALS CRITICAL TO THE DEVELOPMENT OF FUTURE ENERGY TECHNOLOGIES IN HIGH AND LOW SOLAR SCENARIOS

Jayant Sathaye and Henry Ruderman
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

September, 1981

This work was supported by the U.S. Department of Energy, Secretary for Environmental Protection, Safety and Emergency Preparedness, Office of Environmental Assessments. Part II was supported in part by the U.S. General Accounting Office through the Department of Energy under Contract Number DE-AC03-76SF00098.

Table of Contents

Part I: An Analysis of Life Cycle Costs of Solar Facilities

Part II: Minerals Critical to the Development of Future Energy Technologies in High and Low Solar Scenarios

Table of Tables

Part I: An Analysis of Life Cycle Costs of Solar Facilities

Part II: Minerals Critical to the Development of Future Energy Technologies in High and Low Solar Scenarios

Table of Figures

Part I: An Analysis of Life Cycle Costs of Solar Facilities

Part II: Minerals Critical to the Development of Future Energy Technologies in High and Low Solar Scenarios

PART I: AN ANALYSIS OF LIFE CYCLE COSTS OF SOLAR FACILITIES

SUMMARY

The life cycle costs over a range of technological and economic assumptions were compared to investigate the trade offs among solar and renewable energy technologies, and between centralized and decentralized technologies. We looked at these costs under different financial conditions by varying the interest rates, tax rates, and taxable lifetimes. For wood stoves, we varied the fuel price over a wide range. For some technologies cost estimates for alternative designs were compared with the original TASE characterizations.

Life cycle costs under different financial conditions were compared by calculating the derivatives of the fixed charge rate (FCR) with respect to the discount and tax rates for taxable lifetimes ranging from 5 to 30 years. At the upper end of this range (15 years or more) the FCR is not sensitive to the taxable lifetime.

The FCR is most sensitive to changes in the tax rate, especially at high rates. Below tax rates of 30 percent, the dependence is nearly linear, but above 40 percent, the FCR increases rapidly. Tax rates above this level will thus inhibit investment in new capital intensive facilities.

The fixed charge rate is fairly linear with respect to the discount rate over the range 0 to 22 percent. The slope of the linear curve depends strongly on the tax rate.

Fuel costs for wood stoves were varied from zero to $600 per year. This covers a range of prices from a rural consumer gathering his own wood to an urban consumer who purchases four cords of delivered wood at $150 per cord. This spread in fuel costs results in the life cycle costs varying over a factor of four from $2.58 to $6.33 per million Btu. These costs are much lower than the life cycle costs of other residential space heating systems, including passive solar, because the capital

costs are so low.

Comparing the different TASE facilities that generate electricity, we see that the centralized systems are less expensive than dispersed systems on a life cycle cost basis (see Table 1). Wind systems are the least costly, central solar next, and photovoltaics are the most expensive. For residential space heating, wood stoves are least expensive and active solar the most expensive, with passive solar in between. These differences arise primarily from differences in capital costs.

Comparing the TASE characterizations with the SERI characterizations, we see significant differences in life cycle costs in less than half of the technologies (see Table 2). Except for photovoltaic systems, the largest differences are about a factor of 2-3. This range results from differences in the design and in the geographic location of the system. Since the life cycle costs are dominated by the capital costs, the same system located at a site with low input energy will have higher unit energy costs than if it were located at a site with high energy input. The SERI life-cycle costs for photovoltaic systems are much higher than the corresponding TASE costs. The SERI capital costs amount to about $10 per peak kilowatt, which is an accepted estimate for current costs. The TASE costs for central photovoltaic systems are about $1 per peak kilowatt, which corresponds to DOE's design goals for the mid 1980's.

INTRODUCTION

Solar and biomass technologies require more capital than their conventional counterparts. The fuel costs of solar technologies are negligible, while those of biomass technologies are site specific. For example, annual fuel costs for wood stoves can vary from zero in a rural area to $600 in an urban area. In an earlier report [1], we examined the capital costs and labor requirements and the indirect impacts of constructing solar and biomass energy facilities. The purpose of this paper is to examine the life cycle costs of various solar and biomass technologies and to examine the sensitivity of these costs to variations in financial variables.

In comparing solar and biomass technologies with their conventional alternatives, these technologies are often thought of as a single homogeneous technology. Their diversity is ignored in such comparisons. Solar technologies range from centralized solar thermal electric power plants to dispersed or decentralized residential solar heating. In our analysis we examine the difference in costs of centralized vs. decentralized systems.

Most solar and biomass technologies are at the research and development stage; their performance characteristics are not yet proven. The cost of these prototype technologies are generally high. As the technologies develop and their market shares increase the unit costs will decline until they ultimately match or fall below the costs of conventional alternatives. Because of the uncertainties in cost estimates, we compare the costs for alternative characterizations of technologies with similar designs.

Life cycle costs depend on the capital and operating costs and the fuel cost of each facility. The fixed charge rate, which depends upon the financial conditions (tax and interest rates), the expected lifetime of each facility, and its performance characteristics, determines the capital component of the life cycle costs. We examine the effect of changing these variables on the life cycle costs of solar and biomass facilities.

METHODOLOGY

The levelized cost of energy from each solar facility may be expressed as the sum of three types of costs:

$$c_j = (\text{Levelized Capital Cost})_j + (\text{Operations and Maintenance Cost})_j + (\text{Fuel Cost})_j$$

where j = Solar Technology Type

The levelized capital cost is a function of the initial capital cost (CC), the energy generated each year (E), and the fixed charge rate (FCR). For a specific type of solar facility the levelized capital cost is

$$\text{Levelized Capital Cost} = CC_j\ ESC_j\ FCR_j\ /\ E_j$$

The capital costs in our analysis were derived from the technology characterizations previously published as part of the TASE study [2]. The corresponding data for alternative designs were from a SERI study [3]. Capital requirements of solar and biomass power plants are likely to decline according to the SERI study.

The first few renewable power plants will be prototypes of commercial plants to come on line later. Prototypes may cost as much as ten times more than a commercial plant of the same size. Plant costs can be expected to decline because of improved management, more efficient construction practices, competitive bidding on the part of suppliers, mass production of components, and more efficient use of materials. Costs may also increase as a result of unforeseen circumstances, stricter health and safety requirements or environmental regulations, and more expensive on site resources: land, water and labor. Published goals for the cost of renewable facilities indicate that they will decline over the next twenty years. The decline may be fairly rapid during the first 10 to 15 years as the first plants are commercialized, after which it will slow down as unit costs stabilize.

The fixed charge rate used in computing the cost of capital is based on the following equation [4]:

$$FCR = \frac{1}{1 - Tax}\left[C_r(1 - ITC) - \frac{Tax}{n}\right] + B_1 + B_2 \qquad (1)$$

where

$$C_r = \frac{r}{1 - (1+r)^{-n}}$$

n = taxable life (20 years)

r = cost of capital (13%)

tax = tax rate (40%)

ITC = investment tax credit (25%)

B_1 = other taxes (2%)

B_2 = insurance (0.25%)

The fixed charge rate amounts to 0.226 using these values for the variables. The cost of capital is based on constant 1978 dollars.

To examine the sensitivity of the fixed charge rate to the economic conditions under which the solar and renewable energy facilities would be built, we calculated the derivative of the FCR with respect to the tax rate and the discount rate (cost of capital). The resulting expressions are:

$$\frac{dFCR}{dTax} = \frac{C_r(1 - ITC) - 1/n}{(1 - Tax)^2} \qquad (2)$$

$$\frac{dFCR}{dr} = \frac{1 - ITC}{1 - Tax} \quad 1 - \frac{(1 + r)^{-n} - nr(1 + r)^{-n-1}}{\left[1 - (1 + r)^{-n}\right]^2} \qquad (3)$$

The FCR and its derivatives were calculated for taxable lifetimes ranging from 5 to 30 years using a broad range of discount and tax rates.

The capital, operating and fuel costs were derived from the technology characterizations previously published as part of the TASE study [2]. The corresponding data for alternative designs were taken from a SERI study [3]. The alternative designs were analysed since there are widely varying designs, and expectations of future costs of solar technologies. Analysis of alternative designs permits us to assess the sensitivity of costs to design changes. Estimates of fuel costs for wood stoves came from an informal survey by Lipfert [5] and from Lucarelli [6].

RESULTS

Fixed Charge Rate

In calculating the life cycle costs of an energy facility, the initial capital costs are distributed over the lifetime of the system. The factor used to distribute the capital costs, the fixed charge rate (FCR), is defined as the annualized life cycle cost per dollar of capital investment. As can be seen from equation (1), the FCR depends mainly on the taxable life of the facility, the income tax rate, and the cost of capital or discount rate. To investigate the effect of these parameters, we calculated the fixed charge rate and its derivatives over a wide range of these variables. The results are shown in Figures 1 through 3.

In Figure 1, we plot the fixed charge rate as a function of taxable lifetime for several tax rates. For facilities with relatively long lifetimes (greater than 15 years), the FCR is nearly independent of the lifetime. This is especially true as the discount rate gets larger. The taxable lifetime is therefore of less consideration for centralized facilities which have long lifetimes than for dispersed facilities such as wood stoves or residential solar or wind systems which may have a much shorter lifetime.

Of these three parameters, the FCR shows the strongest dependence on the income tax rate. The curves shown in Figure 2 are nearly linear for tax rates less than about 30 percent. Above this level the FCR increases more rapidly than the tax rate. High tax rates, over 30 percent, therefore disproportionately discourage investment in capital intensive energy facilities.

The FCR in our formulation decreases with increasing facility lifetime. However, beyond a rax rate of approximately 40 percent, this trend is reversed. With increasing lifetimes, the tax rate increases slightly. Figure 3 illustrates this anomaly for 30, 40 and 50 year lifetimes.

