Title

TECHNOLOGY ASSESSMENT OF SOLAR ENERGY SYSTEMS: A COMPARISON OF CAPITAL AND LABOR REQUIREMENTS FOR HIGH AND LOW SOLAR DEVELOPMENT SCENARIOS

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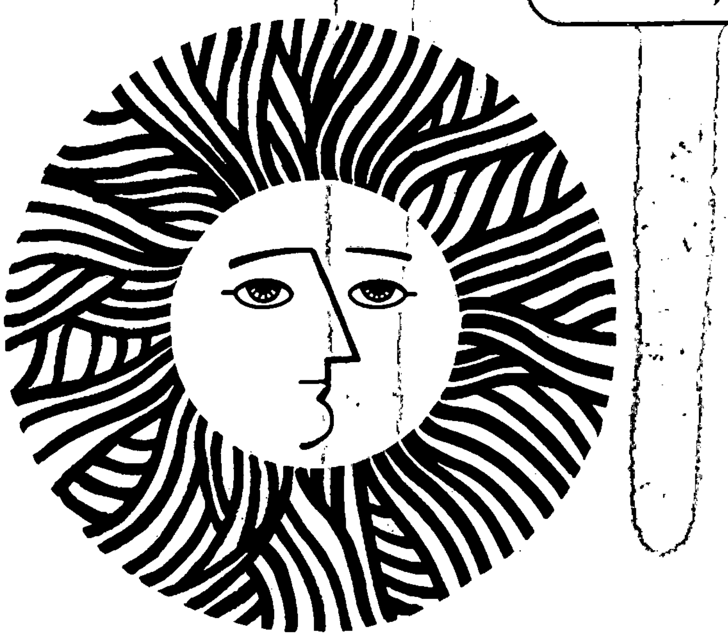

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Technology Assessment of Solar Energy Systems:

A COMPARISON OF CAPITAL AND LABOR REQUIREMENTS FOR HIGH AND LOW SOLAR DEVELOPMENT SCENARIOS

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A COMPARISON OF CAPITAL AND LABOR REQUIREMENTS FOR HIGH AND LOW SOLAR DEVELOPMENT SCENARIOS

SUMMARY

In this report the capital and labor requirements for a high solar scenario are compared with those for a low solar scenario. These requirements are estimated for the conventional and solar components of the energy scenario. Indirect labor requirements are also estimated.

Biomass and solar facilities require $7 billion and $260 billion in the low solar scenrario and $30 billion and $660 billion in the high solar scenario over the 25 year period. The overall investment in the two scenarios is $1370 billion and $1700 billion respectively. Capital investment in the high solar scenario is 24 percent or $330 billion higher than in the low solar scenario. Utility scale solar technlogies require 32 percent of the capital investment in the utility sector from 1975 to 2000 while supplying only 7 percent of the electricity in the year 2000 in the high solar scenario. During 1990-2000 the overall average figure of 32 percent increases to 60 percent. Investment in transmission and distribution facilities will decline by 5 percent as a result of the shift to more decentralized sources in the high scenario.

In the residential/commercial sector the 3 percent of solar energy in 2000 will require 28 percent or $24 billion of all energy investment in 2000 in the high solar scenario. In the industrial sector 6 percent of the energy can be suplied with 15 percent of the investment. Biomass will supply 5 percent of the energy supplied to the industrial sector but will require only 2 percent of the investment in all facilities in 2000.

Labor requirement for the solar sector are 133 percent higher in the high solar scenario. Requirements for chemical, civil, and mechnanical engineers increase while fewer petroleum, nuclear, and mining engineers are needed. Overall the increased need for construction employees should not pose a formidable problem because of the large number of workers already engaged in the construction industry.

During the last decade(1991-2000) indirect employment associated with industries supplying goods for energy construction is almost three times larger for solar facilities in the high solar scenario than in the low solar scenario. In all time periods a dollar spent on materials and equipment generates less employment than a dollar spent on labor.

More than half the construction employment will be generated in federal regions 4,5,and 6. These regions will also experience far higher investment and employment from increased solar energy supplies than other regions.

Overall the introduction of solar technologies will require a disproportionately higher level of capital investment in the solar sector except for energy generated from biomass. The high level of investment may pose a problem for the utility companies in their ability to raise capital in financial markets if the current high rates of interest persist.

INTRODUCTION

The introduction of solar, biomass and other renewable technologies into the nation's energy supply system can reduce the growth in demand for domestic fossil fuels and nuclear fuel as well as decrease our dependence on imported oil. At their current stage of development, however, most of these technologies are far more capital intensive than their conventional counterparts. Their main economic advantage is their low, or even negligible, fuel costs. Whether a specific plant will be cheaper than a conventional plant over its lifecycle will depend on its capital costs, operation and maintenance costs, and fuel costs discounted at appropriate rates. Expectations are that at some time in the future alternative technologies will be sufficiently developed that their life-cycle costs would fall below or be on a par with conventional technologies. The question then is: Will the capital costs of such technologies be prohibitively large, constraining their rapid implementation and development? Large capital outlays will be accompanied by large labor requirements. Will there be a shortage of skilled craftsmen to construct such facilities? Moreover, if alternative technologies do supply increasing amounts of energy, will conventional technologies experience lower growth or a decline in investment and employment?

In a macroeconomic sense, the introduction of alternative technologies will substitute capital costs for the fuel costs of conventional plants. Some of the money that would have gone to pay for fuel in the future can be viewed as going for capital investment today. However, the capital would have to be raised over a shorter time than fuel payments would. Whether such capital can be raised will depend on its cost and availability and on competing demands from other sectors of the economy. In this analysis, we have concentrated primarily on capital requirements and have compared the demand in the United States for capital and labor between a high solar use scenario and a low one. We have not attempted to compare solar versus conventional life-cycle costs of generating or supplying energy.

For the two energy scenarios, capital and labor requirements for constructing new energy facilities to the year 2000 were estimated and analyzed. Labor requirements were analyzed by specific skill categories. Indirect employment and income in industries supplying goods and services for energy construction activities were also estimated.

The analysis is based on a set of interconnected models we developed to evaluate national and regional economic impacts. They have previously been used in an assessment of the effects of accelerated use of coal and in an assessment of the National Energy Plan[1]. The present analysis also builds on these assessments.

Two major changes were made in our earlier methodology. The first was the expansion of our data base to include solar, wind, biomass and other renewable technologies. Capital cost data for nominal-size plants were based on technology characterizations developed by several national laboratories[2]. The labor requirements data were based on a study done for Lawrence Berkeley Laboratory (LBL) of labor skill requirements for each technology[3]. Labor data were modified to match the technology characterizations. Table 1 shows the data in an aggregated form for the solar and renewable technologies that were included in our analysis.

The second modification was updating our input-output (I-O) model and improving our method for regionalizing indirect impacts. The I-O model was originally based on the 1967 national table constructed by the Bureau of Economic Analysis[4] and was updated to 1972 at LBL. During 1980, we further updated the model to reflect 1977 prices. The model calculates national impacts for about 40 sectors of the economy. The method we used to break down the indirect impacts from the national level to the ten federal regions was modified to reflect future changes in income and output of industries. We used the interim revisions to the OBERS[5] projections of earnings by state to determine regionalization coefficients for each sector.

TABLE 1.

COST AND LABOR DATA FOR NOMINAL SOLAR FACILITIES

	Facility Name	Size	Time (yr)	ANNUAL CONSTRUCTION REQUIREMENTS Cost (Million 1978 $)	ANNUAL CONSTRUCTION REQUIREMENTS Labor (Thousands man-hours)	ANNUAL OPERATION REQUIREMENTS Cost (Million 1978 $)	ANNUAL OPERATION REQUIREMENTS Labor (Man-Years)
1.	Central Solar Receiver	(100 MWe)	3	176.865	2304.000	2.750	60.000
2.	Pyrolysis - Municipal Solid Waste	(15.3 TBtu/y)	4	281.336	5028.900	3.021	24.523
3.	IPH-medium, paper/pulp	(0.2166 TBtu/y)	1	23.370	329.570	0.295	4.627
4.	Combustion/Cogeneration-paper/pulp	(5.85 TBtu/y)	3	239.56	398.071	0.695	28.651
5.	IPH-TES	(1.0 TBtu/yr)	2	66.000	44.500	3.479	35.700
6.	Residential Photovoltaics	(165 MMBtu/yr)	1	0.054	1.081	0.002	0.042
7.	Central Wind Energy Conversion	(.05 TBtu/yr)	1	1.615	3.000	0.049	0.417
8.	Residential Wind System	(340 MMBtu/yr)	1	0.035	0.265	0.001	0.004
9.	Solar Domestic Hot Water Heating	(36 MMBtu/yr)	1	0.002	0.048	0.0	0.003
10.	Passive Solar Domestic Heating	(132 MMBtu/yr)	1	0.007	0.085	0.0	0.001
11.	Digestion of Municipal Sludge	(.52 TBtu/yr)	1	5.264	139.114	1.738	15.619
12.	Centralized Photovoltaic System	(2.48 TBtu/yr)	2	116.423	1958.400	2.811	8.429
13.	Biomass Combustion	(.167 TBtu/yr)	1	0.243	0.954	0.033	1.251
14.	Wood Stoves	(160 MMBtu/y)	1	0.001	0.010	0.001	0.0

Note: IPH is industrial process heat and TES is total energy system.

SCENARIOS

To examine the economic impacts of future energy supply, we considered the high and low solar scenarios which were specified in detail in the Department of Energy's Technology Assessment of Solar Energy program[6] (TASE). The major sources of energy are shown in Tables 2 and 3 and in Figure 1. Both scenarios call for large increases in coal and nuclear energy. The significant difference between them is the contribution of solar, biomass and other renewable energy sources to the total energy supply. The two scenarios, labeled TASE 14 and TASE 6, assume 14 and 6 quads (quadrillion Btus) of primary energy, respectively, from these unconventional sources in the year 2000. The high solar scenario is based on DOE's Domestic Policy Review[7] analysis of the maximum feasible level of energy penetration by unconventional technologies. The projected levels of other fuels to the year 2000 come from the DOE NEP-2 scenario[8]. The regional breakdown of energy supply is based on the Energy Information Administration's 1978 Series C projections[9].

