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Direct Labor Requirements for Select Solar Energy Technologies: A Review and Synthesis

SERI Working Paper

SERI

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A Division of Midwest Research Institute

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DIRECT LABOR REQUIREMENTS FOR SELECT SOLAR ENERGY TECHNOLOGIES:
A REVIEW AND SYNTHESIS
Task 5310

I. OBJECTIVES AND MOTIVATION

A. INTRODUCTION

Labor and manpower implications of solar energy adoption are potentially important in two respects. First, significant market penetration of solar energy technologies (SETs) may create expanded job opportunities with different skill requirements. Second, the extent of adoption, consumer acceptance, and competitiveness of solar technologies in energy markets may be affected by the availability of qualified and well-trained manpower to manufacture, design, and install solar equipment.

There is growing interest among policymakers, program managers, solar producers and consumers, the labor community, and researchers in labor requirements and employment impacts of solar energy technologies. Testimony before the Energy Subcommittee of the Joint Economic Committee of Congress (March 15 and 16, 1978) indicated concern about the impact of alternative energy sources on employment. Following the Subcommittee's hearings, Senator Edward Kennedy (Dem., Mass.) highlighted this concern in a letter to the Secretary of Labor, Ray Marshall:

> . . .[O]ur hearings disclosed, for example, that solar energy was three or four times more labor intensive than nuclear energy, and conservation even more so. The accuracy of these microeconomic findings should be verified and integrated with macroeconomic evidence and presented to the President and the Congress when major decisions are made. . .[1]

A major objective of SERI Task 5310 is to examine labor requirements for the manufacture, design, installation and maintenance of solar energy technologies. The purpose of this working paper is to review and synthesize existing estimates of direct manpower needs for select solar systems. Results from this effort will be used as input for future research on employment impacts of SETs.

B. SCOPE AND ORGANIZATION

Virtually all of the existing research on solar job requirements focuses on a single SET--liquid flat-plate collectors for residential space heating (SH) and domestic hot water (DHW) heating.[2] In Section II, various estimates of labor requirements for the design, manufacture, installation and maintenance of SH and DHW systems are presented. To make these estimates comparable, job requirement data are calculated on the basis of person-hours per square foot (ph/ft^2) of collector. Labor requirements for "typical" solar systems are derived by multiplying person-hours per square foot by the total number of square feet of collector needed for DHW and SH applications.

Total projected job requirements by year, calculated by multiplying person-hours per system times market penetration

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[1] Quoted in Environmentalists for Full Employment, "JEC Holds Jobs and Energy Hearings: Energy and Labor Departments Confess." Spring 1978, p. 7.

[2] The MITRE study is an exception to this generalization; labor requirements for air collectors, evacuator tubes (cooling), and solar heat pumps are provided. Since comparable data from other studies do not exist, MITRE estimates for these technologies will not be discussed.

estimates, are provided in Section III. Limitations of previous studies and conclusions about needed research are discussed in Section IV.

II. DIRECT JOB REQUIREMENTS FOR LIQUID FLAT-PLATE COLLECTOR SH AND DHW SYSTEMS

A. PERSON-HOUR REQUIREMENTS PER SQUARE FOOT OF COLLECTOR

Results from three separate studies on direct job requirements for the design, manufacture, installation and maintenance of liquid flat-plate collector systems for domestic hot water and space heating systems are summarized in Tables 1-4.[3] There is considerable variance among the studies with respect to purpose, approach, and level of detail. To the extent possible, we have attempted to present the data in a consistent and comparable format.

Navarro College Study

Navarro College, in a study sponsored by the Department of Energy, projected future manpower requirements for the solar energy industry by determining the expected time necessary to design, install and maintain solar space heating and hot water systems.[4] Four different methods were used to derive estimates of direct labor requirements: 1) statistical analysis of data derived from a nationwide mail survey of experienced solar contractors; 2) personal interviews with solar manufacturers, dealers, and

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[3] Final results from a fourth study, the Council on Economic Priorities Long Island Job Study, are not available and are therefore not included in this review.