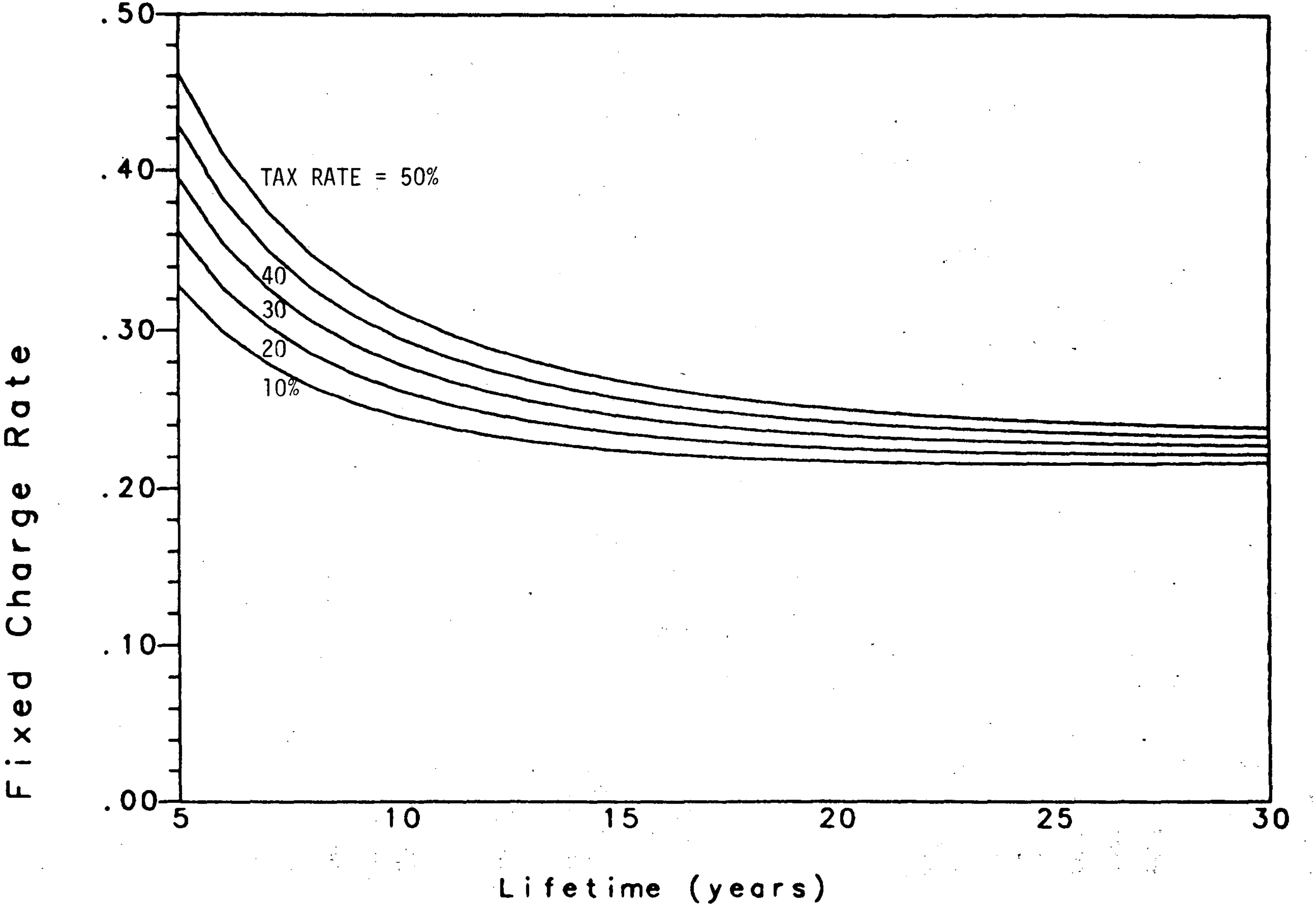


Figure 1 - Fixed Charge Rate as a Function of Facility Lifetime

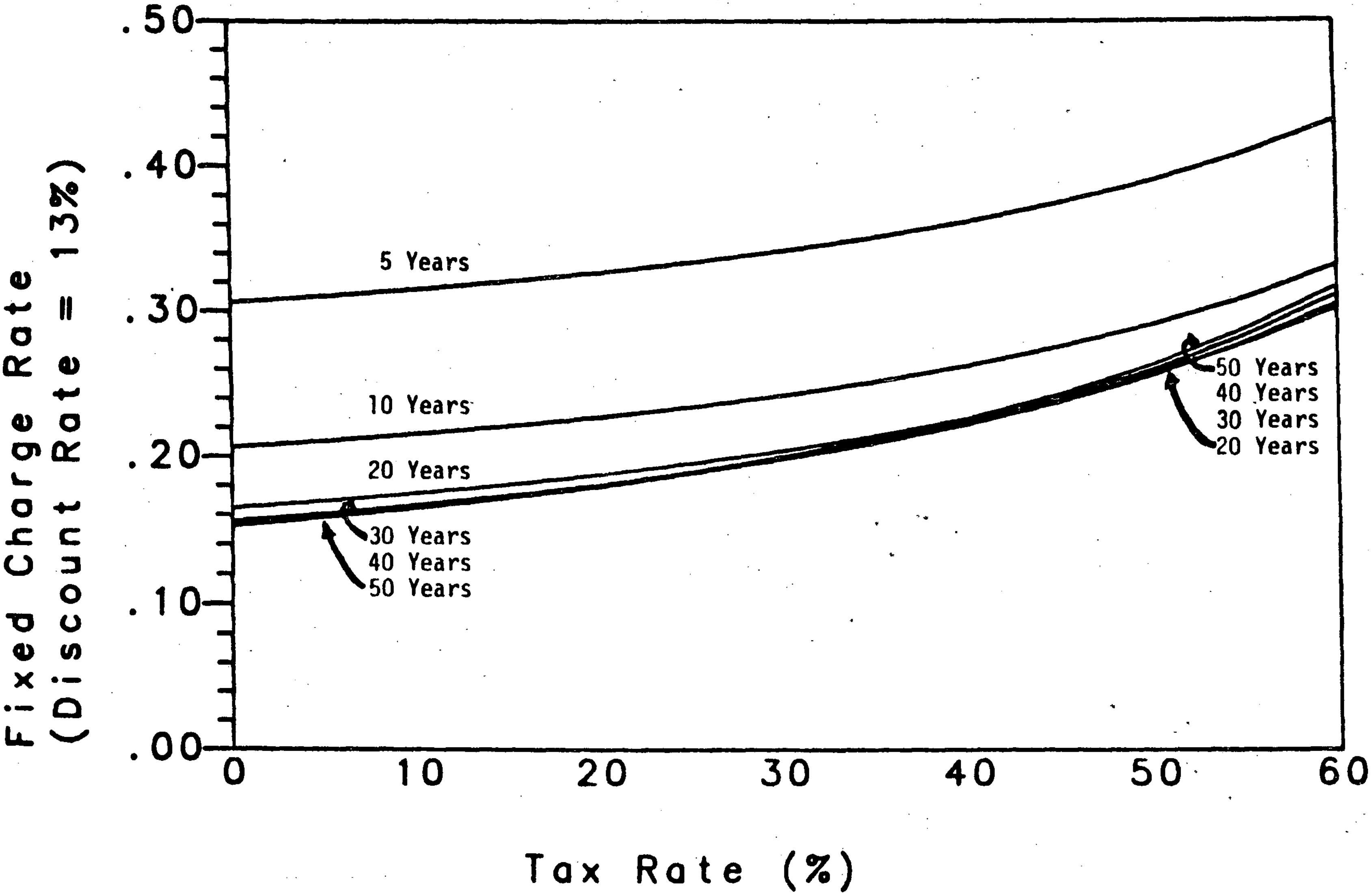


Figure 2 - Fixed Charge Rate as a Function of Tax Rate

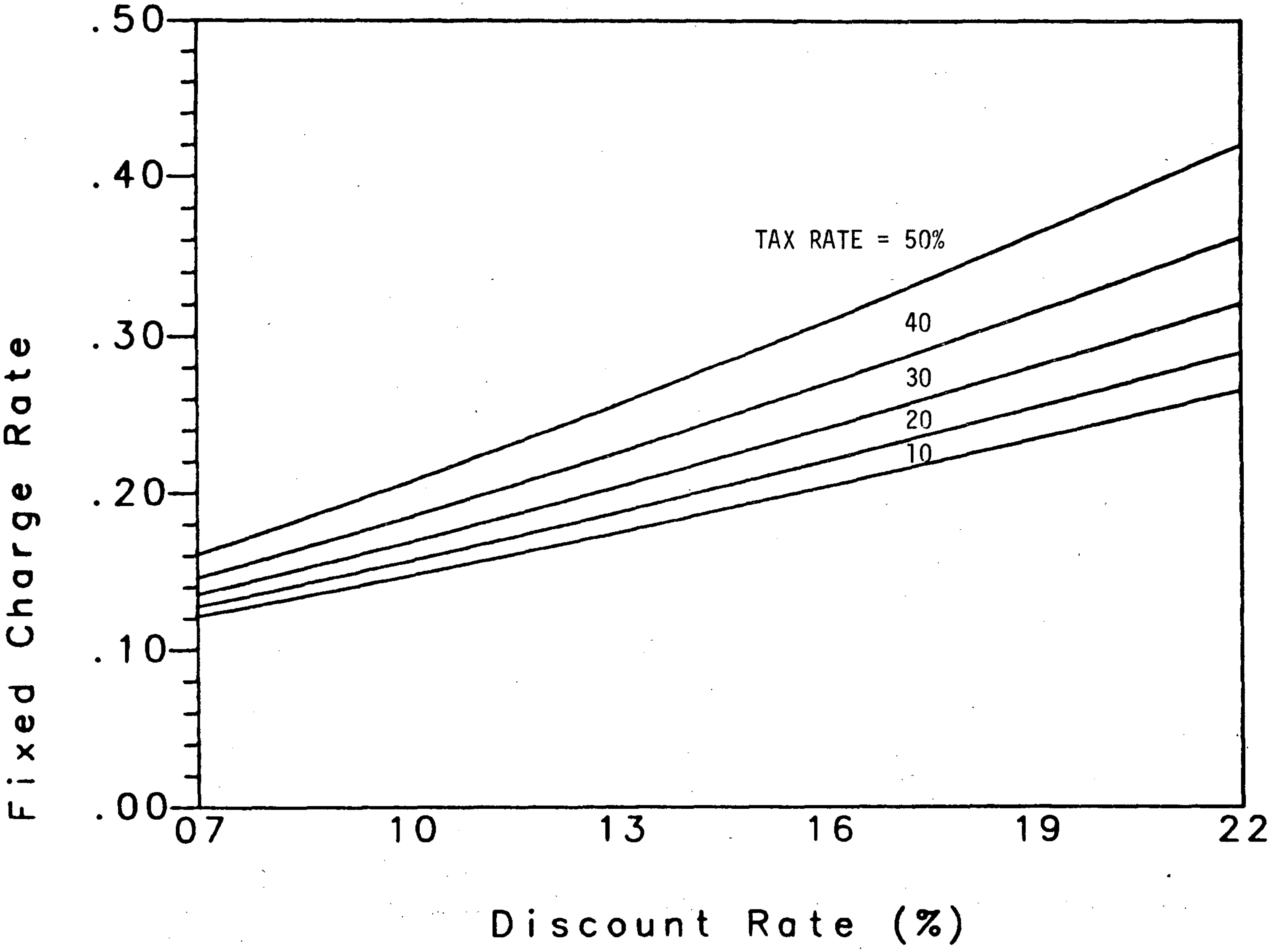


Figure 3 - Fixed Charge Rate as a Function of Discount Rate

The FCR increases nearly linearly with the discount rate over a range of 0 to 22 percent. As shown in Figure 3, the slope of this curve increases with increasing tax rate. The combination of high interest rates and high tax rates that we have been experiencing over the past few years result in a very high fixed charge rate which drives up the cost of energy from new sources and inhibits investment in them.