In the low solar scenario, primary energy consumption increases at 1.9 percent per year from 73 quads in 1975 to 118 quads in 2000, not including coal exports and synthetic fuel conversion losses. Solar, biomass, wind, etc., excluding hydroelectric and geothermal, grow at 5.1 percent annually from 1.8 quads to 6.0 quads in 2000. Industrial use of solar energy more than doubles, and in the residential/commercial sector use increases to 1.3 quads from 0.1 quad in 1975.

In the high scenario, primary energy supply also increases at 2.1 percent per year. Solar and other renewable fuels grow at 8.6 percent annually, reaching 13.8 quads in 2000. Industrial solar energy use increases fourfold, whereas residential/commercial use increases to 3.4 quads.

The greater penetration of solar and renewable fuels in the TASE 14 scenario is primarily at the expense of coal, nuclear power and natural gas. Oil consumption and imports remain virtually unchanged. Coal mining is 3.9 quads lower, nuclear fuel is 1.9 quads lower, and gas is 1.0 quad lower than in TASE 6.

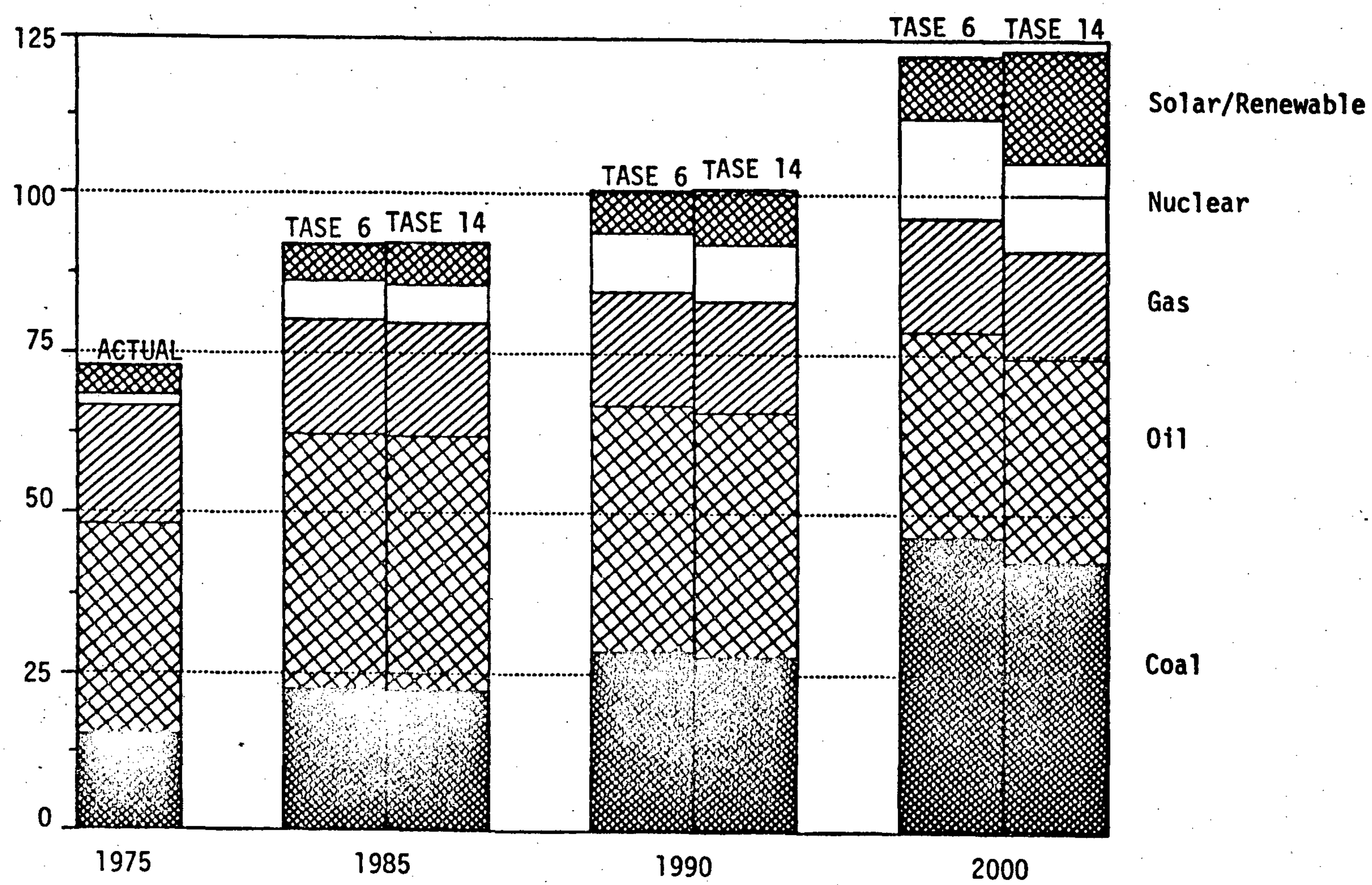


Figure 1. Primary Energy Supply 1975 - 2000 in Quadrillion BTU's.

TABLE 2. PRIMARY ENERGY SOURCES - TASE 6 SCENARIO
[Trillion Btus]

Aggregated Subsector	1975	1985	1990	2000
Electric Utilities	4,546.9	9,432.1	12,777.2	21,018.8
Nuclear	1,774.2	6,114.9	9,236.5	15,966.3
Solar	0.0	2.6	54.9	800.3
Geothermal	41.8	196.8	329.2	532.0
Hydroelectric	2,708.0	3,078.4	3,105.0	3,630.6
Biomass	22.9	39.4	51.6	89.6
Industrial Solar Energy	1,632.8	2,054.8	2,508.6	3,754.8
Solar	0.0	81.0	307.6	1,033.3
Biomass - Process Heat	1,622.5	1,927.4	2,115.8	2,503.5
Biomass - Gas	10.2	45.9	85.6	218.6
Coal Mining	15,140.8	22,406.4	28,517.1	46,296.6
Underground	7,153.8	10,616.2	13,519.8	21,004.9
Strip	7,986.8	11,790.2	14,997.3	25,291.8
Domestic Oil	20,372.1	22,156.8	22,973.5	24,335.3
Onshore	17,148.0	15,471.4	14,858.9	13,829.1
Offshore	2,796.1	2,865.1	3,498.4	3,023.1
Alaska	428.0	3,820.2	4,111.5	4,789.2
Shale Oil	0.0	0.0	504.9	2,693.9
Imported Oil	12,655.9	17,702.4	15,344.6	7,987.6
Crude	8,160.2	16,044.6	13,091.8	5,597.2
Refined	4,495.5	1,657.6	2,252.5	2,390.2
Domestic Gas	18,452.5	17,986.2	17,879.5	17,856.4
Onshore	14,261.4	13,600.8	13,144.0	13,832.4
Offshore	4,074.7	3,496.7	3,094.9	2,407.2
Alaska	116.4	888.7	1,640.7	1,616.7
Residential/Commercial Solar	99.8	305.7	541.0	1,333.2
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	72,900.8	92,044.4	100,541.8	122,582.7
Total Primary Energy Consumption	67,326.6	86,872.5	95343.1	117,834.1

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

TABLE 3. PRIMARY ENERGY SOURCES - TASE 14 SCENARIO
[Trillion Btus]

Aggregated Subsector	1975	1985	1990	2000
Electric Utilities	4,546.9	9,353.2	12,631.2	21,482.0
Nuclear	1,774.2	6,012.4	8,927.9	14,081.3
Solar	0.0	5.9	174.2	2,959.6
Geothermal	41.8	198.0	330.6	535.8
Hydroelectric	2,708.0	3,077.2	3,104.0	3,653.8
Biomass	22.9	59.7	94.5	251.5
Industrial Solar Energy	1,633.1	2,584.2	3,753.9	7,253.8
Solar	0.0	161.9	615.2	2,066.1
Biomass - Process Heat	1,622.9	2,364.3	2,960.4	3,932.8
Biomass - Gas	10.2	58.4	178.5	1,255.2
Coal Mining	15,140.8	22,075.6	27,621.3	42,420.6
Underground	7,135.8	10,459.7	13,095.3	19,246.5
Strip	7,986.8	11,616.3	14,526.2	23,174.4
Domestic Oil	20,372.1	22,150.2	22,897.5	24,162.3
Onshore	17,148.0	15,467.7	14,805.7	13,718.2
Offshore	2,796.1	2,864.5	3,486.5	2,999.0
Alaska	423.0	3,819.0	4,097.6	4,750.9
Shale Oil	0.0	0.0	504.9	2,694.0
Imported Oil	12,655.9	17,697.4	15,292.7	7,925.2
Crude	8,160.2	16,039.9	13,047.6	5,552.7
Refined	4,495.5	1,657.3	2,245.0	2,373.0
Domestic Gas	18,452.5	17,806.1	17,485.9	16,848.3
Onshore	14,261.4	13,464.7	12,854.7	13,051.4
Offshore	4,074.7	3,461.7	3,026.6	2,271.4
Alaska	116.4	879.8	1,604.5	1,525.5
Residential/Commercial Solar	99.8	561.7	1,169.9	3,351.1
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	1,000.7
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	72,901.1	92,228.4	100,852.4	123,443.3
Total Primary Energy Consumption	67,326.6	86,916.7	95,499.9	117,862.4