[4] Charles G. Orsak, Jr., et al., An Assessment of Need for Developing and Implementing Technical and Skilled Worker Training for the Solar Energy Industry, Final Report, Corsicana, Texas: Navarro College, January 1978.

distributors; 3) a survey of experts considered to be pioneers in the solar field; and 4) a task inventory analysis.[5]

The Navarro study identified certain tasks which were considered strictly solar. Two types of solar workers were defined from the categories of solar tasks--solar mechanics and solar technicians. The solar mechanic is expected to perform entry-level tasks of installation and routine maintenance, and is defined as a solar-trained conventional tradesman with knowledge of solar systems.

A solar technician is defined as having knowledge and skills specific to solar system design, installation, and diagnostic troubleshooting. The knowledge required of a solar technician exceeds that of a typical tradesman and would require education beyond the high school level, probably a two-year vocational program. The Navarro study estimates that about 20 percent of total task time will require a solar technician. The remaining 80 percent of tasks can be performed by solar-trained conventional tradesmen (the solar mechanic) such as plumbers, sheet metal workers, electricians, carpenters, glaziers, and heating, ventilation, and air conditioning (HVAC) workers.

Results of the four approaches used in the Navarro study to estimate direct labor requirements are listed in the first column of Tables 1-4. Total system requirements for the design, installation and maintenance (manufacture is not included) of new domestic hot water systems (Table 1) range from 0.52 to 1.32 ph/ft^2 of collector. The "average" Navarro estimate for new DHW systems is 1.04 ph/ft^2.

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[5]The task inventory analysis consisted of identifying the specific tasks necessary to design, install, and maintain solar systems and determining the levels and time requirements for each task.

TABLE 1 - DOMESTIC HOT WATER SYSTEMS (NEW)

Direct Labor Requirements for Design, Manufacture, Installation and Maintenance of Liquid Flat-Plate Collector Systems (ph/ft^2 Collector)

STAGE	STUDY						
	NAVARRO COLLEGE[1]					MITRE CORPORATION[1]	CALIFORNIA PUBLIC POLICY CENTER[1]
DESIGN							
Contractor						0.173	
Professional						0.150	
Solar							
HVAC							
Unspecified	0.30[1]	0.0[2]	0.10[3]	0.20[4]	0.20[5]		
TOTAL DESIGN	0.30	0.0	0.10	0.20	0.20	0.323	N/A
MANUFACTURE							
Manual						0.225	
Supervisory						0.022	
Administrative						0.033	
Collectors							0.103
Components							0.144
TOTAL MANUFACTURE	N/A					0.280	0.247
INSTALLATION							
Manual						0.419	
Supervisory						0.078	
Professional						0.100	
Solar							
HVAC							
Plumber							
Electrician							
Carpenter							
Unspecified	0.88	0.40	1.0	0.92	0.80		0.80
TOTAL INSTALLATION	0.88	0.48	1.0	0.92	0.80	0.597	0.80
MAINTENANCE							
Solar							
Plumber							
Unspecified	0.14	0.04	0.04	0.02	0.04		
TOTAL MAINTENANCE	0.14	0.04	0.04	0.02	0.04	N/A	N/A
TOTAL SYSTEM	1.32	0.52	1.14	1.14	1.04	1.20	1.047

1/ Navarro's analysis is based on a typical system size of 50 ft^2; the CPPC study assumes a system of 48 ft^2; MITRE collector areas range from 22.5 to 55.5 ft^2.
2/ Statistical analysis of contractor survey data.
3/ Interviews with solar manufacturers/dealers/distributors.
4/ Survey of experts.
5/ Task analysis.
6/ "Average" from methods 1-4.