Life Cycle Costs of TASE Facilities

Life cycles costs for 16 facilities characterized as part of the TASE study [2] were calculated under the following financial conditions:

Taxable life	20 years
Cost of capital	13 percent
Tax rate	40 percent
Investment tax credit	0.25 percent
Other taxes	2 percent
Insurance	0.25 percent

The results per million Btu of input energy are presented in Table 1.

Except for wood stoves, no fuel costs are involved for the biomass facilities because they are assumed to have a captive source of fuel. For this reason and because they have lower capital and operating costs, biomass facilities are in general less expensive per Btu than solar facilities (see Table 1). The only exceptions are the Industrial Process Heat systems which have high capital costs; for these, the levelized energy costs are comparable to those for solar facilities.

Centralized solar systems shown in Table 1 appear to be less expensive than decentralized ones. This is especially true for photovoltaic systems, but in this case the capital costs for the central system is quite low while the operating cost for the residential system provided in Reference 3 seems high. The capital costs correspond to approximately $1 per peak watt, whereas current estimates are closer to $10 per peak watt. The $1 figure represents DOE's goals for the cost of photovoltaics in 1985 [7]. The operating costs for residential photovoltaics come to nearly $2,000 per year which seems unreasonably high.

Wood stoves are the least expensive way to supply residential heating. Passive solar heating costs about twice as much, and active heating is another factor of two higher. These cost figures should only be considered as rough estimates of the actual cost of a real system in a given location. The cost per million Btu depends to a large extent on the details of the technical design of the system and, for a solar system, on its geographic location. The latter factor determines the amount of energy incident on the system annually.

Comparison of TASE and SERI Facilities.

To investigate the sensitivity of the life cycle costs of solar and biomass energy systems to differences in design and location, we compared our results with a similar cost calculation we performed using the data in a recent report by the Solar Energy Research Institute [3]. We chose the SERI systems that fulfilled the same end-use demand as the TASE systems. In some cases the SERI systems were given for two locations in the country.

Comparing the data in Tables 1 and 2, we see that for almost all systems the life cycle costs differ by a factor of 2 to 3. The major exceptions are centralized photovoltaic systems. The difference arises because the SERI life cycle costs are based on estimates of the current system costs whereas the TASE results are based on estimates of future costs. As discussed in the previous section, current installed costs for photovoltaic systems are ten times the estimates for systems installed in 1985.

The life cycle cost for centralized facilities are consistently larger for the SERI systems than for the TASE systems. For residential wind and solar systems they are nearly the same. The costs for the SERI residential solar space and water heating system are about twice as large as that gotten by combining the two corresponding TASE facilities (Solar Space Heating and Active Solar Domestic Water Heating).

Table 1

Levelized Capital, Operating and Fuel Costs
of TASE Solar and Biomass Facilities
[Dollars per Million Btus]

	Annualized Life Cycle Costs			
	Capital	Operating	Fuel	Total
Central Solar Receiver	9.06	.62	0.	9.68
Central Wind Energy System	7.29	.99	0.	8.28
Centralized Photovoltaic System	10.60	1.13	0.	11.73
Residential Photovoltaics	74.46	11.95	0.	86.41
Residential Wind System	23.05	4.18	0.	27.23
Active Solar Domestic Water Heating	11.82	4.25	0.	16.07
Passive Solar Domestic Heating	11.98	1.15	0.	13.13
Solar Space Heating	21.54	1.65	0.	23.19
Solar Space Conditioning	30.29	2.45	0.	32.74
Combustion/Cogeneration - Paper/Pulp	.92	.12	0.	1.04
IPH - Medium, Paper/Pulp	23.99	1.34	0.	25.33
IPH - TES	14.90	3.48	0.	18.38
Pyrolysis - M.S.W.	4.15	.20	0.	4.35
Anaerobic Digestion Municipal Sludge	2.29	3.34	0.	5.63
Biomass Combustion	.33	.20	0.	.52
Wood Stoves	1.17	1.42	3.64	6.22

Table 2

Levelized Capital, Operating and Fuel Costs
for SERI Solar and Biomass Facilities
[Dollars Per Million Btus]

	Annualized Life Cycle Costs			
	Capital	Operating	Fuel	Total
Central Solar Receiver	24.90	2.17	0.	27.07
Centralized Photovoltaic System	185.65	8.22	0.	193.87
Central Wind Energy System	19.73	.28	0.	20.01
Solar Water and Space Heating	62.79	5.60	0.	68.39
Solar Water and Space Heating*	72.70	6.11	0.	78.81
Active Solar Domestic Water Heating	9.01	.83	0.	9.84
Active Solar Domestic Water Heating*	9.79	.95	0.	10.74
Passive Solar Domestic Heating	15.11	.28	0.	15.40
Passive Solar Domestic Heating*	16.38	.22	0.	16.60
Residential Photovoltaics	93.05	1.56	0.	94.61
Residential Wind System	.13	.00	0.	.13
Residential Wind System*	.25	.01	0.	.25
Combustion/Cogeneration - Paper/Pulp	.46	.37	0.	.83

*Cost at a less favorable location.

Wood Stoves

Our results indicate that wood stoves are the least expensive source of energy for residential space heating because of their low capital costs. We investigated the life cycle cost of wood stoves for a range of fuel costs. According to Lipfert [5] and Lucarelli [6] the price of wood can range from essentially zero for a rural consumer who collects his own to $150 per cord for an urban consumer who has it trucked in. Assuming that up to four cords of wood per year would be burned, we calculated life cycle costs for an fuel bill of zero to $600 per year. The results are plotted in Figure 4. This range of wood prices results in the life cycle costs for wood stoves varying over a factor of four from $2.58 to $6.33 per million Btu.

Comparison of Low and High Solar Scenarios

The solar and biomass share of primary energy supply varies by a factor of two between the two scenarios. All the consuming sectors have a larger supply of energy from renewable sources in the high solar scenario. The fraction of total solar and biomass energy used in industry is 63 percent in the low scenario and 51 percent in the high scenario (see Table 3). The fractions of renewable energy consumed in the electric utility and residential sectors are 13 and 22 percent in the low solar scenario and 21 and 27 percent respectively in the high scenario.

The life cycle costs of biomass systems are the lowest among the technologies we considered. Centralized utility systems are somewhat more expensive, followed by residential heating, industrial process heat, and residential wind and photovoltaics.

For the low and high solar scenarios, the annualized life cycle cost for each consuming sector is shown in Table 4. Unit costs for supplying energy in the electric utility sector and in the industrial sector are nearly identical between the two scenarios. In the residential sector there is a significant difference in costs due to a different mix of technologies in the two cases. In this sector, passive solar designs