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

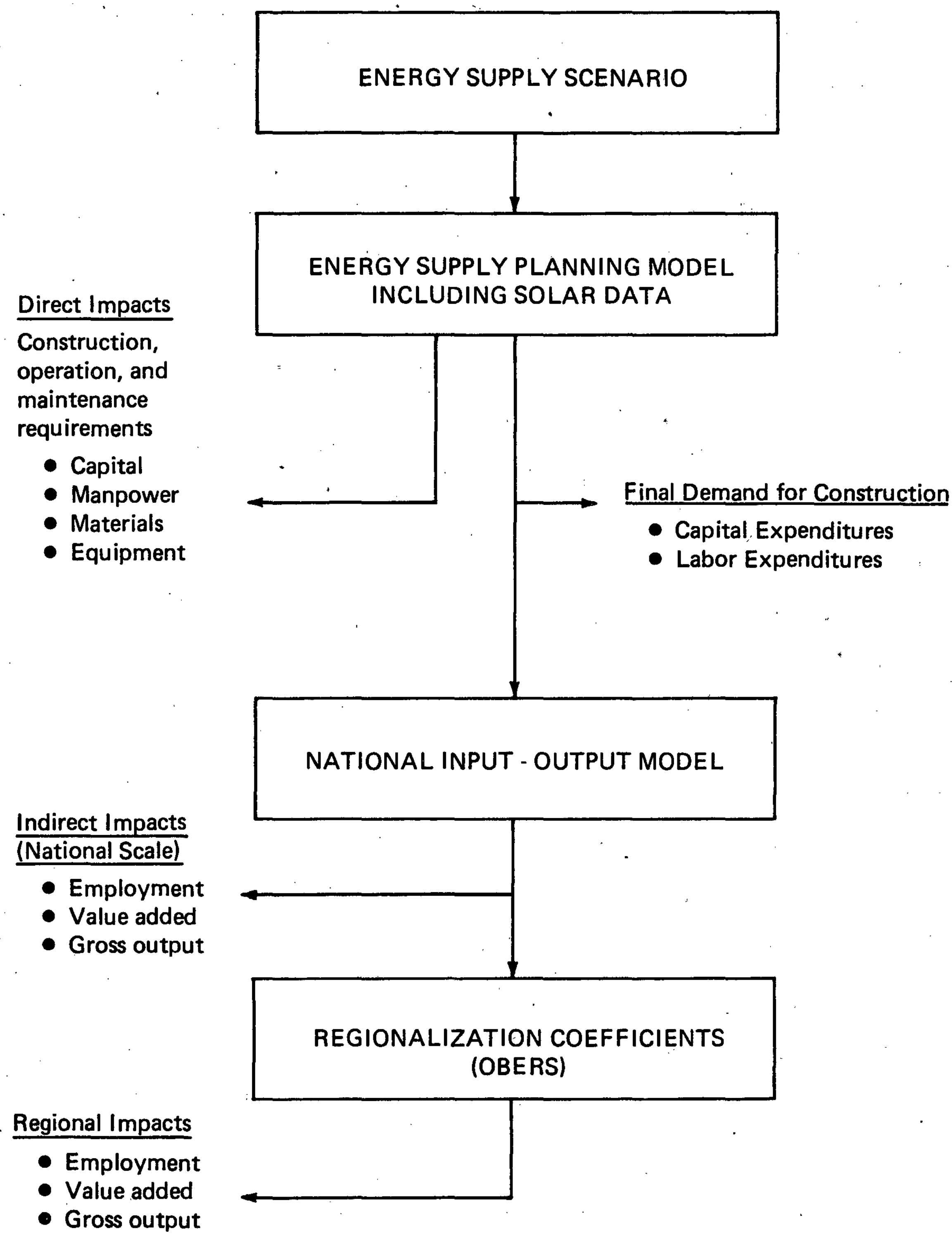
METHODOLOGY

Energy scenarios specifying the amount of primary energy available from each type of energy facility serve as the basic data for the chain of models--an energy supply planning model and a U.S. input-output model (see Figure 2). The TASE 6 and TASE 14 scenarios provide detailed specifications of the amount of energy supplied by oil, gas, coal, nuclear, solar, wind, ocean, and biomass sources.

The Energy Supply Planning Model (ESPM)[10] translates the scenarios into the number of energy facilities of each type which have to be constructed and operated to meet the specified levels of energy supply. The model's 122 types of facilities include coal mines, various types of power conventional plants, oil wells, solar and wind generators, and others. The model includes algorithms for determining the number of transportation facilities required to move coal, oil, gas, and other energy 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 detailed 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 at LBL to include data on solar and other renewable technologies. The detail for the 20 solar and renewable technologies was furnished at the four-digit SIC level by Argonne, Brookhaven, Lawrence Berkeley, Los Alamos, and Oak Ridge National Laboratories[2].

In addition to calculating construction requirements, the ESPM also calculates requirements to operate and maintain the new and existing energy facilities. The operation and maintenance (O&M) requirements include the annual manpower, materials, and costs to run each type of facility.



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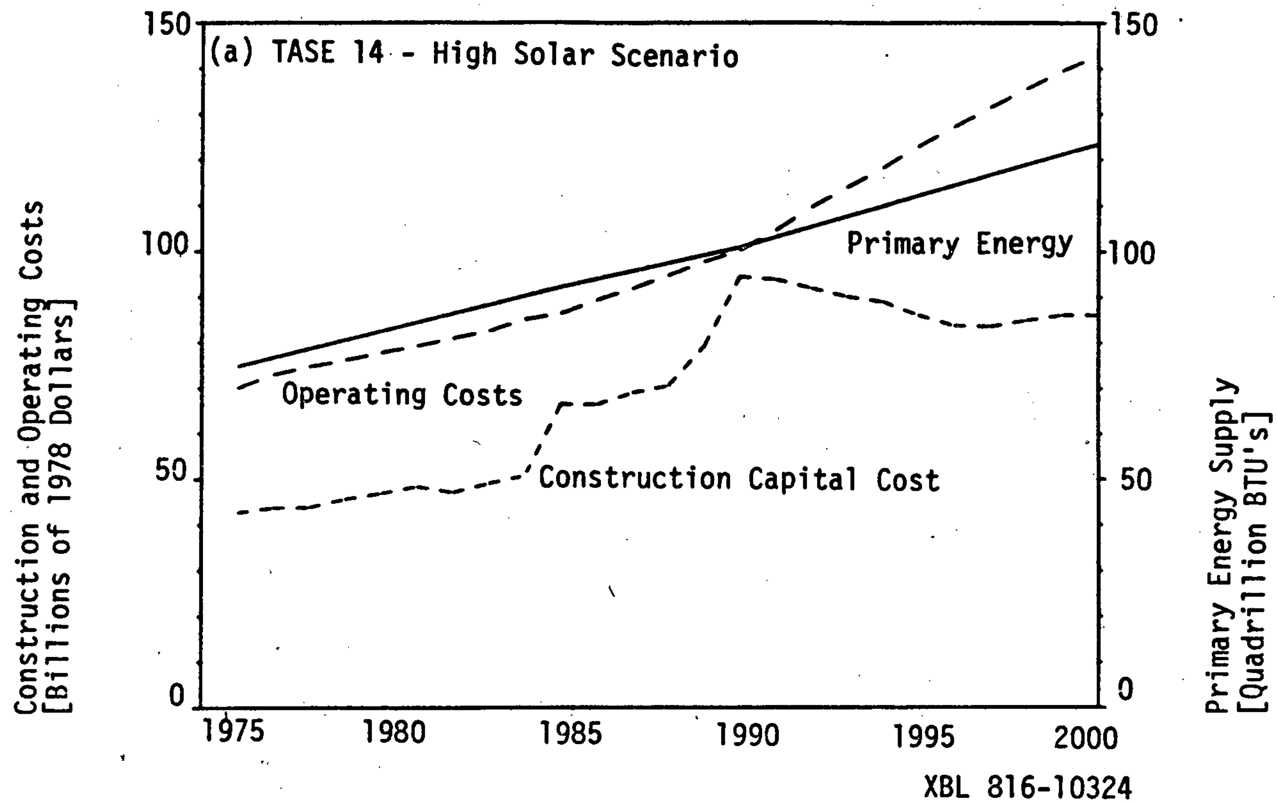
The capital costs include expenditures on manpower, equipment, and materials. The equipment and materials costs are presented by two-digit SIC I-O sectors. These capital expenditures are treated as final demand vectors in the I-O model. Fuel costs and O&M costs are not part of final demand and thus are not included in the I-O model. Two final demand vectors are created to match the I-O table sectors. The equipment and materials expenditures are disaggregated, using fractional shares in the Gross Private Domestic Capital Formation vector, and the manpower expenditures are disaggregated, using the shares in the Personal Consumption Expenditures vector. The vectors used for disaggregation are part of the I-O table. The output required from each industry to meet these demands is estimated for the next twenty years. Employment associated with the indirect output is estimated using coefficients adjusted to include future changes in labor productivity.

RESULTS

We now examine the differences between the two scenarios and attempt to relate them to differences in the amount of energy supplied by solar and biomass technologies. We concentrate on the costs of materials and equipment and the labor needed to construct and operate new and existing energy facilities. Fuel costs are not included as part of the operating costs in the modelling exercise but are analysed separately. The secondary employment generated by constructing new facilities is also discussed, and regional differences are pointed out.

Capital and operating requirements show opposite behaviors when compared to the postulated growth in energy consumption. As can be seen in Figures 3 and 4, energy use grows linearly over the 25-year period. Construction costs and manpower increase in both scenarios until the early 1990s; when they remain fairly constant in the low solar scenario, but they decline slightly in the high. In the TASE 14 scenario, construction costs nearly double between 1984 and 1990. The doubling in construction costs is due to the rapid(four fold) increase in solar energy development during this period as compared to prior ten years. Operating costs and manpower, which follow the growth in energy consumption up to about 1990, exhibit a more rapid growth during the last