TABLE 2 - DOMESTIC HOT WATER SYSTEMS (RETROFIT)

Direct Labor Requirements for Design, Manufacture, Installation and Maintenance of Liquid Flat-Plate Collector Systems
(ph/ft^2 Collector)

STAGE	STUDY						
	NAVARRO COLLEGE					MITRE CORPORATION	CALIFORNIA PUBLIC POLICY CENTER
DESIGN							
Contractor							
Professional							
Solar							
HVAC							
Unspecified	0.36[1]	0.04[2]	0.14[3]	0.20[4]	0.20[5]		
TOTAL DESIGN	0.36	0.04	0.14	0.20	0.20	N/A	N/A
MANUFACTURE							
Manual							
Supervisory							
Administrative							
Collectors							0.103
Components							0.144
TOTAL MANUFACTURE	N/A					N/A	0.247
INSTALLATION							
Manual							
Supervisory							
Professional							
Solar							
HVAC							
Plumber							
Electrician							
Carpenter							
Unspecified	0.88	0.32	1.0	0.92	0.80		0.429
TOTAL INSTALLATION	0.88	0.32	1.0	0.92	0.80	N/A	0.429
MAINTENANCE							
Solar							
Plumber							
Unspecified	0.04	0.0	0.04	0.02	0.04		
TOTAL MAINTENANCE	0.04	0.0	0.04	0.02	0.04	N/A	N/A
TOTAL SYSTEM	1.28	0.36	1.18	1.14	1.04	N/A	0.626

[1] Statistical analysis of contractor survey data.
[2] Interviews with solar manufacturers/dealers/distributors.
[3] Survey of experts.
[4] Task analysis.
[5] "Average" from methods 1-4.

As indicated by data in Table 2, there is little difference between Navarro's labor requirement estimates for new and retrofit DHW applications. For retrofit DHW systems, person-hours per square foot range from 0.36 to 1.28, with the average estimated at 1.04 ph/ft^2 of collector.

For new domestic hot water and space heating systems, Navarro's manpower estimates are between 0.53 and 0.82 ph/ft^2, with a typical application requiring 0.55 ph/ft^2 (Table 3). Retrofits of combined DHW and SH systems will require 0.25 to 0.58 ph/ft^2 and an average application is estimated at 0.55 ph/ft^2 (Table 4). Lower labor requirements per square foot of collector for combined DHW/SH than DHW only are probably the result of "economies" in application; a DHW/SH system with 300 ft^2 of collector area will not require six times as much labor input as a DHW system with 50 ft^2 of collector.

MITRE Corporation

Detailed discussion of MITRE's methodology to derive labor requirements for solar manufacture, design, and installation is not available. Data on input requirements were apparently derived from several sources, including a survey of solar manufacturers in 1976, cost data from demonstration and privately funded projects, and secondary data on construction costs.[6] According to a MITRE report, the following methodology was used:

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[6]P.C. Spewak, "Labor Requirements for Solar Heating, Cooling, and Hot Water," MITRE Working Paper 12569, Sept. 1977; and Systems Descriptions and Engineering Costs for Solar Related Technologies, Volume II (SHACOB), METREK Division of the MITRE Corporation, June 1977.

TABLE 3 - DOMESTIC HOT WATER AND SPACE HEATING SYSTEMS (NEW)

Direct Labor Requirements for Design, Manufacture, Installation and Maintenance of Liquid Flat-Plate Collector Systems (ph/ft^2 Collector)