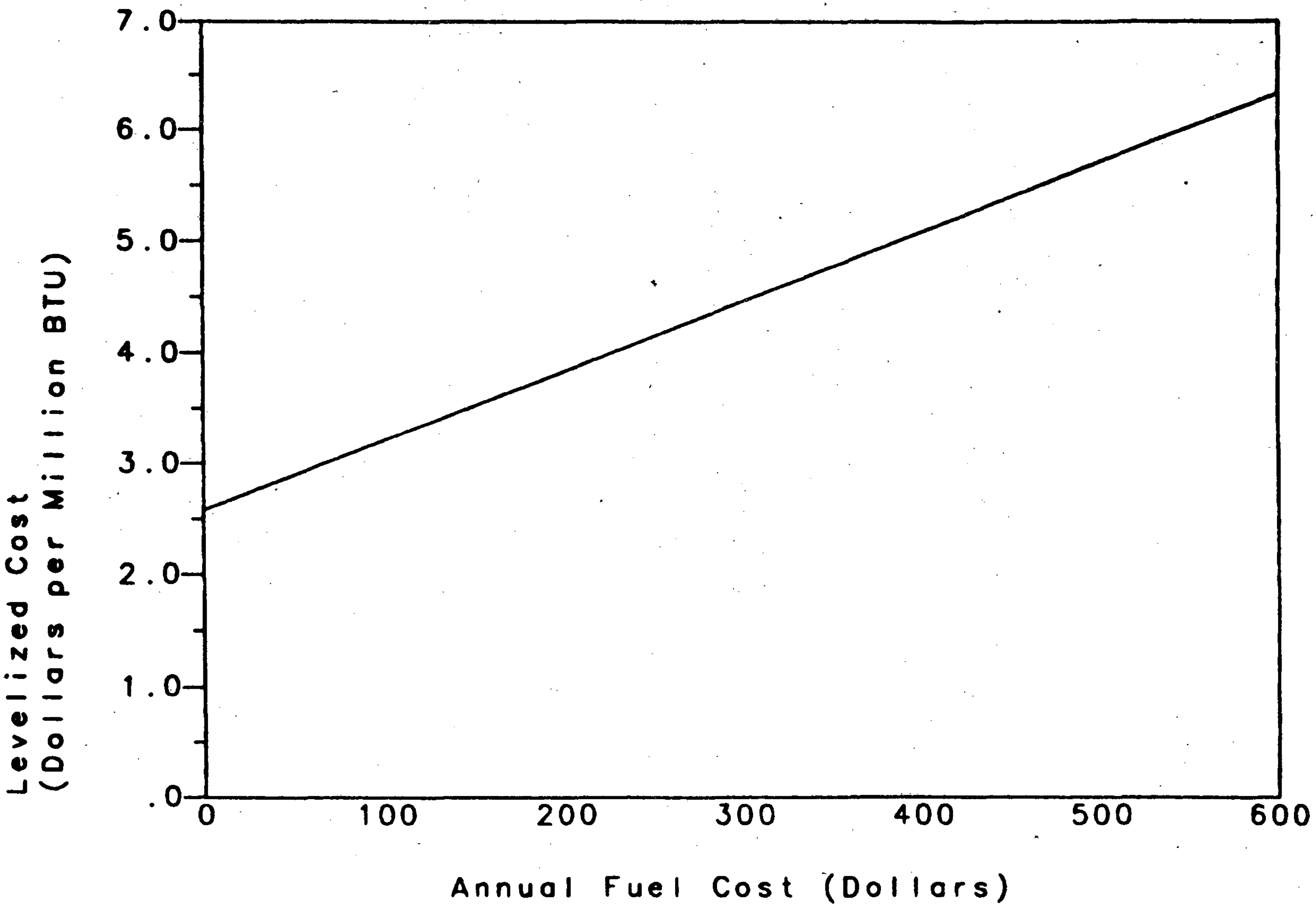


Figure 4 - Life Cycle Costs for Wood Stoves

TABLE 3
TASE SOLAR ENERGY AND SYSTEM ESTIMATES
Year 2000 Comparison

TECHNOLOGY	14.2 Q		6.0 Q		Δ	
	10^{12} Btu (FFE)	NUMBER OF SCALED SYSTEMS	10^{12} Btu (FFE)	NUMBER OF SCALED SYSTEMS	10^{12} Btu (FFE)	NUMBER OF SCALED SYSTEMS
E. U. Wind	1,484.5	37,695	601.5	15,189	883.0	22,506
E. U. PV	232.3	110	99.4	48	132.9	62
E. U. Solar Thermal	1,242.7	326	99.4	24	1,143.3	302
E. U. - Total	2,959.5		800.3		2,159.2	
RDF	251.4	22	89.5	7	161.9	15
IPH - TES	617.2	9,375	308.4	4,719	308.8	4,656
IPH - Low T.	226,1	1,851,300	113.2	929,540	112.9	921,760
IPH - Med. T.	1,222.5	5,229	611.1	2,612	611.4	2,617
IPH - Total	2,065.8		1,032.7		1,033.1	
Incinerator	247.1	202	89.8	75	157.3	127
Direct Combustion	1,085.7	6,495	101.9	609	983.8	5,886
Cogen. P+P	2,599.7	444	2,311.9	398	287.8	46
P. H. - Total	3,932.5		2,503.6		1,428.9	
A. D. - Sludge	32.0	62	32.0	62	0.0	0
PYR. - MSW	74.9	3	20.0	1	54.9	2
A. D. - Manure	66.9	446	66.9	446	0.0	0
PYR. - Ag. Res.	327.8	2,801	99.9	856	227.9	1,945
PYR. - Wood	699.6	178	0.0	0	699.6	178
Gas - Total	1,201.2		218.8		1,036.9	
Industrial - Total	7,199.5		3,755.1		3,444.4	
Act. Heating	959.3	10,350,620	416.2	4,498,066	543.1	5,852,554
Act. H + Cool.	330.8	2,752,601	142.0	1,184,474	188.8	1,568,127
Passive H+C	999.9	10,736,504	200.0	2,232,591	799.9	8,503,913
Hot Water	709.9	25,183,985	341.0	12,096,032	368.9	13,087,953
R/C Wind	418.2	1,556,373	53.2	202,581	365,0	1,353,792
R/C PV	51.7	373,287	33.9	245,775	17.8	126,512
Wood Stoves	299.9	1,893,000	200.0	1,270,000	99.9	623,000
R/C - Total	3,769.7		1,336.5		2,383.4	

Source: US Department of Energy, Assistant Secretary for Environmental Protection, Safety, and Emergency Preparedness, ' Environmental and Socioeconomic Comparison of High and Low Solar Scenarios,' Vol.1, Published by the Mitre Corporation, May 1981. MTR-80W215-01

Table 4

Life Cycle Costs for the High and Low Solar Scenarios in the Year 2000

Technology Sector	High Solar (14.2 Quads)		Low Solar (6.0 Quads)	
	Total Levelized Cost (Billion dollars)	Unit Cost (Dollars per million Btu)	Total Levelized Cost (Billion dollars)	Unit Cost (Dollars per million Btu)
Electric Utilities	27.1	9.2	7.1	8.9
Refuse Derived Fuel	0.1	0.5	0.1	0.5
Industrial				
Process Heat	45.9	22.2	23.0	22.3
Combustion and Cogeneration	3.4	0.9	2.5	1.0
Gasification	6.7	5.6	1.1	5.0
Residential				
Space Conditioning and Water Heating	57.6	19.2	22.4	22.4
Wind and Photovoltaics	15.9	33.8	4.4	50.3
Wood Stoves	1.9	6.2	1.2	6.2
Total	158.6	11.2	61.8	10.3

account for a larger fraction of energy use for space heating in the high scenario, hence the unit cost is lower. Residential electricity is less expensive in the high solar scenario than in the low because a larger proportion of the electricity is generated by cheaper wind systems.

The overall unit cost of supplying energy is nine percent higher in the high solar scenario. The total capital cost for the high solar scenario between 1976 and 2000 will amount to $690 billion in constant 1978 dollars, while for the low solar scenario it will amount to $270 billion. This is not surprising since the fuel costs for all biomass technologies except for wood stoves are negligible since we assumed a captive fuel source. It also implies that operating costs vary in proportion to capital costs for all the technologies.

REFERENCES

1. Sathaye, J. A., Ruderman, H., and Chan, P., "A Comparison of Capital and Labor Requirements for High and Low Solar Scenarios," LBL-12845, (June 1981).

2. U.S. Department of Energy, Office of Environmental Assessments, "Summary of Solar Energy Characterizations," DOE/EV-0099, Washington DC (September 1980).

3. Solar Energy Research Institute, "Cost of Energy from Some Renewable and Conventional Technologies," vol. I - Summary, SP-741-1022 (1980).

4. J. W. Doane, R. P. O´Toole, R. G. Chamberlain, P. B. Bos, and P. D. Maycock, "The Cost of Energy from Utility-Owned Solar Electric Systems," ERDA/JPL-1012-76/3, Pasadena, CA (June, 1976)

5. Lipfert, Fred, Private Communication, Brookhaven National Laboratory (June 1981).

6. Lucarelli, Frank Bart, Jr., "California´s Biomass and its Energy Potential," LBL-10058, Lawrence Berkeley Laboratory, Berkeley CA (April 1980).

7. Magid, L. M., U.S. Department of Energy, "Briefing to the First National Conference on the Health Effects of Photovoltaic Power Systems," Brookhaven National Laboratory, Upton, NY (17-21 June 1980).

PART II: MINERALS CRITICAL TO THE DEVELOPMENT OF FUTURE ENERGY TECHNOLOGIES IN HIGH AND LOW SOLAR SCENARIOS

SUMMARY

Solar and renewable technologies account for most of the increase in material requirements for energy technologies. Our analysis identified 20 minerals where domestic reserves are inadequate to meet the demand. Domestic mine capacity is inadequate for 23 minerals. However, the world wide mine production capacity is adequate to meet the U.S. demand for all the minerals. Energy related demand can therefore provide a potential market for some of these 23 minerals provided the U.S. has deposits that can be exploited at worldwide competitive prices.

For some critical and strategic minerals such as chromium the U.S. demand peaks during a time period different than the period during which world demand peaks. The time period differences will help smooth market fluctuations and reduce the U.S. vulnerability.

Alternative technology designs can help mitigate adverse supply disruptions or sharp price increases. Alternatives may not always be available for a specific strategic and critical mineral. Each mineral may have to be analyzed and evaluated on its own merits before comparative options can be completely analyzed.

INTRODUCTION

The next 20 to 30 years are expected to be a period of transition from major dependence on conventional energy sources such as oil and natural gas to an era heavily dependent on nonconventional renewable and virtually inexhaustible sources of energy. The viability of these future alternative energy sources is contingent, in part, on future materials and minerals availability.

In this analysis we have estimated the amounts of 46 non-fuel minerals needed to construct the new energy facilities called for in a high and a low solar scenario. Twenty-five of these 46 minerals were selected for a careful analysis of demand and supply. The other 21 minerals, for which the U.S. is a net exporter with adequate reserves and for which resources are readily available, geographically dispersed, and virtually inexhaustible, were excluded from this analysis. Table 1 lists all the sectors which were included in our analysis.

Energy-related and total U.S. and world primary demand for minerals, and U.S. and world mine production capacity, were projected in five-year periods to the year 2000. The percent of U.S. and world demand and capacity needed for both the alternative and conventional energy technologies were calculated under each scenario. The primary demand for the 25 minerals was also projected in the five-year periods to the year 2000 for each group of technologies--coal, oil, gas, solar and other renewables, nuclear, and synfuels.