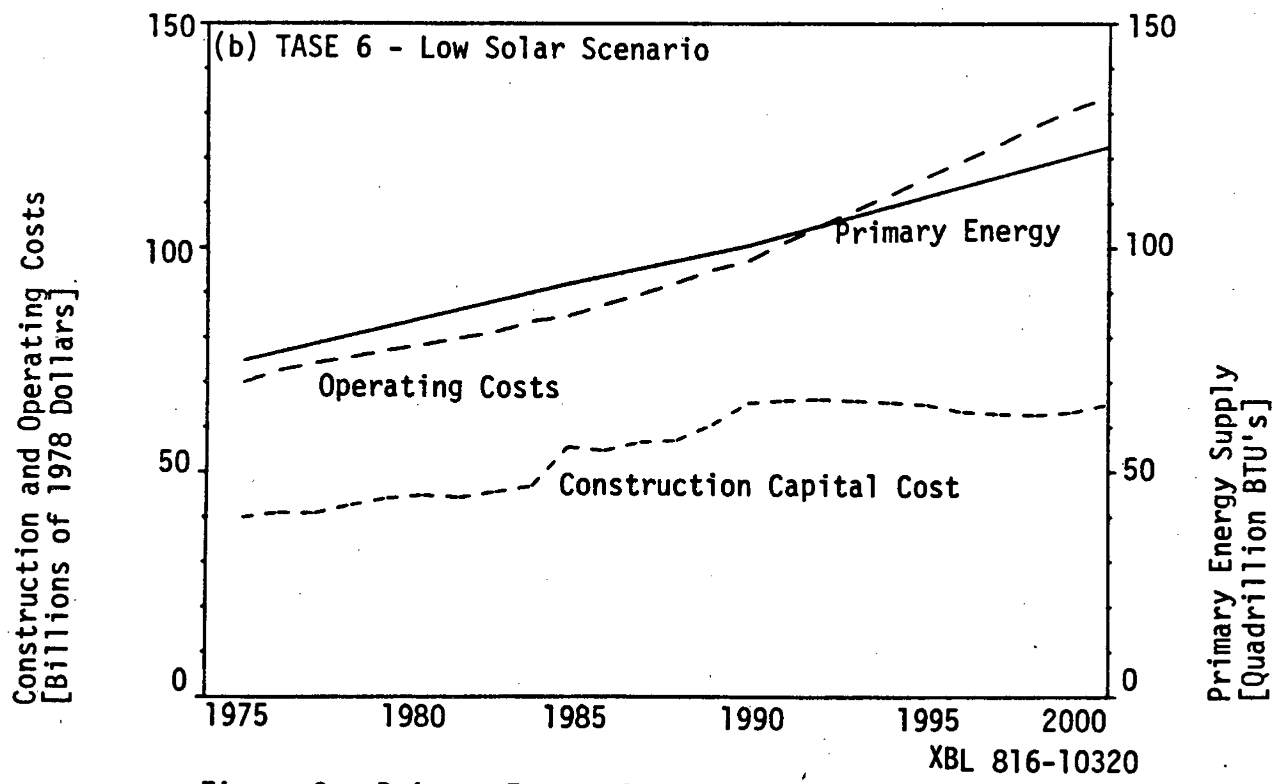
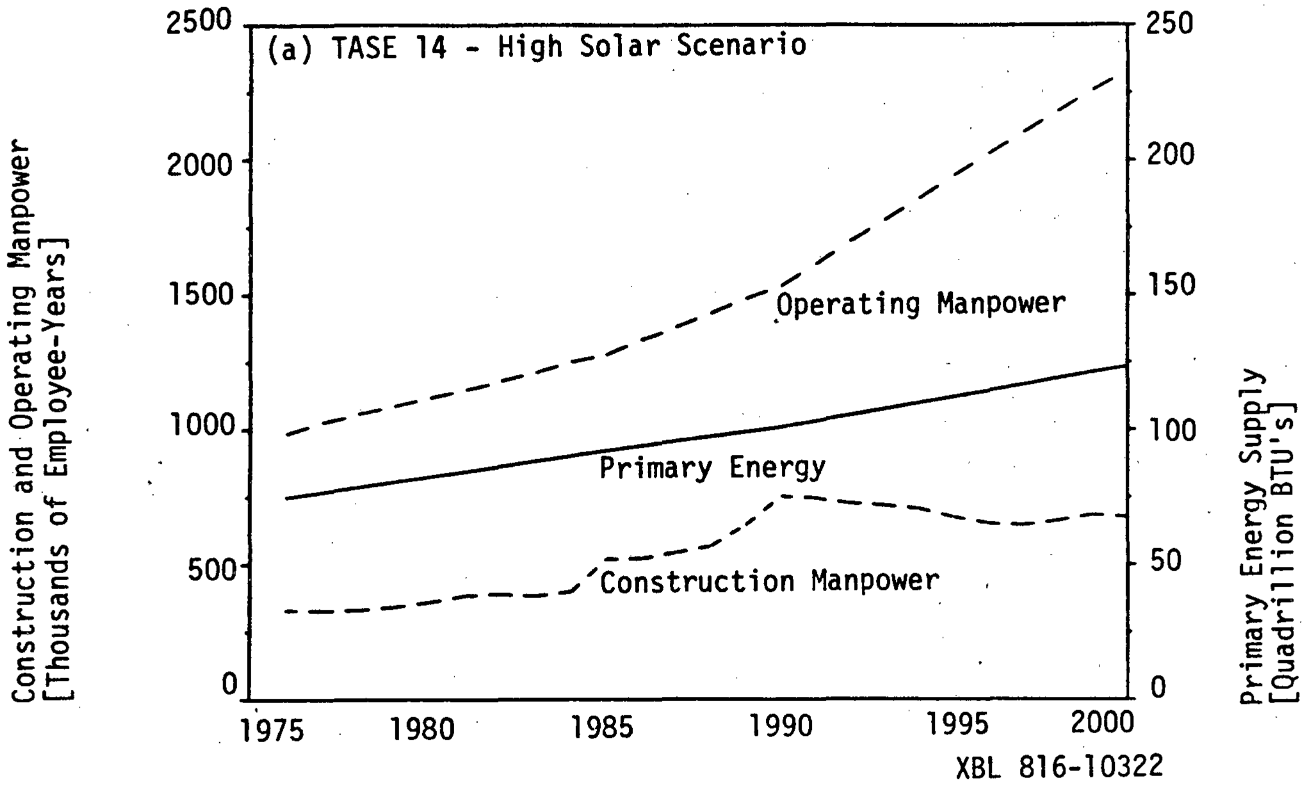


Figure 3. Primary Energy Supply and Capital and Operating Costs, 1975 - 2000 for (a) High (TASE 14) and (b) Low (TASE 6) Solar Scenarios.



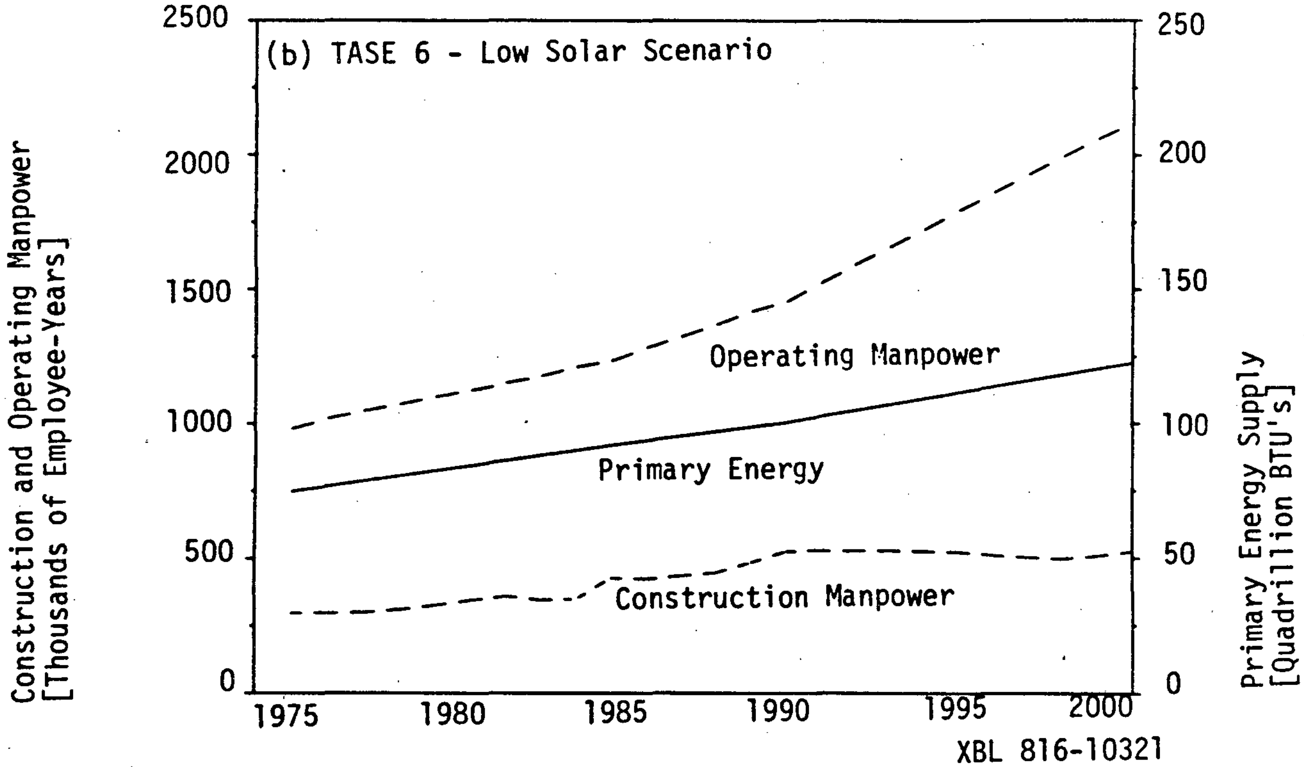


Figure 4. Primary Energy Supply and Construction and Operating Manpower, 1975 - 2000, for (a) High (TASE 14) and (b) Low (TASE 6) Solar Scenarios.

decade. This effect is stronger in TASE 14, demonstrating that it is due to increased use of solar and biomass facilities.

Capital requirements

Most solar and renewable technologies are capital and labor intensive, and will probably remain so. Market penetration by these technologies therefore will require considerably more capital investment, in proportion to the energy they supply, than conventional technologies do. Such additional investment in solar installations will be primarily at the expense of investment in new coal and nuclear facilities. Utilities will need to raise more capital in the TASE 14 scenario than in TASE 6 to finance these plants.

The low solar scenario calls for $1,370 billion of capital investment between 1975 and 2000, whereas the high solar scenario requires $1,700 billion during the same period. These totals are broken out by facility in Table 4. Investment in solar facilities ranges from $270 billion in the low scenario to $690 billion in the high, a difference of 156 percent. Investment in conventional energy sources, e.g., coal, oil, nuclear, gas, etc., is $1,100 billion in the low scenario and $1010 billion in the high. For both scenarios, investment increases with time. In the low scenario, average annual investment increases from $44 billion in the 1976-85 period to $64 billion in the last decade (see Table 5). In the high scenario, it increases from $47 billion to $86 billion over the same period (see Table 6). Investment in solar facilities increases steadily, whereas it declines in nuclear, coal and gas industries. These investment figures may be compared with a fixed nonresidential investment of $76 billion in 1978.