STAGE	STUDY						
	NAVARRO COLLEGE[1]					MITRE CORPORATION[1]	CALIFORNIA PUBLIC POLICY CENTER[1]
DESIGN							
Contractor						0.138	
Professional						0.126	
Solar Mechanic and Technician				0.09			
HVAC				0.03			
Unspecified	0.18	0.17	0.10		0.10		
TOTAL DESIGN	0.18[2]	0.17[3]	0.10[4]	0.12[5]	0.10[6]	0.264	N/A
MANUFACTURE							
Manual						0.385	
Supervisory						0.038	
Administrative						0.056	
Collectors							0.103
Components							0.048
TOTAL MANUFACTURE	N/A					0.479	0.151
INSTALLATION							0.320
Manual						0.745	
Supervisory						0.141	
Professional						0.179	
Solar Mechanic and Technician				0.02			
HVAC				0.0036			
Plumber				0.25			
Electrician				0.03			
Carpenter				0.01			
Other				0.05			
Unspecified	0.61	0.33	0.44		0.42		
TOTAL INSTALLATION	0.61[1]	0.33[2]	0.44[3]	0.35[4]	0.42[5]	1.065	0.320
MAINTENANCE							
Solar Mechanic and Technician				0.01			
Plumber				0.03			
Other				0.01			
Unspecified	0.03	0.03	0.05		0.03		
TOTAL MAINTENANCE	0.03	0.03	0.05	0.05	0.03	N/A	N/A
TOTAL SYSTEM	0.82	0.53	0.59	0.52	0.55	1.808	0.471

[1] Navarro's estimates are based on a typical system size of 300 ft^2; the CPPC study assumes a system of 395 ft^2; MITRE's collector areas range from 180-538 ft^2 (depending on geographic location).
[2] Statistical analysis of contractor survey data.
[3] Interviews with solar manufacturers/dealers/distributors.
[4] Survey of experts.
[5] Task analysis.
[6] "Average" from methods 1-4.

TABLE 4 - DOMESTIC HOT WATER AND SPACE HEATING SYSTEMS (RETROFIT)

Direct Labor Requirements for Design, Manufacture, Installation and Maintenance of Liquid Flat-Plate Collector Systems
(ph/ft^2 Collector)

STAGE	STUDY						
	NAVARRO COLLEGE					MITRE CORPORATION	CALIFORNIA PUBLIC POLICY CENTER
DESIGN							
Contractor							
Professional							
Solar							
HVAC							
Unspecified	0.08[1]	0.03[2]	0.07[3]	0.11[4]	0.10[5]		
TOTAL DESIGN	0.08	0.03	0.07	0.11	0.10	N/A	N/A
MANUFACTURE							
Manual							
Supervisory							
Administrative							
Collectors							0.103
Components							0.048
TOTAL MANUFACTURE			N/A			N/A	0.151
INSTALLATION							
Manual							
Supervisory							
Professional							
Solar							
HVAC							
Plumber							
Electrician							
Carpenter							
Unspecified	0.40	0.20	0.44	0.42	0.42		0.453
TOTAL INSTALLATION	0.40	0.20	0.44	0.42	0.42	N/A	0.453
MAINTENANCE							
Solar							
Plumber							
Unspecified	0.03	0.02	0.03	0.05	0.03		
TOTAL MAINTENANCE	0.03	0.02	0.03	0.05	0.03	N/A	N/A
TOTAL SYSTEM	0.51	0.25	0.54	0.58	0.55	N/A	0.604

[1] Statistical analysis of contractor survey data.
[2] Interviews with solar manufacturers/dealers/distributors.
[3] Survey of experts.
[4] Task analysis.
[5] "Average" from methods 1-4.

> . . .factors depicting the amount of person-hours/square foot of collector installed were determined for each of the specific types of labor in light of each type of solar system analyzed in the METREK study.[7]

How these labor requirements were determined is unclear. It appears that some combination of task analysis, survey data, and accounting procedures was used.

MITRE labor requirements are not separated into new and retrofit categories. This limitation is particularly important in the installation phase for space heating systems, since retrofits are likely to require considerably more labor than installations incorporated into new houses. MITRE estimates for direct labor requirements are considered to apply to new systems and are therefore listed only in Tables 1 and 3.

A major advantage of the MITRE study is its inclusion of labor requirements to manufacture solar systems. However, estimates of maintenance requirements are not provided by MITRE. MITRE labor estimates are somewhat higher than those provided by Navarro, partially because the manufacturing phase is included in the MITRE analysis. Direct requirements for design, manufacture, and installation are estimated by MITRE to be approximately 1.2 ph/ft^2 for hot water systems and 1.8 ph/ft^2 for combined DHW and SH systems (Tables 1 and 3, Column 2). The "economies" of labor input for larger applications projected by the Navarro study are not apparent in the estimates provided by MITRE.