Table 1. Sectors in the Minerals Input-Output Table

	Input-Output Sector	BEA Sectors
1	Livestock and Livestock Products	1.0100-1.0302
2	Other Agricultural Products	2.0100-2.0702
3	Forestry and Fishery Products	3.0000
4	Agricultural Forestry, Fishery Services	4.0000
5	Iron Ores	pt. 5.0000
6	Molybdenum Ores	pt. 5.0000
7	Chromium Ores	pt. 5.0000
8	Tungsten Ores	pt. 5.0000
9	Manganese Ores	pt. 5.0000
10	Nickel Ores	pt. 5.0000
11	Columbium Ores	pt. 5.0000
12	Tantalum Ores	pt. 5.0000
13	Copper Ores	6.0100
14	Lead Ores	pt. 6.0200
15	Zinc Ores	pt. 6.0200
16	Gold Ores	pt. 6.0200
17	Silver Ores	pt. 6.0200
18	Bauxite and Other Aluminum Ores	pt. 6.0200
19	Metal Mining Services	pt. 6.0200
20	Mercury Ores	pt. 6.0200
21	Uranium Ores	pt. 6.0200
22	Vanadium Ores	pt. 6.0200
23	Titanium Ores	pt. 6.0200
24	Antimony Ores	pt. 6.0200
25	Platinum Group Metals	pt. 6.0200
26	Other Metallic Minerals (Ores)	pt. 6.0200
27	Coal Mining	7.0000
28	Crude Petroleum, Natural Gas Extraction	8.0000
29	Dimension Stone	pt. 9.0000
30	Crushed and Broken Stone	pt. 9.0000
31	Sand and Gravel	pt. 9.0000
32	Bentonite	pt. 9.0000
33	Fire Clay	pt. 9.0000
34	Fullers Earth	pt. 9.0000
35	Kaolin and Ball Clay	pt. 9.0000
36	Feldspar	pt. 9.0000
37	Other Clay, Ceramic, Refractory Minerals	pt. 9.0000
38	Nonmetallic Minerals Services	pt. 9.0000
39	Gypsum	pt. 9.0000
40	Talc, Soapstone, and Pyrophyllite	pt. 9.0000
41	Mica	pt. 9.0000
42	Asbestos	pt. 9.0000
43	Other Nonmetallic Minerals	pt. 9.0000
44	Barite	pt. 10.0000
45	Fluorspar	pt. 10.0000
46	Potash, Soda, and Borate Minerals	pt. 10.0000
47	Phosphate Rock	pt. 10.0000
48	Rock Salt	pt. 10.0000
49	Sulfur	pt. 10.0000

Table 1. Sectors in the Minerals Input-Output Table

	Input-Output Sector	BEA Sectors
50	Chemical, Fertilizer Mining, N.E.C.	pt. 10.0000
51	New Construction	11.0101-11.0508
52	Maintenance and Repair Construction	12.0100-12.0216
53	Ordnance and Accesories	13.0000
54	Food and Kindred Products	14.0000
55	Tobacco Manufactures	15.0000
56	Broad+Narrow Fabric, Yarn+Thread Mills	16.0000
57	Misc Textile Goods and Floor Coverings	17.0000
58	Apparel	18.0000
59	Misc Fabricated Textile Products	19.0000
60	Lumber, Wood Products Except Containers	20.0000
61	Wooden Containers	21.0000
62	Household Furniture	22.0000
63	Other Furniture and Fixtures	23.0000
64	Paper and Allied Products	24.0000
65	Paperboard Containers and Boxes	25.0000
66	Printing and Publishing	26.0000
67	Chemicals and Selcted Chemical Products	27.0000
68	Plastics and Synthetic Materials	28.0000
69	Drugs, Cleaning, Toilet Preparations	29.0000
70	Paints and Allied Products	30.0000
71	Petroleum Refining and Related Products	31.0000
72	Rubber and Misc Plastics Products	32.0000
73	Leather Tanning and Leather Products	33.0000
74	Footwear and Other Leather Products	34.0000
75	Glass and Glass Products	35.0000
76	Cement, Hydraulic	36.0100
77	Brick and Structural Clay Tile	36.0200
78	Ceramic Wall and Floor Tile	36.0300
79	Clay Refractories	36.0400
80	Structural Clay Products, N.E.C.	36.0500
81	Vitreous Plumbing Fixtures	36.0600
82	Vitreous China Food Utensils	36.0701
83	Fine Earthenware Food Utensils	36.0702
84	Porcelain Electrical Supplies	36.0800
85	Pottery Products, N.E.C.	36.0900
86	Concrete Block and Brick	36.1000
87	Concrete Products, N.E.C.	36.1100
88	Ready-Mixed Concrete	36.1200
89	Lime	36.1300
90	Gypsum Products	36.1400
91	Cut Stone and Stone Products	36.1500
92	Abrasive Products	36.1600
93	Asbestos Products	36.1700
94	Gaskets, Packing and Sealing Devices	36.1800
95	Minerals, Ground or Treated	36.1900
96	Mineral Wool	36.2000
97	Nonclay Refractories	36.2100
98	Nonmetallic Mineral Products, N.E.C.	36.2200

Table 1. Sectors in the Minerals Input-Output Table

	Input-Output Sector	BEA Sectors
99	Blast Furnaces and Steel Mills	37.0101
100	Electrometallurgical Products	37.0102
101	Steel Wire and Related Products	37.0103
102	Cold Finishing of Steel Shapes	37.0104
103	Steel Pipe and Tubes	37.0105
104	Iron and Steel Foundries	37.0200
105	Iron and Steel Forgings	37.0300
106	Metal Heat Treating	37.0401
107	Primary Metal Products, N.E.C.	37.0402
108	Primary Copper	38.0100
109	Primary Lead	38.0200
110	Primary Zinc	38.0300
111	Primary Aluminum	38.0400
112	Primary Nonferrous Metals, N.E.C.	38.0500
113	Secondary Nonferrous Metals	38.0600
114	Copper Rolling and Drawing	38.0700
115	Aluminum Rolling and Drawing	38.0800
116	Nonferrous Rolling and Drawing, N.E.C.	38.0900
117	Nonferrous Wire Drawing and Insulating	38.1000
118	Aluminum Castings	38.1100
119	Brass, Bronze, and Copper Castings	38.1200
120	Nonferrous Castings, N.E.C.	38.1300
121	Nonferrous Forgings	38.1400
122	Metal Containers	39.0000
123	Metal Sanitary Ware	40.0100
124	Plumbing Fixture Fittings and Trim	40.0200
125	Heating Equipment, Except Electric	40.0300
126	Fabricated Structural Metal	40.0400
127	Metal Doors, Sash, and Trim	40.0500
128	Fabricated Plate Work (Boiler Shops)	40.0600
129	Sheet Metal Work	40.0700
130	Architectural Metal Work	40.0800
131	Prefabricated Metal Buildings	40.0901
132	Miscellaneous Metal Work	40.0902
133	Screw Machine Products, Stampings, Etc.	41.0000
134	Other Fabricated Metal Products	42.0000
135	Engines and Turbines	43.0000
136	Farm Machinery	44.0000
137	Construction, Mining, Oil Field Equipment	45.0000
138	Materials Handling Machine and Equipment	46.0000
139	Metalworking Machinery and Equipment	47.0000
140	Special Industry Machine and Equipment	48.0000
141	General Industry Machine and Equipment	49.0000
142	Machine Shop Products	50.0000
143	Office, Computing and Accounting Machines	51.0000
144	Service Industry Machines	52.0000
145	Electric Transmission and Distribution	53.0000
146	Household Appliances	54.0000
147	Electric Lighting and Wiring	55.0000

Table 1. Sectors in the Minerals Input-Output Table

Input-Output Sector	BEA Sectors
148 Radio, TV, Communication Equipment	56.0000
149 Electronic Components, Accessories	57.0000
150 Misc Elec Machine, Equipment, Supplies	58.0000
151 Motor Vehicles and Equipment	59.0000
152 Aircraft and Parts	60.0000
153 Other Transportation Equipment	61.0000
154 Professional, Scientific and Control Inst	62.0000
155 Optical, Opthalmic, Photo Equipment	63.0000
156 Miscellaneous Manufacturing	64.0000
157 Transportation and Warehousing	65.0000
158 Communication, Except Radio and TV	66.0000
159 Radio and Tv Broadcasting	67.0000
160 Electric, Gas, Water, Sanitary Service	68.0000
161 Wholesale and Retail Trade	69.0000
162 Finance and Insurance	70.0000
163 Real Estate and Rental	71.0000
164 Hotels and Lodging, Personal, Repair Serv	72.0000
165 Business Services	73.0000
166 Eating and Drinking Places	74.0000
167 Automobile Repairs and Service	75.0000
168 Amusements	76.0000
169 Medical, Educational, Social Services	77.0000
170 Federal Government Enterprises	78.0000
171 State and Local Enterprises	79.0000
172 Noncomparable Imports	80.0000
173 Comparable Imports	
174 Scrap, Used and Second Hand Goods	81.0000
175 Government Industry	82.0000
176 Rest Of The World Industry	83.0000
177 Household Industry	84.0000
178 Inventory Valuation Adjustment	85.0000
179 Total Intermediate Inputs	
180 Value Added	
181 Total Industry Output	

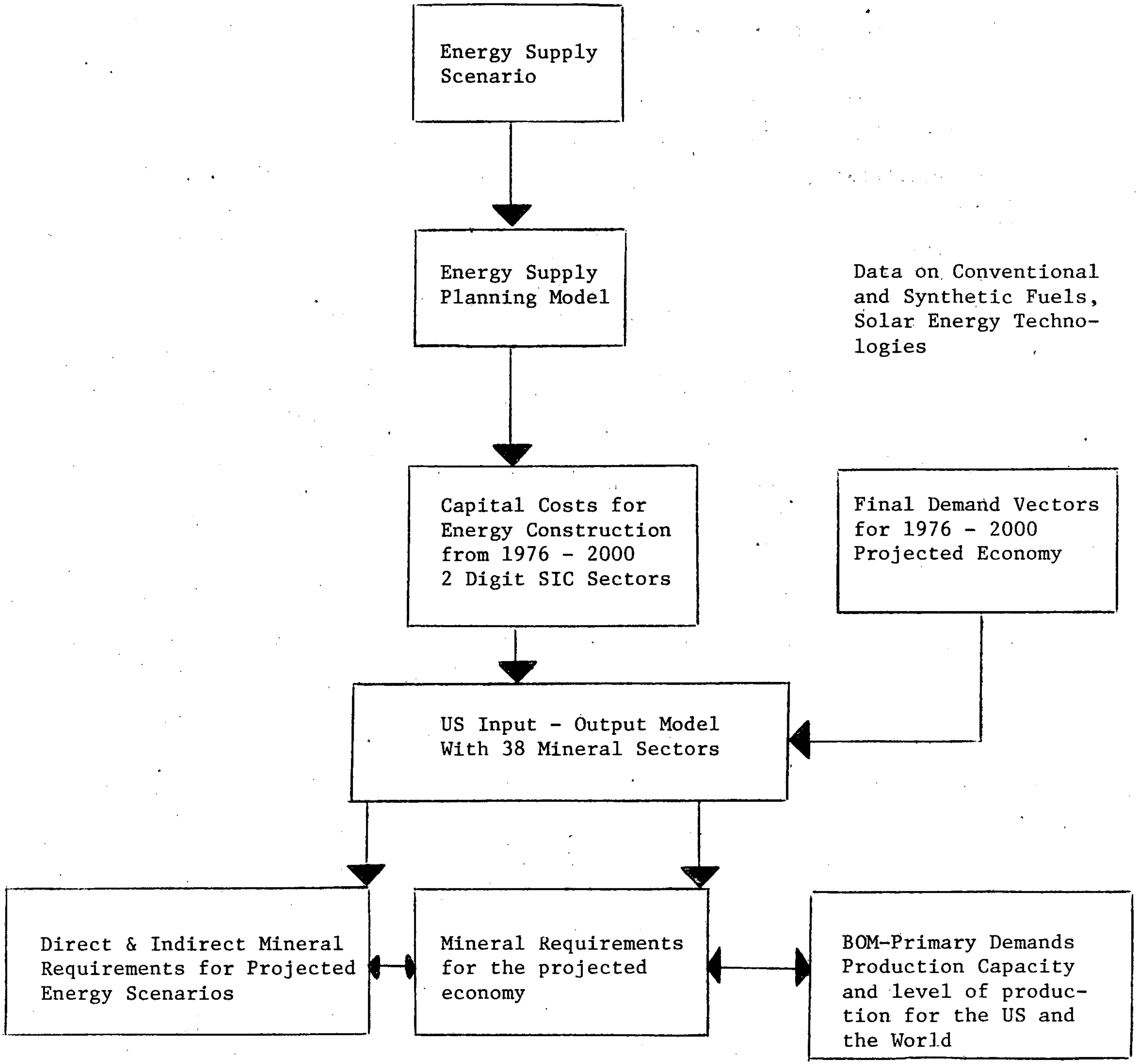
Since the results from our analysis were limited to the energy-related demand for non fuel minerals, the Department of the Interior's Bureau of Mines was requested to provide projections of total U.S. and world primary demand, mine production capacity, and level of production for each mineral evaluated. The Bureau's projections were based on both statistical and contingency analyses.