Investments in solar technologies account for a significantly higher share of the money invested in energy, given their expected contribution to the national energy supply. In the low scenario, solar is projected to contribute six quads, or five percent, of the national domestic energy consumption of 118 quads in the year 2000 (see Figure 1). This level of solar energy requires an investment of $18 billion per year

TABLE 4

CAPITAL INVESTMENT IN CONSTRUCTION OF ENERGY FACILITIES
Cumulative Totals 1976-2000 in Millions of 1978 Dollars

	Nominal Facility	TASE 6	TASE 14
	Coal		
1	Underground Coal Mine	18,500	16,700
2	Surface Coal Mine	18,400	16,500
3	Coal Gasification and Liquefaction	65,500	65,500
4	Coal Fired Power Plant-Low Btu	59,700	47,300
5	Coal Fired Power Plant-High Btu	45,800	3,700
6	Coal/Waste Power Plant-High Btu Coal	1,000	4,300
7	Sulfur Oxide Removal	36,200	29,200
8	Coal Train	15,700	14,100
9	Coal Slurry Pipeline	5,400	4,800
10	Other Coal Transportation Facilities	1,800	1,600
	Subtotal	268,000	229,300
	Oil		
11	Oil Recovery - Lower 48	277,700	276,100
12	North Alaskan Oil Recovery	1,900	1,900
13	Oil Refinery	22,200	21,800
14	Alaskan Oil Export	400	400
15	Onshore Oil Import	500	500
16	Underground Oil Shale Mine	3,300	3,300
17	Oil Shale Retorting And Upgrading	14,800	14,800
18	Oil-Fired Power Plant	2,400	2,700
19	Crude Oil Pipeline - Lower 48	1,800	1,800
20	Alaskan Oil Pipeline	2,000	2,000
21	Oil Tanker	3,800	3,900
22	Oil Barges	200	200
23	Oil Tank Truck	6,000	6,000
24	Product Pipeline	3,500	3,500
25	Refined Products Bulk Station	800	800
	Subtotal	341,400	339,700
	Gas		
26	Gas Recovery - Lower 48	133,000	127,600
27	North Alaska Gas Recovery	2,000	1,800
28	High Btu Gas-Fired Power Plant	100	100
29	Gas Pipeline - Lower 48	12,100	10,400
30	Gas Distribution Facilities	23,000	19,900
31	Alaskan Gas Pipeline	6,800	6,800
	Subtotal	176,900	166,600

TABLE 4

CAPITAL INVESTMENT IN CONSTRUCTION OF ENERGY FACILITIES
Cumulative Totals 1976-2000 in Millions of 1978 Dollars

	Nominal Facility	TASE 6	TASE 14
	Nuclear		
32	Uranium Mining and Enrichment	19,600	5,600
33	LWR Fuel Fabrication, Reprocessing, and Waste Disposal	3,200	3,100
34	Light Water Reactor - LWR	144,300	115,100
	Subtotal	167,100	123,800
	Solar and Biomass		
35	Solar Space Heating	82,900	183,800
36	Solar Space Conditioning	17,500	40,900
37	Central Solar Reciever	4,500	54,500
38	Pyrolysis - M.S.W.	2,400	23,100
39	Industrial Process Heat - Medium, Paper/Pulp	65,000	130,000
40	Combustion/Cogeneration - Paper/Pulp Waste	2,700	3,700
41	Industrial Process Heat - TES	22,500	45,100
42	Residential Photovoltaics	10,900	16,700
43	Central Wind Energy System	19,300	47,700
44	Residential Wind System	5,400	42,500
45	Active Solar Domestic Water Heating	17,400	36,200
46	Passive Solar Domestic Heating	10,400	52,300
47	Anaerobic Digestion Municipal Sludge	1,000	1,000
48	Centralized Photovotaic System	5,000	11,500
49	Biomass Combustion	100	1,600
50	Wood Stoves	500	1,000
	Subtotal	267,700	691,600
	Other Generation and Transportation		
51	Dam + Hydroelectric Power Plant	16,800	17,400
52	Pumped Storage	3,700	3,700
53	Geothermal Power Complex	6,300	6,300
54	Rail Line	1,200	1,200
55	Transmission Lines	32,300	31,100
56	Electric Distribution Facilities	92,600	88,100
	Subtotal	152,900	147,800
	Total	1,374,100	1,702,900

TABLE 5

AVERAGE ANNUAL EMPLOYMENT IMPACTS
Low Solar Scenario (TASE 6)

	1976-85		1986-90		1991-2000	
Capital Investment (10^9 $)	Solar	Total	Solar	Total	Solar	Total
Manpower	1.3	10.9	3.7	15.1	5.2	16.7
Materials	1.0	8.1	4.3	12.2	6.2	13.9
Equipment	0.3	11.1	1.5	14.6	3.3	16.7
Other	0.6	14.0	1.9	16.2	3.1	17.0
Total	3.2	44.1	11.4	58.1	17.8	64.3
Employment (10^3 employee-years)						
Direct Construction	37	331	110	459	156	516
Direct Operation	53	1112	101	1370	214	1825
Indirect	111	1198	336	1462	442	1405
Total	201	2641	547	3291	812	3746
Indirect Employment per Million Dollars of Capital Investment						
In Materials, Equipment and Other Costs	36.3	25.0	29.5	23.6	22.4	20.5
In Manpower	33.1	33.9	29.5	29.6	25.8	25.7
Employment per Million Dollars of Capital Investment						
Direct Construction	11.6	7.5	9.7	7.9	8.8	8.0
Indirect	38.4	35.1	33.0	31.7	27.6	27.1
Indirect/Direct	3.3	4.7	3.4	4.0	3.1	3.4

TABLE 6

AVERAGE ANNUAL EMPLOYMENT IMPACTS
High Solar Scenario (TASE 14)

	1976-85		1986-90		1991-2000	
Capital Investment (10^9 $)	Solar	Total	Solar	Total	Solar	Total
Manpower	2.8	12.2	8.8	19.7	13.2	22.6
Materials	2.3	9.2	10.1	17.6	15.3	22.0
Equipment	0.8	11.4	5.1	17.6	11.5	22.2
Other	1.2	14.4	4.7	18.5	7.7	19.6
Total	7.1	47.2	28.7	73.4	47.7	86.4
Employment (10^3 employee-years)						
Direct Construction	82	369	264	597	397	689
Direct Operation	80	1134	182	1432	437	1978
Indirect	244	1307	843	1917	1179	1954
Total	406	2810	1289	3946	2013	4621
Indirect Employment per Million Dollars of Capital Investment						
In Materials, Equipment and Other Costs	35.1	25.5	29.6	25.7	24.3	21.5
In Manpower	33.2	33.8	29.9	29.7	25.8	25.7
Employment per Million Dollars of Capital Investment						
Direct Construction	11.5	7.8	9.2	8.1	8.3	8.0
Indirect	38.6	36.3	32.7	31.8	27.4	27.1
Indirect/Direct	3.4	4.7	3.6	3.9	3.3	3.4

during the last decade, or 28 percent of capital invested in the energy sector (see Table 5). In the high scenario, solar is projected to supply 12 percent of the total energy, at the cost of up to 55 percent of the capital invested in energy (see Table 6).

These investment shifts are magnified within certain sectors. In the high scenario, for example, utility-scale solar technologies in the year 2000 provide seven percent of the electricity produced by the utility sector. But this level of production requires 32 percent of the utility industry's capital investment over the 25-year period compared to nine percent in the low. Over this period, the investment in power plants will be nine percent greater in the high scenario than in the low, although electricity generation in 2000 will be ten percent lower. A large fraction of this additional investment will occur during the last decade. Solar power plants will account for 60 percent of the total investment. Investment in other power plants amounts to only 40 percent in the high scenario as compared to 82 percent in the low scenario, although total investment in the high scenario is 16 percent greater than in low scenario during the same period. Utilities may face difficulty raising this capital if more attractive investments available. Their bond rating in the market place may also be affected, thereby making capital more expensive.

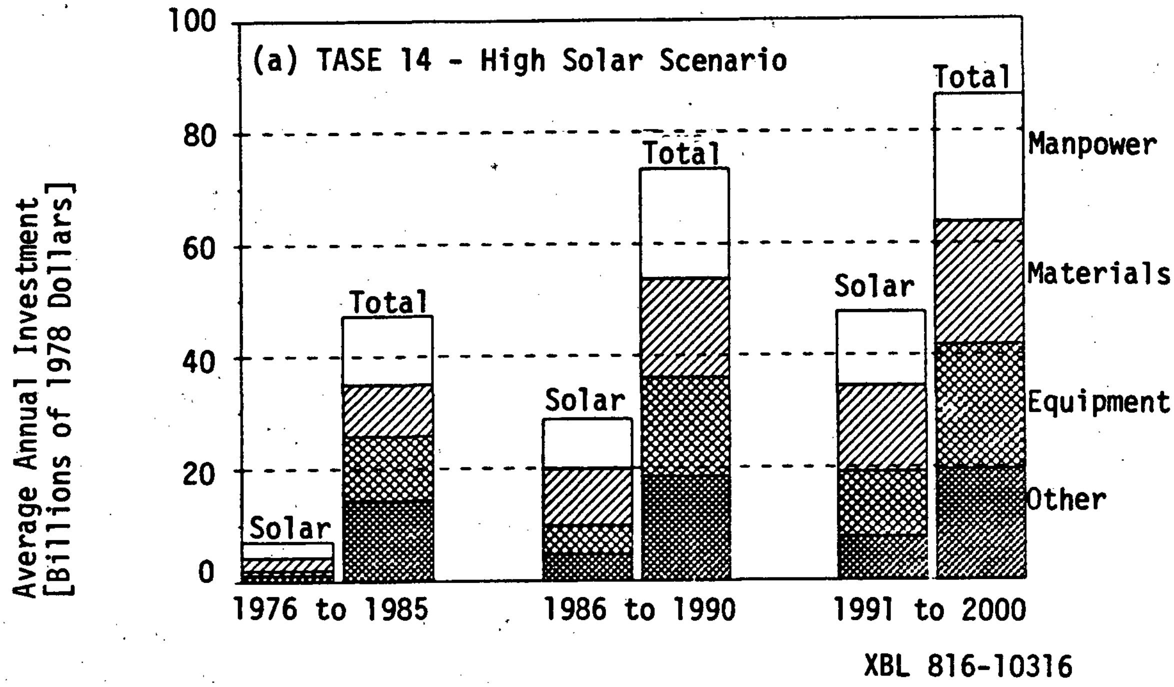
The solar technologies installed in the residential/commercial sector also require a larger proportion of investment in the high scenario. By the year 2000 in this scenario, these technologies would supply 3.4 quads, or three percent, of the total U.S. supply of energy using distributed solar heating and cooling systems, wind, photovoltaic, and wood stoves. Providing this energy would require an investment of $24 billion, or 28 percent of all energy investments in the year 2000. In the industrial sector, six percent of the energy can be supplied with only 15 percent of the investment because of the high percentage of biomass use. Biomass used by all sectors in the high scenario provides 5.7 quads or five percent of the national total, but it requires only two percent of the investment.