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[7] P.C. Spewak, op. cit., p. 4.

Although there is some difference in individual categories, the MITRE and Navarro estimates for total person-hours required to design and install domestic hot water systems are similar. Navarro estimated that approximately 1.04 ph/ft^2 will be required for DHW; the comparable MITRE estimate is 0.92 ph/ft^2. There is, however, considerable divergence between the two studies on labor requirements for combined domestic hot water and space heating systems. This divergence is primarily in the installation portion, where the MITRE estimate is 1.065 ph/ft^2 and Navarro's is only 0.42 ph/ft^2. Given the lack of explanation of MITRE's labor estimation methodology, it is difficult to ascertain factors which might explain discrepancies in the two estimates.

California Public Policy Center

In the summer of 1977, the California Public Policy Center (CPPC) conducted a mail survey of every solar firm it could locate in California.[8] Of the 281 firms surveyed, 130 (44.5%) responded. Results of the survey were used to calculate job requirements for collector and component manufacturing, installation, and distribution. Information on system design and maintenance requirements was not obtained. Although some firms were utilizing air systems, job requirements are reported on the basis of person-hours per square foot of liquid flat-plate collectors.[9]

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[8] LaMar, Steve and Fred Branfman, Jobs From the Sun: Employment Development in the California Solar Energy Industry, Los Angeles, California: California Public Policy Center (February 1978).

[9] Although the CPPC survey includes commercial applications, no distinction is made between labor requirements for residential and commercial systems. This approach assumes that single-family residences, multi-family residences, and commercial applications will require the same number of person-hours/ft^2 of collector area.

Unlike the Navarro and MITRE studies, the CPPC research provides job estimates for manufacturing ancillary components for solar systems. However, the definition of components is limited and includes only storage tanks, controls, and pumps. Other component items--such as ducting, insulation, and valves--are excluded. The CPPC study also allows for jobs created in the distribution of solar systems. Jobs included in the distributive function include architects, designers, engineers, sales and marketing people, and administrative and support personnel. CPPC estimates that distribution tasks will employ about 25% as many people as those involved in manufacture and installation. Since these job requirements for distribution are not derived from survey results, we have chosen to omit them from Tables 1-4.

As indicated in Table 1-4, the CPPC study does not attempt to estimate maintenance requirements. For new domestic hot water systems, manufacture and installation are estimated to require 1.047 ph/ft^2 of collector (Table 1, Column 3). Retrofit DHW labor requirements are considerably lower, 0.676 ph/ft^2 (Table 2, Column 3). Labor "economies" are apparently evident in the manufacture and installation of combined DHW and SH systems. For new DHW and SH systems, total person-hours per square foot are 0.471 (Table 3, Column 3). Labor requirements are somewhat higher for retrofit DHW and SH systems--0.604 ph/ft^2 (Table 4, Column 4).

As can be seen from the foregoing discussion and data in Tables 1-4, there is significant variance among the direct employment estimates of the three studies. Part of the discrepancies can be explained by different methodologies and definitions. None of the studies includes all of the steps necessary to produce and deliver solar systems--design, manufacture (collectors and components), installation, and maintenance. The remaining differences in labor requirement estimates are probably attributable to the nature of the solar industry. It is not a mature industry with considerable

market experience. At this stage, procedures for estimating solar labor needs are part observation and part hypothetical. More precise and consistent estimates will be obtainable only when substantial market experience is achieved.