METHODOLOGY

The high and low scenarios provide the basic data for the chain of models--an Energy Supply Model and a U.S. Input-Output Model (see Figure 1). The scenarios specify the amount of energy supplied by oil, gas, coal, nuclear, solar, wind, ocean, and biomass sources, disaggregated to give geographic and technological detail (see Tables 2 and 3).

The Energy Supply Model (ESPM) [1] translates this data into the number of energy facilities of each type which have to be constructed to meet the specified levels of energy supply. The 122 types of facilities in the model include coal mines, oil wells, various types of power plants, solar and wind generators, etc. The ESPM also includes algorithms for determining the number of transportation facilities required to move coal, oil, gas and other fuels. The number of trains, pipelines, trucks, etc., are estimated on the basis of projected energy supply and demand by origin and destination for each federal region of the country.

The capital and labor needed to construct and operate each type of facility are subdivided into 140 categories. On the basis of these data, the direct capital costs and labor required to meet the prescribed energy supply scenario are computed. The 1978 ESPM data base was modified to include data on solar and other renewable technologies. The detail for the 20 solar and renewable technologies was constructed at the four-digit SIC level as part of the solar characterizations [2].



XBL 8111-1583

Figure 1- Minerals Assessment Methodology

TABLE 2. PRIMARY ENERGY SUPPLY - LOW SOLAR SCENARIO
[Trillion Btus]

Aggregated Subsector	1975	1985	1990	2000
Electric Utilities	6179.7	9432.1	12777.2	21018.8
Nuclear	1774.2	6114.9	9236.5	15966.3
Solar	0.0	2.6	54.9	800.3
Geothermal	41.8	196.8	329.2	532.0
Hydroelectric	2708.0	3078.4	3105.0	3630.6
Biomass	22.9	39.4	51.6	89.6
Industrial Solar Energy	1632.8	2054.8	2508.6	3754.8
Solar	0.0	81.0	307.6	1033.3
Biomass - Process Heat	1622.5	1927.4	2115.8	2503.5
Biomass - Gas	10.2	45.9	85.6	218.6
Coal Mining	15140.8	22406.4	28517.1	46296.6
Underground	7153.8	10616.2	13519.8	21004.9
Strip	7986.8	11790.2	14997.3	25291.8
Domestic Oil	20372.1	22156.8	22973.5	24335.3
Onshore	17148.0	15471.4	14858.9	13829.1
Offshore	2796.1	2865.1	3498.4	3023.1
Alaska	428.0	3820.2	4111.5	4789.2
Shale Oil	0.0	0.0	504.9	2693.9
Imported Oil	12655.9	17702.4	15344.6	7987.6
Crude	8160.2	16044.6	13091.8	5597.2
Refined	4495.5	1657.6	2252.5	2390.2
Domestic Gas	18452.5	17986.2	17879.5	17856.4
Onshore	14261.4	13600.8	13144.0	13832.4
Offshore	4074.7	3496.7	3094.9	2407.2
Alaska	116.4	888.7	1640.7	1616.7
Residential/Commercial Solar	99.8	306.0	549.8	1353.9
Active Heating	0.0	82.1	161.4	416.2
Active Heating and Cooling	0.0	25.7	44.6	141.7
Passive	0.0	7.0	41.8	200.0
Hot Water	0.0	59.3	136.6	340.6
Wind	0.0	0.2	10.0	53.5
Photovoltaic	0.0	0.0	3.8	33.7
Wood Stoves	99.8	131.7	151.6	200.2
Total Primary Energy Supply	72900.8	92044.7	100550.3	122635.4
Total Primary Energy Consumption	67326.6	86872.5	95343.1	117834.1

Note: Primary energy consumption does not include coal exports and synthetic fuel losses.

TABLE 3. PRIMARY ENERGY SUPPLY - HIGH SOLAR SCENARIO
[Trillion Btus]

Aggregated Subsector	1975	1985	1990	2000
Electric Utilities	4546.9	9353.2	12631.2	21482.0
Nuclear	1774.2	6012.4	8927.9	14081.3
Solar	0.0	5.9	174.2	2959.6
Geothermal	41.8	198.0	330.6	535.8
Hydroelectric	2708.0	3077.2	3104.0	3653.8
Biomass	22.9	59.7	94.5	251.5
Industrial Solar Energy	1633.1	2584.2	3753.9	7253.8
Solar	0.0	161.9	615.2	2066.1
Biomass - Process Heat	1622.9	2364.3	2960.4	3932.8
Biomass - Gas	10.2	58.4	178.5	1255.2
Coal Mining	15140.8	22075.6	27621.3	42420.6
Underground	7135.8	10459.7	13095.3	19246.5
Strip	7986.8	11616.3	14526.2	23174.4
Domestic Oil	20372.1	22150.2	22897.5	24162.3
Onshore	17148.0	15467.7	14805.7	13718.2
Offshore	2796.1	2864.5	3486.5	2999.0
Alaska	423.0	3819.0	4097.6	4750.9
Shale Oil	0.0	0.0	504.9	2694.0
Imported Oil	12655.9	17697.4	15292.7	7925.2
Crude	8160.2	16039.9	13047.6	5552.7
Refined	4495.5	1657.3	2245.0	2373.0
Domestic Gas	18452.5	17806.1	17485.9	16848.3
Onshore	14261.4	13464.7	12854.7	13051.4
Offshore	4074.7	3461.7	3026.6	2271.4
Alaska	116.4	879.8	1604.5	1525.5
Residential/Commercial Solar	99.8	566.6	1250.0	3770.3
Active Heating	0.0	189.1	373.3	959.3
Active Heating and Cooling	0.0	59.5	104.1	330.8
Passive	0.0	35.5	210.1	1000.7
Hot Water	0.0	123.0	284.2	709.7
Wind	0.0	4.6	80.0	418.2
Photovoltaic	0.0	0.0	5.3	51.7
Wood Stoves	99.8	154.9	193.0	299.9
Total Primary Energy Supply	72901.1	92233.3	100932.5	123862.5
Total Primary Energy Consumption	67326.6	86916.7	95499.9	117862.4

Note: Primary energy consumption does not include coal exports and synthetic fuel losses.

The capital costs include expenditures on manpower, equipment, and materials. The equipment and materials costs are presented by two-digit I-O sectors. These capital expenditures are treated as final demand vectors in the I-O model. Two final demand vectors are created to match the I-O table sectors, one representing expenditures on materials and equipment, and the other expenditures on construction manpower. The output of each industry over the next twenty years required to meet these demands is calculated by the model.

The U.S. Input-Output Model was derived from the 496-sector national table for 1972 prepared by the Bureau of Economic Analysis. The disaggregation of the minerals from 7 to 46 sectors was based on data from the Bureau of Mines and Bureau of Economic Analysis worksheets for 1972. This table was aggregated to 178 sectors keeping the detail in the mineral producing and using sectors (see Table 1).

The industrial outputs from the input-output table in dollar units were converted to physical quantities of minerals. These outputs are the direct and indirect demand for each mineral required for construction of energy facilities called for in the scenario.

RESULTS AND CONCLUSIONS

The methodology provided detailed demand for 46 nonfuel mineral sectors in five year intervals to the year 2000 for the two scenarios. Twenty of these mineral sectors were excluded from detailed analysis because: (1) The United States is a net exporter with adequate reserves and resources, (2) there are readily available geographically dispersed and virtually inexhaustible world resources, (3) the mineral sector included two or more minerals or (4) the sector was not applicable to any given mineral (see Table 4).

Domestic energy-related and total U.S. and world primary demand, together with U.S. and world mine production capacity, were projected in 5-year periods to the year 2000. Percent of U.S. and world demand and capacity were calculated for both the alternative and conventional energy technologies under each scenario. The primary demand for the 26 minerals was also projected in 5-year periods to the year 2000 for each group of technologies--coal, oil, gas, solar and other renewables, nuclear, and synfuels. A similar analysis was conducted substituting a different technological design for the solar heating and cooling of building facilities.

Mineral Demand

Our analysis indicated that implementation of either of the national energy scenarios to replace or supplement conventional oil, natural gas, and coal with energy sources that are either renewable or available on a scale sufficient for centuries would require large increases in the supply and availability of certain nonfuel minerals.

Energy related demand for the 26 minerals is shown in Table 5. Demand for minerals is highest in the high solar scenario primarily due to the large component of solar and other renewable energy technologies.