Manufacturing, constructing, and installing solar systems on a large scale means shifting fiscal resources away from conventional energy sources, primarily coal and nuclear (see Table 4). Comparing the two scenarios over the 25-year period, the electric utility industry would need 20 percent less investment in nuclear and coal-fired power plants in thehigh solar scenario. Expenditures for transmission and distribution facilities would be lower by five percent as a result of a shift to more decentralized systems. Investments in uranium mining and processing would decline sharply as few nuclear plants are built in the later decades of the high solar scenario. Oil extraction, coal mining, and gas extraction would require lower levels of investments on the order of one, ten, and four percent, respectively, as a result of reduced demands for fossil fuels in the high scenario.

Solar facilities show a different pattern of expenditures than conventional facilities. As can be seen in Figure 5, the manpower, materials, equipment and other expenditures for all energy facilities are nearly equal in each period. Solar facilities require relatively larger expenditures for manpower and materials. This reflects the fact that the solar technologies generally employ less sophisticated equipment.

Fuel Costs

The two energy scenarios are markedly different in their projected levels of solar penetration. Increased use of solar energy will come about mainly by substituting solar energy for nuclear and coal. Oil and gas use will be relatively unaffected. Comparing the primary energy supply in the TASE 14 and TASE 6 scenarios as shown in Tables 2 and 3, we see that in TASE 14 oil supply will be 235 trillion Btu lower and gas supply 1,008 trillion Btu lower, a difference of one and six percent, respectively. Coal supply will be 3,876 trillion Btu or eight percent lower while the use of nuclear energy to generate electricity will be 1,885 trillion Btu, or about 12 percent lower.



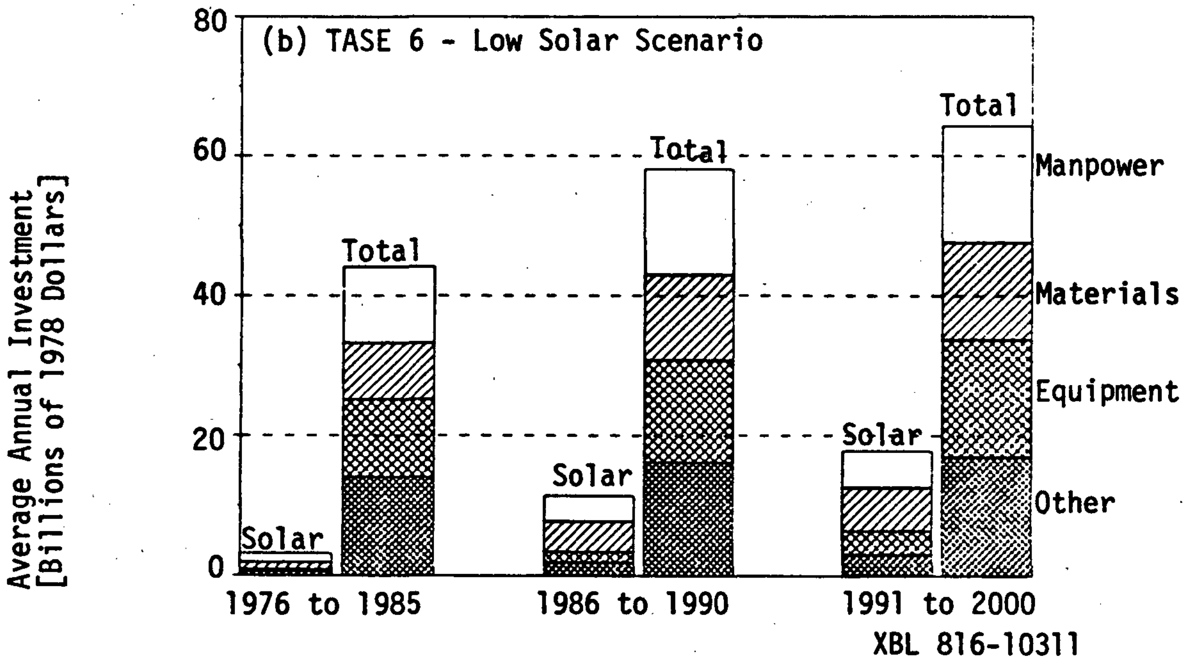


Figure 5. Comparison of average annual investment in solar and all energy facilities (a) High (TASE 14) solar scenario; (b) Low (TASE 6) solar scenario.

In the solar sector, wood and other biomass fuels will be greater in the TASE 14 than in the TASE 6 scenario. Additional wood used in stoves will amount to 100 trillion Btu. Biomass fuels for conversion to gas and for process heat will total 2,467 trillion Btu more.

In our analysis of capital and O&M costs, we do not account for fuel use explicitly. The price paid for fossil and nuclear fuels includes the production costs incurred for extraction, processing and conversion into a usable end product. We estimate these costs and include them in our analysis. For example, we compare capital costs for solar power plants with those required not only for the coal-fired power plants but also for the coal mines and the transportation facilities. Thus we take into account the costs incurred along the entire fuel chain.

There are two costs that the model does not take into account. First, we do not include costs incurred in foreign counties, e.g. the cost of extracting oil in Venezuela. In comparing the two scenarios, however, we see that there will be little or no difference in the amount of imports. Thus the costs incurred in foreign countries may be assumed the same in both scenarios.

The second exception is that fuel prices, and in particular oil prices, are dictated more by market conditions than by production costs. Our estimate of production costs will therefore underestimate the fuel costs borne by the customers. If oil costs $23.50 per barrel in the year 2000[9], the difference in costs between the two scenarios will be $920 million. Similarly, at $5 per million Btu, there will be a difference of $5 billion paid for natural gas.

From a consumer's standpoint, it would be legitimate to compare the lower natural gas costs with the costs of additional solar facilities. Additional information is needed on which solar facilities will substitute for natural gas use before such a comparison can be made. Similarly, the cost of wood would have to be included to completely account for the costs of using wood stoves. Biomass fuels can be viewed as an expense or as a source of additional income to the consumer. In some localities, scavenging companies will pay for municipal waste disposal because they will be paid by the power plant operator. A locally specific solar scenario is needed before the fuel costs of the two scenarios can be compared.

Labor Requirements

Labor requirements for both construction and operation of solar facilities will be larger in the TASE 14 scenario than in the TASE 6. The difference is most noticeable between 1991 and 2000, when the market penetration of solar systems increases dramatically. The high solar scenario will require significantly more direct on-site labor in the energy sector than will the low solar scenario. Construction, operation, and maintenance employment in conventional power plants and fuel facilities in the high scenario will be less than in the low. Employment will be higher, however, in solar electric facilities, biomass systems, solar heating and cooling, and in industrial process heat systems. Solar and renewable facilities generate relatively less indirect employment than do conventional facilities.

Construction

Construction labor requirements for the TASE 6 and TASE 14 scenarios are 10.8 million employee-years and 13.5 million employee-years, respectively (see Tables 5 and 6). Labor required for solar industries accounts for roughly 25 percent of total labor required for the TASE 6 scenario. This fraction is almost twice as large (47 percent) for the TASE 14 scenario. Labor requirements for solar industries are 133 percent greater in the high scenario than in the low. Average annual labor requirements for all facilities increase from 370,000 employee-years between 1976 and 1985 to 690,000 employee-years between 1991 and 2000, an increase of 86 percent for the TASE 14 scenario. In TASE 6, they increase from 330,000 to 520,000 employee-years, an increase of 56 percent.

Labor for constructing solar facilities increases from 82,000 to 397,000 employee-years for TASE 14 and from 37,000 to 156,000 employee-years for TASE 6. Labor requirements for conventional energy industries are substantially lower in the TASE 14 than in the TASE 6 scenario. Over the twenty-five years, 896,000 fewer employee-years are required in other industries in the TASE 14 scenario. The decrease in manpower is more than compensated by the additional 3.63 million employee-years of employment created by the solar industry.

The solar industry in the scenarios employs a mix of skilled and unskilled labor. Some of the technologies, such as solar space heating, require primarily manual labor; central solar receivers require a mix of skills generally similar to that required for conventional power plants. As a result, requirements for both skilled and unskilled labor increase substantially in TASE 14. Requirements for chemical, civil, and mechanical engineers increase, while fewer petroleum, geological, nuclear, and mining engineers are needed. Most skills, such as carpenters and pipefitters, are required in increasing numbers; the need for boilermakers and linemen, however, decreases in every period.

Employment of civil and mechanical engineers doubles in TASE 14, increasing to 16,000 employee-years annually. Requirements for chemical engineers increase fivefold from 450 to 2,400 employee-years annually. These figures may be compared with the number of engineers in nonmanufacturing private industry[11] in 1975: civil engineers, 71,000; mechanical engineers, 71,000; and chemical engineers, 14,000.

The total employment in nonresidential building construction and in public utility construction amounted to 1.65 million employee-years in 1977. The Bureau of Labor Statistics (BLS) projects an increase in this employment to 2.23 million by 1990[12]. The TASE 14 scenario calls for an increase from 370,000 to 690,000 employee-years from the first to the last ten year period, or roughly an increase from 22 percent to 31 percent of the projected BLS figures; in the TASE 6 scenario it increases from 20 percent to 24 percent. Part of the TASE 14 increase would be accounted for by solar space heating and conditioning in residential buildings. Employment in nonresidential building and public utility construction would be reduced.

Overall, the increased need for construction employees should not pose a formidable problem, because of the large number of workers already in the construction industry. Some workers with specific skills, however, will find fewer jobs available, particularly in some engineering fields.

Among the investment requirements for solar technologies, solar space heating requires by far the largest capital investment, followed by wind generation, industrial process heat - medium, and central solar receivers. Solar space heating requires $50 billion more in the TASE 14 scenario than in TASE 6.

Operation and Maintenance (O&M)

TASE 14 calls for 38.3 million employee-years from 1975 to 2000, 2.1 million more than the TASE 6 scenario. Employment in solar facilities will be more than twice as large in TASE 14 (5.4 million vs. 2.5 million). The coal industry shows 610,000 fewer employee-years over the same period. although the nuclear industry will have 400,000 fewer employee-years in construction, it will have only 67,000 fewer in operation and maintenance. Differences between the two scenarios for the gas and oil industries are minor.