B. TOTAL LABOR REQUIREMENTS FOR TYPICAL SOLAR SYSTEMS

To provide an indication of total labor requirements for typical residential installations, estimates of person-hours per square foot of collector area (from Tables 1-4) are multiplied by collector requirements for representative systems. Results from this exercise are presented in Table 5. Typical systems are assumed to require 50 ft^2 of collector for DHW and 300 ft^2 for DHW/SH systems. These system sizes probably represent minimum collector requirements and therefore provide conservative employment estimates.[10]

For design and installation of new DHW systems, total labor requirements are quite similar among the three studies. Total MITRE estimates are somewhat higher than the Navarro and CPPC results, primarily because manufacturing requirements are relatively high in the MITRE study. There appears to be reasonable consensus that a new DHW system will require approximately 50 person-hours for design, installation, and maintenance.

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[10] A recent study has estimated that larger collector areas of 84 ft^2 for DHW and 350 ft^2 for DHW and SH systems might be considered "typical." Silvio J. Flaim, et al., Economic Feasibility and Market Readiness of Eight Solar Technologies, Interim Draft Report, SERI-34, Golden, Colorado: Solar Energy Research Institute, June 1978, p. 12, 16.

TABLE 5

TOTAL PERSON-HOURS FOR TYPICAL RESIDENTIAL SYSTEMS

SYSTEM	STUDY		
	Navarro College[1]	MITRE Corporation	California Public Policy Center
DHW : New ($50\ ft^2$)	52 ph	60.0 ph	52.3 ph
DHW : Retrofit ($50\ ft^2$)	52	N/A	33.8
DHW/SH : New ($300\ ft^2$)	165	542.4	141.3
DHW/SH : Retrofit ($300\ ft^2$)	165	N/A	181.2

1. "Typical" labor requirements from the Navarro College study are used.

Total labor requirements for retrofitting DHW systems are estimated by CPPC to require about two-thirds as much labor as a new system. Navarro's estimates for retrofits of DHW are the same as new systems, 52 person-hours.

Although there is general agreement between the Navarro and CPPC studies on labor requirements for new DHW and SH systems, MITRE estimates are somewhat greater. Some of this difference can be explained by MITRE's calculations for manufacturing, which account for approximately 150 person-hours per installation. However, a major divergence among the three studies is in the installation function; MITRE's labor estimates in this phase are more than double those calculated by either the Navarro or CPPC studies.

C. LABOR COSTS FOR TYPICAL SYSTEMS

In Table 6, labor costs for residential DHW and DHW/SH systems are calculated. Wage rates used to calculate these costs are provided in a footnote to Table 6.

Labor costs, according to MITRE estimates, for a 50 ft^2 DHW system total $440. This total includes design, manufacture, and installation, but excludes any allowance for maintenance costs. Total DHW hot water systems costs for a 50 ft^2 installation have been estimated to be $1,012.[11] Labor costs therefore represent almost one-half of total direct costs for this type of application.

For combined DHW/SH systems, total labor costs are estimated, using MITRE data, to be $3,755. Total labor cost estimates based on the Navarro College study, which include maintenance but omit manufacturing requirements, are $2,283 for a 300 ft^2 system.

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[11] Ibid.

Total DHW/SH system costs for a 300 ft^2 unit have been estimated in one study to be approximately $12,000.[12] The labor cost component for a DHW/SH system represents one-quarter to one-third of total system cost.

[12] Ibid., p. 17.

TABLE 6

TOTAL LABOR COSTS FOR RESIDENTIAL DHW AND DHW/SH SYSTEMS[1]

STUDY	DESIGN		MANUFACTURE		INSTALLATION		MAINTENANCE[2]		TOTAL SYSTEM
MITRE Corp. DHW System ($50\ ft^2$)	Contractor	$ 69.20	Manual	$ 56.26	Manual	$104.75			
	Professional	90.00	Supervisory	8.80	Supervisory	31.20			
			Administrative	19.80	Professional	60.00			
		$159.20		$ 84.85		$195.95	N/A		$440.00
MITRE Corp. DHW/SH System ($300\ ft^2$)	Contractor	$331.20	Manual	$577.50	Manual	$1,117.50			
	Professional	453.60	Supervisory	91.20	Supervisory	338.40			
			Administrative	$201.60	Administrative	644.40			
		$784.80		$870.30		$2,100.30	N/A		$3,755.40
Navarro College DHW/SH System ($300\ ft^2$)	Solar	$420.00			Solar	$ 104.00	Solar	$ 32.00	
	HVAC	133.28			HVAC	17.28	Plumber	162.08	
					Plumber	1,184.00	Other	15.40	
					Electrician	120.00			
					Carpenter	25.05			
					Other	$ 70.00			
		$553.28	N/A			$1,520.33		$209.48	$2,283.09