Tables 6 and 7 exhibit the percentage of mineral demanded by each group of energy facilities. The 122 types of energy and transportation facilities were combined into eight groups or industries for convenient presentation. Solar facilities dominate the mineral requirements in each scenario. The lowest mineral demand for solar facilities occurs in the low solar scenario. Among the minerals required for other industrial groups, vanadium use in the coal industry, copper in electric power transmission, and asbestos in the nuclear industry account for over 20 percent of the total energy related demand for the respective mineral.

The oil industry is expected to be a major consumer of minerals, second only to the solar industry. Thirty percent of the barite will be used for drilling muds. Fluorspar, iron ore, manganese and molybdenum use exceeds 20 percent of their total demand. These minerals are not directly used in large quantities in the oil industry, but their indirect demand is large because they are used in iron and steel products used by the oil industry. Coal, gas, nuclear and energy transportation account for roughly 10 percent of the demand for each of these four minerals.

Table 4. Mineral sectors excluded from projection.

Reason for Exclusion	Mineral Sector
Net exporter, adequate reserves and resources	Construction sand and gravel gravel Industrial sand Bentonite Fire clay Fuller's earth Kaolin and ball clay Other clay, ceramic, and refractory minerals except feldspar Phosphate rock Talc, soapstone, and pyrophyllite
Inexhaustible world resources	Dimension stone Limestone Granite Other stone (marble, sandstone, etc.) Rock salt
Could not be disaggregated	Potash, soda, and borate minerals Other chemical and fertilizer minerals (lithium, strontium, etc.) Ferroalloys, including cobalt, except chromium, columbium, manganese, molybdenum, nickel, tantalum, tungsten, and vanadium Other metalic minerals including beryllium, ilmenite, rare earths, rutile, thorium, tin, and zirconium Other nonmetallic minerals including corundum, industrial diamonds, gem and precious stones, graphite, mica, and pumice
Not applicable to any given mineral	Metal mining services Nonmetallic minerals services

Table 5. Mineral Requirements for High and Low Solar Scenarios (1976-2000).

Mineral	Low Solar	High Solar
Aluminum ores (10^3 st)	26569	35186
Antimony (10^3 st)	206	293
Asbestos (10^3 mt)	3336	3972
Barite (10^3 st)	6434	8520
Chromium (10^3 st)	9859	13043
Columbium (10^6 lbs)	123	177
Copper (10^3 mt)	4566	5734
Feldspar (10^3 st)	2776	4274
Fluorspar (10^3 st)	6657	7900
Gold (10^3 ounces)	25521	39018
Gypsum (10^6 st)	116	246
Iron (10^6 st)	425	472
Lead (10^3 mt)	3010	5223
Manganese (10^3 st)	26388	30010
Mercury (761b flasks)	119565	201280
Molybdenum (10^3 lbs)	104510	119140
Nickel (10^3 st)	1606	2139
Platinum group (10^3 ounces)	3385	5173
Silver ore (10^6 ounces)	594	906
Sulfur (10^3 mt)	7924	10973
Tantalum (19^3 lbs)	49283	70625
Titanium (19^3 st)	1990	2971
Tungsten (10^3 lbs)	76577	87709
Vanadium oxide (10^5 lbs)	164	167
Zinc (10^3 mt)	3056	4785

Note:

st: short tons.

mt: metric tons.

lbs: pounds.

Table 6

Schedule of Demand for Nonfuel Minerals by Energy Technology Group Under the Low Solar Scenario (1976-2000)

Mineral	Technology Group						Electric power transmission	Energy transmission	Total
	Coal	Oil	Gas	Solar	Nuclear	Synfuels			
	%	%	%	%	%	%	%	%	%
Aluminum ores	12	13	5	29	13	9	13	6	100
Antimony	8	22	8	36	7	4	10	5	100
Asbestos	16	12	4	24	21	8	9	6	100
Barite	3	39	20	25	4	5	2	2	100
Chromium	8	25	11	29	8	9	4	6	100
Cobalt	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
Columbium	10	16	7	38	9	6	7	7	100
Copper	12	11	5	20	13	7	26	6	100
Feldspar	2	25	12	44	3	12	1	1	100
Fluorspar	12	25	12	19	10	7	5	10	100
Gold	9	13	6	45	8	5	8	6	100
Gypsum	3	28	14	43	5	3	2	2	100
Iron ore	13	26	13	14	11	8	4	11	100
Lead	10	16	7	35	10	6	9	7	100
Manganese	13	26	12	16	11	7	5	10	100
Mercury	8	19	7	38	8	4	10	6	100
Molybdenum	13	25	12	16	11	8	5	10	100
Nickel	11	20	9	30	10	6	6	8	100
Platinum Group	9	13	6	46	8	5	7	6	100
Silver	9	13	6	43	9	5	9	6	100
Sulfur	9	21	8	32	8	5	11	6	100
Tantalum	10	17	8	36	9	6	7	7	100
Titanium	8	17	7	41	7	4	9	7	100
Tungsten	12	20	9	16	13	17	5	8	100
Vanadium	29	11	3	14	23	17	1	2	100
Zinc	12	14	6	29	12	7	13	7	100
Cumulative Average	10	20	9	30	10	7	8	6	100

Table 7

Schedule of Demand for Nonfuel Minerals by Energy Technology Group Under the High Solar Scenario (1976-2000)

Mineral	Technology Group						Electric power transmission	Energy transmission	Total
	Coal	Oil	Gas	Solar	Nuclear	Synfuels			
	%	%	%	%	%	%	%	%	%
Aluminum ores	7	10	4	52	7	7	9	4	100
Antimony	5	15	6	57	4	3	7	3	100
Asbestos	11	10	4	43	14	7	7	4	100
Barite	2	29	14	47	2	4	1	1	100
Chromium	5	19	8	50	4	7	3	4	100
Cobalt	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
Columbium	5	11	5	62	5	4	4	4	100
Copper	8	9	4	43	7	5	20	4	100
Feldspar	1	16	7	64	2	8	1	1	100
Fluorspar	8	21	10	38	6	6	4	7	100
Gold	5	9	4	67	4	3	5	3	100
Gypsum	1	13	6	75	2	1	1	1	100
Iron ore	9	24	11	30	7	7	3	9	100
Lead	5	9	4	65	4	4	5	4	100
Manganese	9	23	10	33	7	6	4	8	100
Mercury	4	11	4	66	3	3	6	3	100
Molybdenum	9	22	10	33	7	7	4	8	100
Nickel	7	15	7	52	5	5	4	5	100
Platinum group	5	9	4	67	4	3	5	3	100
Silver	5	8	4	68	4	3	5	3	100
Sulfur	5	15	6	56	4	3	7	4	100
Tantalum	6	11	5	61	5	4	4	4	100
Titanium	4	11	4	64	4	3	6	4	100
Tungsten	8	18	8	34	7	15	4	6	100
Vanadium	22	10	3	28	17	17	1	2	100
Zinc	6	9	4	60	5	4	8	4	100
Cumulative Average	10	20	9	30	10	7	8	6	100

The two scenarios evaluated required an average of between 17 percent and 23 percent of total projected U.S. demand for the 26 minerals to the year 2000 (Table 8). However, the percentage of each mineral varied sharply from a low of 3 percent for molybdenum to a high of 75 percent for tantalum.

Demand for the 26 nonfuel minerals by the conventional oil, gas, and coal technologies remained relatively constant between the two energy scenarios averaging between 8 percent and 9 percent of total projected U.S. demand. However, demand by the alternative solar, synfuel, and nuclear technologies varied from 8 percent to 15 percent depending primarily on the amount of energy in the scenario provided by the solar and other renewable technologies.

Average demand under the energy technology scenarios comprised between 5 percent and 7 percent of total projected world demand for the 26 minerals to the year 2000. Again, the amount of energy in the scenario provided by the solar and other renewable technologies was the primary driver for any increase in average demand.

Mineral Supply-Demand Comparison

Different technological designs can reduce dependence on critical and strategic minerals. For example, a substitute design for the solar heating and cooling of buildings having the same life expectancy reduced the amount of chromium required for the solar group by over 50 percent.

The consensus among most of the scientific community supported by current geologic, economic, and demographic evidence is that physical or "crustal" exhaustion of world mineral resources is not likely to be a problem through the remainder of this century. Also, world reserves of most minerals, defined as that portion of resources which are located in identified deposits and can be economically extracted given current technology and mineral prices, are also expected to be adequate. Our analysis resulted in similar findings, despite the increased demand generated by the alternative energy technologies.

Table 8

Schedule of Demand by the Conventional and Alternative Energy Technologies as a Percent Of Total U.S. and World demand (1976-2000)

Mineral	Percentage of U.S. Demand						Percentage of World Demand					
	Conventional[1]		Alternative[2]		Total		Conventional[1]		Alternative[2]		Total	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Aluminum ores	5	5	10	6	15	11	2	2	3	2	5	4
Antimony	12	12	22	14	34	26	4	4	7	4	11	8
Asbestos	8	8	14	11	22	19	1	1	1	1	2	2
Barite	5	5	5	3	10	8	2	2	2	1	4	3
Chromium	19	20	30	22	49	42	4	4	6	4	10	8
Columbium	13	15	30	15	43	30	4	4	10	4	14	8
Copper	4	4	5	3	9	7	1	1	1	1	2	2
Feldspar	4	4	11	6	15	10	1	1	3	1	4	2
Fluorspar	8	8	8	5	16	13	2	2	2	1	4	3
Gold	7	8	22	10	29	18	1	1	2	1	3	2
Gypsum	6	8	26	8	32	16	2	2	9	2	11	4
Iron ore	10	10	8	5	18	15	2	1	1	1	3	2
Lead	5	6	15	5	20	11	1	1	4	1	5	2
Manganese	30	31	25	17	55	48	4	4	4	2	8	6
Mercury	4	4	11	5	15	9	1	1	3	1	4	2
Molybdenum	3	2	2	1	5	3	1	1	1	0	2	1
Nickel	10	10	16	8	26	18	3	3	4	2	7	5
Platinum group	2	2	7	3	9	5	1	1	2	1	3	2
Silver	5	5	14	6	19	11	2	2	6	2	8	4
Sulfur	3	4	5	2	8	5	0	0	1	0	1	0
Tantalum	23	32	52	31	75	63	18	22	40	21	58	43
Titanium	4	4	10	6	14	10	1	1	3	2	4	3
Tungsten	5	5	6	4	11	9	1	1	2	1	3	2
Vanadium	9	9	15	12	24	21	3	2	4	3	7	5
Zinc	4	4	9	4	13	8	1	1	2	1	3	2
Cumulative Average	8	9	15	8	23	17	3	2	5	2	7	5

The Bureau of Mines' estimates of reserves and resources for the minerals included in our analysis have been historically very conservative. Increases over the 20-year period 1960 to 1980 ranging between 200 percent and 300 percent were not uncommon for the minerals we analyzed due to discoveries of major new deposits technological advances in recovery processing permitting inclusion of lower grade ores, and an upward movement in prices.