Solar space heating is the largest contributor to increased employment in the solar industry, with 1.6 million more employee-years in TASE 14 than in TASE 6. The regional distribution of increased solar employment is similar to the distribution of solar industry construction employment since very few solar facilities were in place in 1976. Within the coal industry, coal mining shows the largest difference between scenarios, with 365,000 employee-years less, primarily in the Mid-Atlantic, North Central, South Atlantic, and Midwest regions. The New York/New Jersey and Pacific Northwest regions show minor gains in coal mining employment.

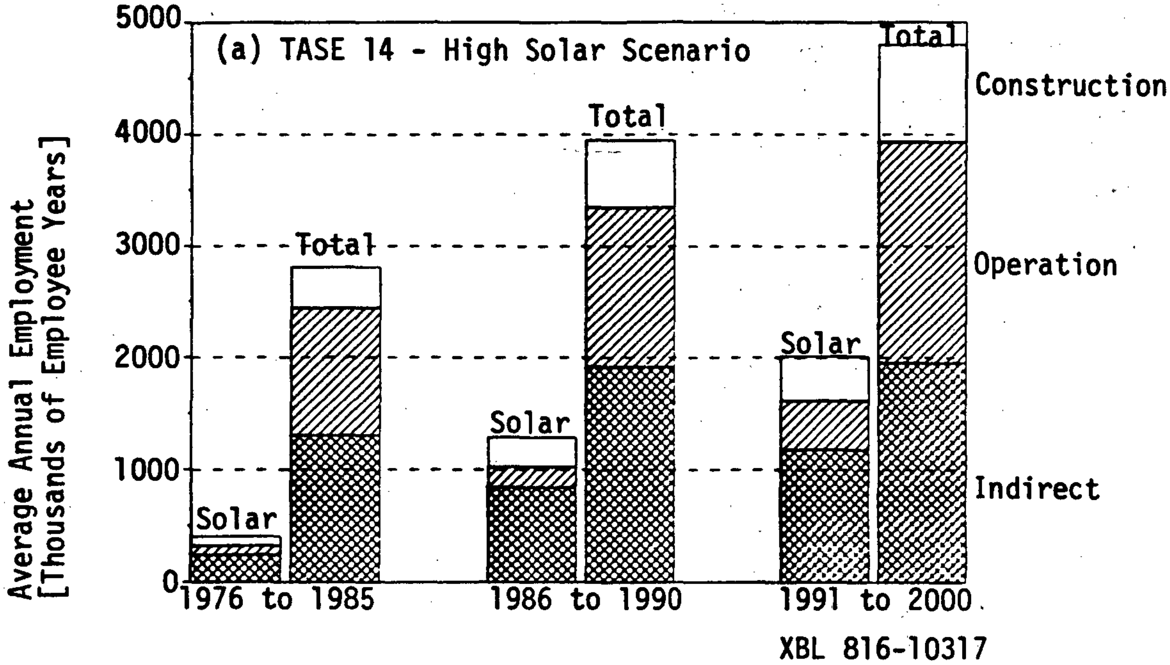
Figure 6 illustrates the difference in O&M labor requirements between solar and conventional facilities. Whereas construction and indirect employment are in the same proportion for both types of facilities, solar facilities require a much smaller proportion of O&M employment because of the simpler technologies involved.

Indirect Employment

For the decade 1991 to 2000, indirect employment associated with industries supplying goods for energy construction is almost three times larger for solar facilities in the TASE 14 scenario than in the TASE 6. In TASE 14, average annual indirect employment for the decade amounts to 1.95 million employee-years (Table 6), compared to 1.40 million employee-years in the TASE 6 scenario (Table 5).

Total annual employment in the energy sector, which includes direct and indirect construction employees, plus operation and maintenance employees, increases from 2.64 million to 3.75 million in the TASE 6 scenario, and from 2.81 million to 4.62 million in the TASE 14 scenario. The total employment in solar and associated industries increases from 200,000 employee-years to 810,000 in TASE 6, and from 410,000 to 2.01 million in TASE 14 (Tables 5 and 6).

In all time periods, a dollar spent for materials and equipment generates less indirect employment than a dollar spent on labor. Indirect employment per dollar expended amounts to three or four times the direct employment. In all cases, the solar sector has fewer associated indirect employees than the overall energy sector per dollar spent. Ratios of indirect to direct employment range from 3.1 to 3.4 for solar facilities and from 3.4 to 4.7 for all energy facilities. The ratios generally decrease with time, since average labor productivity for the economy is assumed to be higher than for energy construction activity. The ratios for solar facilities do not change significantly, indicating that labor intensity in solar construction changes in the same proportion as it does in associated industries.



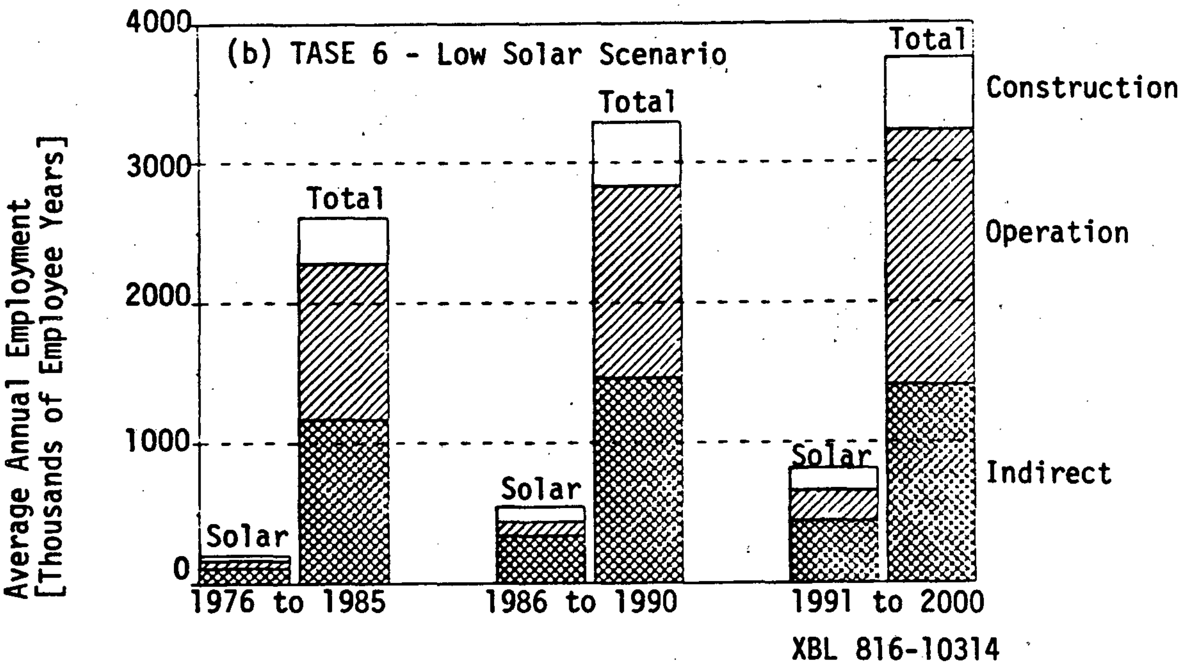


Figure 6. Comparison of average annual employment in solar and all energy facilities (a) High (TASE 14) Solar Scenario; (b) Low (TASE 6) Solar Scenario.

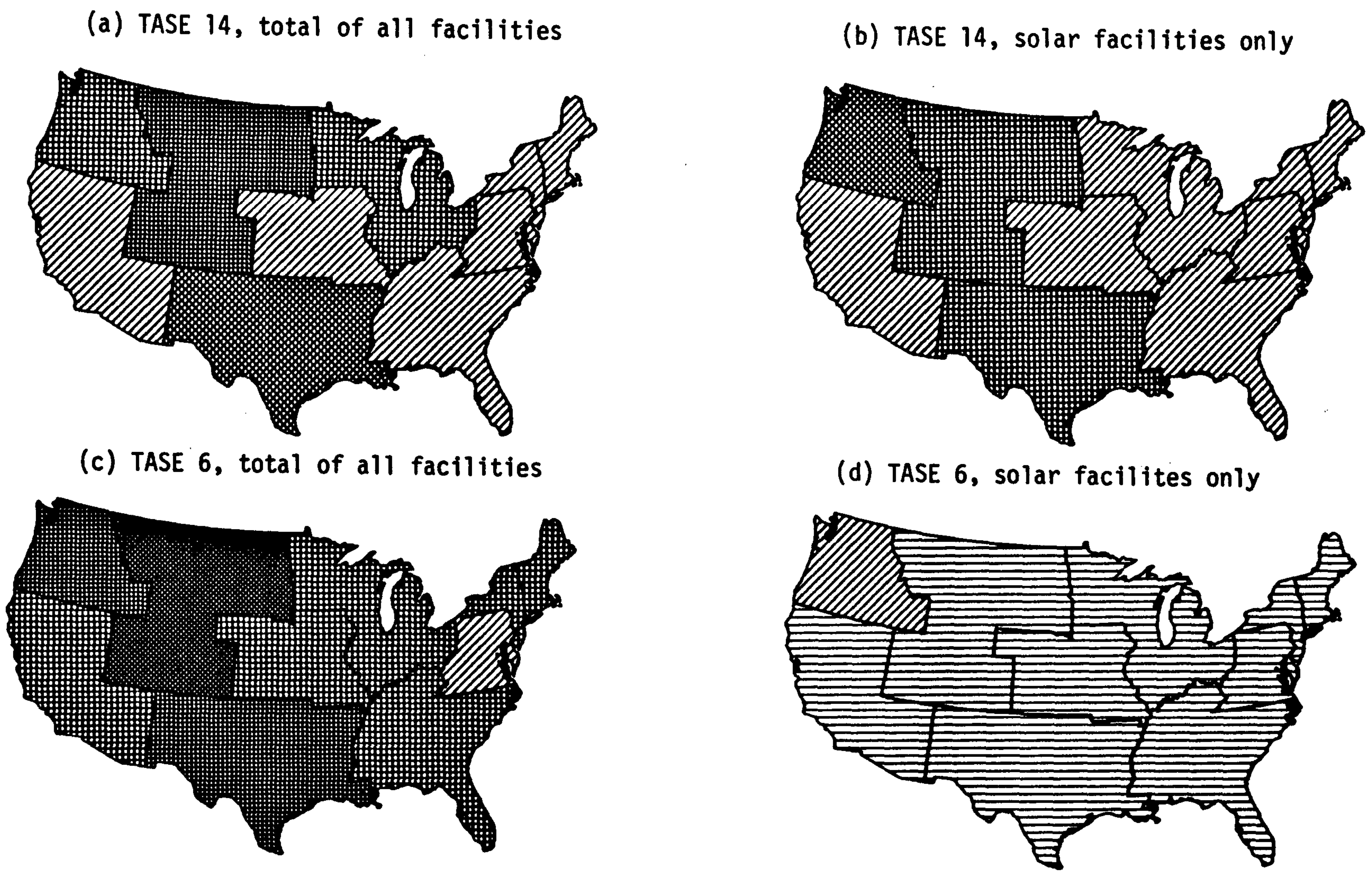
Indirect employment in manufacturing industries increases faster in TASE 14 than does overall employment. Construction of solar facilities in this scenario generally provides more stimulus to manufacturing industries than to other sectors of the economy.