Of the 26 minerals analyzed, copper, feldspar, iron ore, lead, molybdenum, and sulfur presented no long-range supply problems in the form of either U.S. or world mineral exhaustion. Demand for these minerals is less than projected U.S. reserves. Demand for gypsum and titanium will exceed projected U.S. reserves by 30 and 17 percent respectively. Judging from historical errors of 200 to 300 percent in projected reserves, the excess demand for gypsum and titanium is no cause for concern.

Further, of the remaining minerals for which the U.S. has no or inadequate reserves or resources, world reserves and resources appear adequate (see Table 9). Energy related demand for aluminum, antimony, chromium, cobalt, fluorspar, manganese, nickel, and the platinum group metals exceeds projected U.S. mine capacity of the next 25 year period. Total demand for all minerals except feldspar, molybdenum, and sulfur exceeds U.S. mine capacity over the same period (see Table 10). This indicates that there is potential for domestic expansion of the U.S. industry for 23 minerals provided these minerals can be extracted at worldwide competetive prices.

Table 9

Schedule of Highest Energy-Related and Total U.S. Demand as a Percent of U.S. and World Reserves and Resources and Highest World demand as a Percent of World Reserves and Resources (1976-2000)a

Mineral	Highest energy-related demand				Highest total U.S. demand				Highest total world demand	
	% of reserves		% of resources		% of reserves		%of resources		% reserves	% of resources
	U.S.	World	U.S.	World	U.S.	World	U.S.	World	World	World
Aluminum ores	381	<1	51	<1	2487	4	332	2	14	6
Antimony	244	6	209	5	733	17	628	16	49	46
Asbestos	99	3	40	<1	452	13	181	7	137	79
Barite	27	7	8	<1	265	68	85	4	167	10
Chromium	c	1	502	<1	c	2	1028	<1	11	1
Cobalt	b	b	b	b	c	12	37	5	32	14
Columbium	c	2	22	<1	c	5	52	1	14	3
Copper	6	1	2	<1	67	12	16	3	60	13
Feldspar	2	<1	<1	<1	14	<1	3	<1	b	b
Fluorspar	49	2	4	<1	297	12	25	6	47	22
Gold	87	4	16	4	300	14	56	13	147	132
Gypsum	42	12	<1	<1	130	38	<1	<1	111	b
Iron ore	4	<1	<1	<1	23	2	4	<1	10	3
Lead	12	4	<1	<1	61	19	<1	<1	81	<1
Manganese	c	2	41	<1	c	4	75	2	25	12
Mercury	57	4	25	1	378	29	165	8	118	32
Molybdenum	1	<1	<1	<1	24	13	14	11	44	37
Nickel	594	3	14	<1	2345	14	55	4	51	14
Platinum group	517	<1	2	<1	5629	5	19	2	16	6
Silver	60	11	16	4	315	59	83	19	149	49
Sulfur	6	1	3	<1	87	15	46	2	88	13
Tantalum	c	49	2354	13	c	65	3125	17	86	22
Titanium	16	1	3	<1	117	7	20	3	23	9
Tungsten	32	<1	9	<1	297	14	81	5	58	22
Vanadium	74	<1	8	<1	307	2	35	1	7	2
Zinc	32	3	7	2	238	22	55	12	120	66

a Demand by the alternative synfuel, nuclear, solar, and other renewable technologies was added to Bureau of Mines total projected demand. Since demand by these alternative technologies varied between energy scenarios, the highest demand was used for analytical purposes.

b Analyzed separately.

c The U.S. has no known reserves.

Table 10. Schedule of maximum U.S. total and energy-related demand as a percent of projected U.S. mine capacity (1976-2000)[a]

	Total U.S. Demand		Energy-Related Demand	
Mineral	For any 5-year period to 2000	For entire 25-year senario	For any 5-year period to 2000	For entire 25-year senario
Aluminum Ores	3,3000	1,881	446	289
Antimony	790	617	277	205
Asbestos	504	449	111	99
Barite	167	141	21	14
Chromium	(b)	(b)	(b)	(b)
Cobalt	1,823	542	(c)	(c)
Copper	117	111	12	11
Feldspar	104	98	19	15
Fluorspar	1,107	813	178	135
Gold	1,107	813	178	135
Gypsum	218	180	98	58
Iron Ore	135	124	25	22
Lead	157	143	42	30
Maganese	(b)	6,276	(b)	3,429
Mercury	(b)	205	(b)	31
Molybdenum	45	45	2	2
Nickel	1,052	578	238	147
Platinum Group	10,000	9,963	1,503	916
Silver	312	283	77	54
Sulfur	94	87	10	6
Tantalum	(b)	(b)	(b)	(b)
Titanium	244	221	42	31
Tungsten	516	349	49	37
Vanadium	128	110	30	26
Zinc	232	228	40	30

a Demand by the alternative sysfuel, nuclear, and solar and other renewable technologies was added to Bureau of Mines total projected demand. Since demand by these alternative technologies varied in each of the four energy scenarios, the highest demand was used for analytical purposes.

b The U.S. has no mine capacity.

c Not available.

The availability of each mineral is a function of both U.S. and world mine capacity and reserves. As compared to world mine capacity the energy related U.S. demand is a small fraction for every mineral except tantalum, gypsum, columbium, chromium, antimony, and silver. The total U.S. demand for 18 minerals is well over 20 percent of world production capacity. The demand for tantalum accounts for 95 percent of peak mine capacity. Demand for eight of the 26 minerals exceeds 30 percent of world production capacity (see Table 11).

The peak demand for these minerals occurs during different 5-year time periods. World wide demand projected by the Bureau of Mines peaks during the 1976-1985 period for all the minerals except for aluminum, columbium, molybdenum, nickel, and tantalum. Demand for these minerals peaks during the 1996-2000 period. Often the peak demand in the U.S. occurs during a time period different than the period during which the world demand reaches a peak. Chromium is one such mineral; U.S. demand peaks during 1996-2000 period while world demand peaks during 1976-1985 period. The difference in peaks would help smooth market fluctuation and also deter formation of cartels or sudden price increases in such commodities.

While world supplies appeared adequate to meet U.S. energy-related demand, the uncertain availability of some minerals pose potential constraints to a smooth transition from major dependence on oil and natural gas to alternative sources of energy. This uncertainty stems primarily from the possibility that there might be either a serious disruption in supplies or a sharp increase in prices of certain minerals. Either could delay implementing a national energy program. In this sense, "strategic" refers to the relative availability of a mineral, while "critical" refers to its essentiality for energy-related uses.

Based on our analysis of energy-related demand for minerals presented above and additional research at the General Accounting Office, we have identified nine minerals which may be "energy-critical" and "strategic" (see Table 12).

Table 11. Schedule of maximum U.S. energy-related demand and total demand as a percent of projected world mine capacity (1976-2000)[a]

Mineral	Highest Energy Related Demand as Percentage of World Capacity		Highest Total U.S. Demand as Percentage of World Capacity		5-year period during which demand peaks	
	For any 5-year period to 2000	For entire 25-year scenario	For any 5-year period to 2000	For entire 25-year period	U.S. Demand Peak Period	World Demand Peak Period
Aluminum ores	4	3	29	23	1996-2000	1996-2000
Antimony	11	8	31	25	1996-2000	1976-1985
Asbestos	2	2	9	10	1976-1985	1976-1985
Barite	5	4	40	37	1976-1985	1976-1985
Chromium	12	10	23	22	1996-2000	1976-1985
Cobalt	-	-	-	-		
Columbium	18	13	35	31	1996-2000	1996-2000
Copper	2	2	20	18	1976-1985	1976-1985
Feldspar	4	3	22	21	1976-1985	1976-1985
Flourspar	4	4	25	23	1976-1985	1976-1985
Gold	5	4	14	12	1996-2000	1976-1985
Gypsum	19	11	42	32	1996-2000	1976-1985
Iron ore	3	2	16	13	1976-1985	1976-1985
Lead	6	4	22	20	1976-1985	1976-1985
Manganese	9	8	13	15	1976-1985	1976-1985
Mercury	3	2	11	13	1976-1985	1976-1985
Molybdenum	1	2	23	28	1996-2000	1996-2000
Nickel	5	5	22	19	1996-2000	1996-2000
Platinum group	3	3	20	23	1976-1985	1976-1985
Silver	10	7	41	36	1976-1985	1976-1985
Sulfur	2	2	19	19	1976-1985	1976-1985
Tantalum	81	63	95	84	1996-2000	1996-2000
Titanium	4	3	23	25	1976-1985	1976-1985
Tungsten	3	2	32	23	1996-2000	1976-1985
Vanadium	5	5	21	18	1976-1985	1976-1985
Zinc	3	3	17	17	1976-1985	1976-1985

[a] Demand by the alternative synfuel, nuclear, and solar and other renewable technologies was added to Bureau of Mines total projected demand. Since demand by these alternative technologies varied between energy scenarios, the highest demand was used for analytical purposes.

\- Not available.

Table 12. -- Strategic and Critical Minerals

Mineral	U.S. import dependence	Potentially unreliable foreign source(s)	Few foreign sources	Inadequate domestic mine capacity	Energy intensified U.S. vulnerability	Energy essential
Aluminum Ores	x		x	x		x
Chromium	x	x	x	x	x	x
Cobalt	x	x	x	x		x
Columbium	x	x	x	x	x	x
Gold	x		x	x	x	x
Manganese	x	x	x	x	x	x
Nickel	x		x	x	x	x
Platinum Group	x	x	x	x		x
Tantalum	x	x	x	x	x	

REFERENCES

1. Sathaye, J., and Ruderman, H., "Materials Analysis for Energy Scenarios," LBL-12696, (April 1981).

2. U.S. Dept of Energy, Assistant Secretary for Environment, Office of Environmental Assessments, "Summary of Solar Energy Technology Characterizations," DOE/EV-0099, (September 1980).

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720