These indirect impacts may not represent a net increase in employment and income for the economy as a whole. If the economy were operating at full employment, energy sectors would have to compete against other industries for employees. Only if workers with the required skill categories were unemployed would a net increase in employment be seen.

Regional Employment Impacts

Regional differences in direct construction employment over the next twenty-five years are shown in Table 7. More than half the construction employment will be generated in federal regions 4, 5, and 6. The East Coast states will account for about 20 percent of the total, and the West Coast states for about 15 percent. To show the relative growth in employment, we divided the employment figures in Table 7 by the regional construction employment in 1977[13] and plotted the results in Figure 7. The largest growth will occur in region 8, the North Central states, where current employment is small. The Northwest and Southwest regions will also show large relative growth compared to the eastern and far western states. There is not much difference in the growth pattern between scenarios.

Examining the differences in employment between the high and low solar scenarios given in Table 7, we see that the South Atlantic, Midwest, and Southwest regions (4, 5, 6) will experience far higher investment and employment from increased solar energy than other regions. Each of these three regions will gain more than 600,000 employee-years in the solar industry while losing over 55,000 employee-years in the coal industry. Regions 4 and 5 will also experience substantially less employment in the nuclear industry. Overall, from 1975 to 2000, this industry is expected to require nearly 420,000 fewer employee-years.



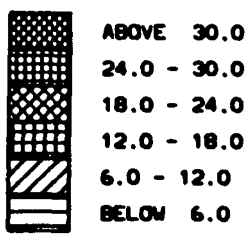


Figure 7. Relative growth in direct construction employment by federal region. The data plotted show the ratio of total employee-years required during the period 1976 - 2000 to the construction employment in the region during 1977.

TABLE 7

CONSTRUCTION MANPOWER REQUIREMENTS FOR
TASE 14 AND TASE 6 SCENARIOS, 1976-2000
[In Employee-Years]

	Federal Region											
	Northeast 1	New York-New Jersey 2	Middle Atlantic 3	South Atlantic 4	Midwest 5	Southwest 6	Central 7	North Central 8	West 9	Northwest 10	Coastal	Total
All Facilities												
TASE 14	421,553	839,927	930,072	2,249,353	2,067,361	3,274,289	587,843	957,731	1,243,802	850,374	135,553	13,557,857
TASE 6	324,847	590,297	723,204	1,776,760	1,664,514	2,795,537	442,850	794,204	904,790	612,264	136,429	10,765,693
Difference	96,706	249,630	206,868	472,593	402,847	478,752	144,993	163,527	339,012	238,110	-876	2,792,164
Percentage	29.8	42.3	28.6	26.6	24.2	17.1	32.7	20.6	37.5	38.9	-0.6	25.9
Solar Only												
TASE 14	212,394	503,717	466,864	1,090,869	1,064,287	1,066,682	241,306	306,362	674,744	486,734	0	6,113,960
TASE 6	91,180	206,967	209,445	440,086	435,123	448,661	90,779	106,309	263,778	194,367	0	2,486,694
Difference	121,214	296,750	257,419	650,783	629,164	618,021	150,527	200,053	410,966	292,367	0	3,627,266
Percentage	132.9	143.4	122.9	147.9	144.6	137.7	165.8	188.2	155.8	150.4	0	145.9
TASE 6 Solar / TASE 6 Total	.281	.351	.290	.248	.261	.160	.205	.134	.292	.317	0	.231
TASE 14 Solar / TASE 14 Total	.504	.600	.502	.485	.515	.326	.410	.320	.542	.572	0	.451
Differences												
Solar	121,215	296,752	257,420	650,782	629,167	618,024	150,528	200,054	410,968	292,367	0	3,627,265
Coal	-4,001	-2,880	-33,492	-57,202	-55,604	-59,498	-5,638	-27,591	-31,025	-2,699	0	-279,662
Oil	8	-17	-190	-268	633	-9,882	-244	-489	562	0	-640	-10,552
Gas	773	-2,743	-4,154	-10,728	-6,585	-35,642	2,334	-2,621	-7,466	-1,506	-235	-68,584
Nuclear	-19,180	-40,384	-12,338	-90,253	-160,296	-27,072	49	-1,389	-31,049	-35,802	0	-417,724
Other	-2,103	-1,088	-361	-19,704	-4,452	-7,153	-2,025	-4,429	-2,964	-14,240	0	-58,550

Differences between the two scenarios in investment and labor requirements for the solar technologies are dominated by solar space heating, industrial process heat - medium, solar space conditioning and central solar receivers. The differences in investment in solar space heating occur mainly in federal regions 5, 6, 4, 9 and 2. Investment in industrial process heat - medium is larger in regions 4, 6 and 10; central solar receivers will require more investment in regions 4, 6 and 9. Wind generators require heavier investment in TASE 14 over the TASE 6 scenario in regions 4 and 5. Solar space heating requires 1.4 million employee-years, industrial process heat - medium requires 480,000 employee-years, central solar receivers need 370,000 employee-years, and solar space conditioning requires 320,000 employee-years more labor in the TASE 14 scenario than in TASE 6. The same regions which will benefit from the heavier investment will also require increased labor. Wind generators are an exception, since these are not labor intensive. Solar space conditioning will affect primarily regions 5, 6, 4, 2 and 9.

Indirect employment also exhibits regional differences. In Figure 8 we plot the ratio of indirect to direct construction employment in each federal region. As can be seen by comparing Figures 7 and 8, the regions with the largest direct impacts have relatively small indirect impacts. In the TASE 14 scenario, the states in the industrialized Northeast and Midwest will benefit from energy construction in the rest of the country.

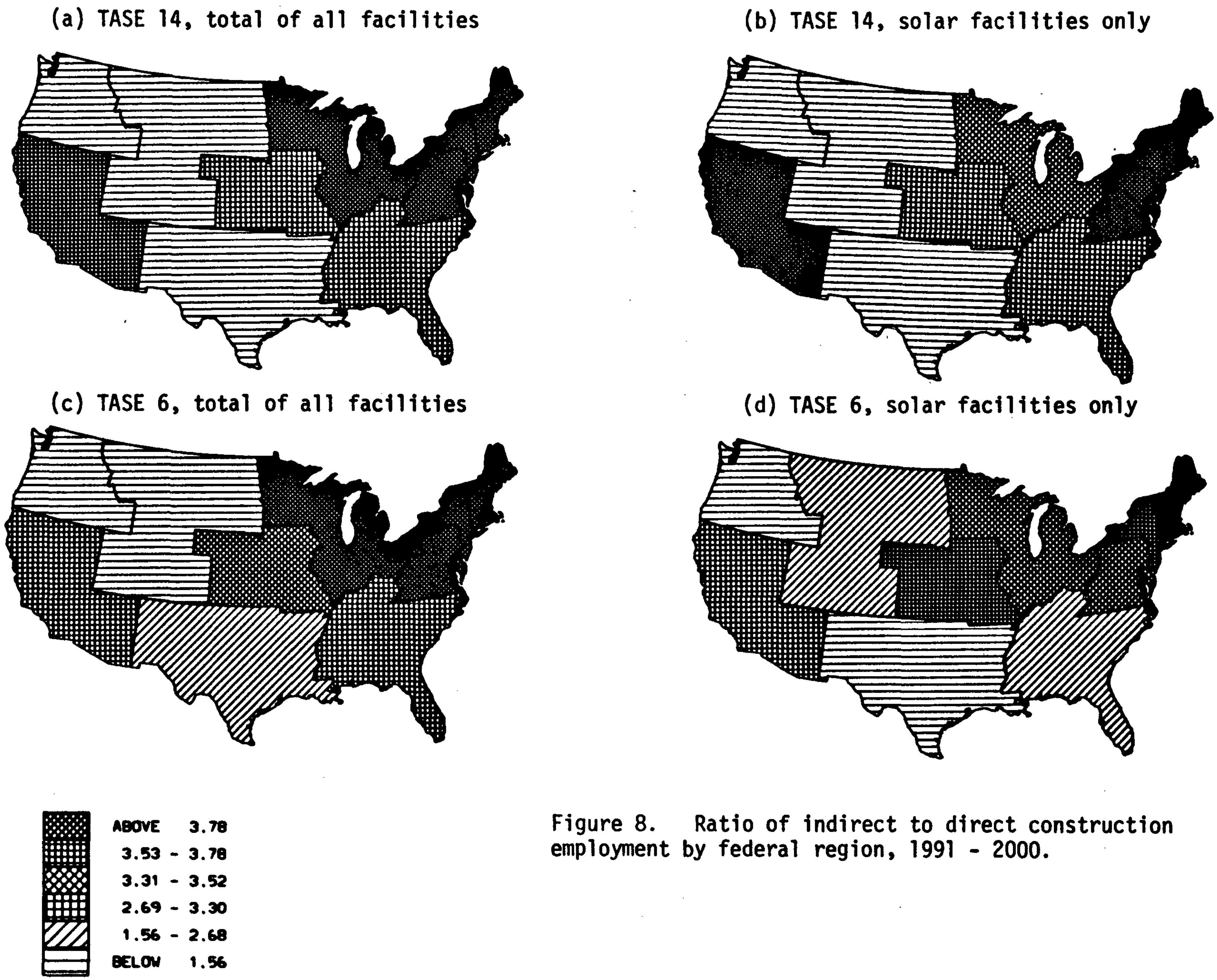


Figure 8. Ratio of indirect to direct construction employment by federal region, 1991 - 2000.

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