[1]Wage rates for various trades are as follows:

MITRE Corp.:

Manual	- $5.00/hr.
Supervisory	- $8.00/hr.
Professional	- $12.00/hr.
Contractor	- $8.00/hr.
Administrative	- $12.00/hr.

CEP Long Island Jobs Study (NY Union Wage: [$/hr. 9-77]):

Solar/HVAC	- $16.00/hr.
Plumber	- $16.00/hr.
Electrician	- $15.00/hr.
Carpenter	- $15/00/hr.
Other	- $5.00/hr.

P. C. Spewak, "Labor Requirements for Solar Heating, Cooling and Hot Water," McLean, Virginia: MITRE Corporation, Working Paper No. 12569, September 1977; and James Benson, "Long Island Jobs Study," New York, New York: Council on Economic Priorities (unpublished).

[2]Yearly maintenance requirements.

III. TOTAL SOLAR-RELATED JOBS, 1978-1990

To determine total job requirements for design, manufacture, installation and maintenance of residential solar systems, it is necessary to project market penetration of solar technologies. Direct labor requirements for typical systems can be multiplied by the number of projected installations to derive estimates of total job requirements.[13] Results from this exercise are presented in Tables 7-9.

Three different market penetration studies are used to indicate the range of total job requirements through 1990--MITRE,[14] University of New Mexico,[15] and the Solar Energy Industries Association.[16] For comparative purposes, total job estimates have been derived by using each possible combination of direct job calculations and market penetration projections.

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[13] This procedure calculates gross rather than net jobs created by solar energy technologies. To determine net job creation, it is necessary to include displacement effects of reducing employment in conventional energy industries.

[14] P. C. Spewak, Labor Requirements for Solar Heating, Cooling, and Hot Water, MITRE Working Paper No. 12569, McLean, Virginia: The MITRE Corporation, September 1977.

[15] William D. Shulze and Shaul Ben-David, The Economics of Solar Home Heating: A Study Prepared for the Use of the Joint Economic Committee, Washington, D.C.: Congress of the United States, March 13, 1977.

[16] Sheldon Butt, Solar Market Capture and Market Penetration. Washington, D.C.: Solar Energy Industries Association, October 1976.

Examination of Tables 7-9 indicates the wide range of estimates of solar job potential. For DHW systems, total job requirements range from 8,127 to 50,004 in 1985. Among the studies, total job requirements in 1985 for DHW/SH systems range from a low of 7,348 to a high of 77,346. If the NEP goal of 2.5 million total installations in 1985 is achieved, approximately 25,000 person-years/year will be required in 1985 for residential DHW and DHW/SH applications (according to the MITRE study). Although estimates of manpower per system are important in determining total employment impacts, it is obvious from these calculations that market penetration forecasts are the dominant variable. SEIA projections are clearly the most optimistic and therefore obtain relatively large employment requirements.

TABLE 7
TOTAL SOLAR JOBS, DHW SYSTEMS, 1978-1990

YEAR	U.N.M.[1] Installations New - N Retro - R	Navarro[2] Jobs/Year[5]	MITRE[3] Jobs/Year	CPPC[4] Jobs/Year	MITRE Installations New and Retro.	Navarro Jobs/Year	MITRE Jobs/Year	CPPC Jobs/Year[7]	SEIA Installations New and Retro.	Navarro Jobs/Year	MITRE Jobs/Year	CPPC Jobs/Year
1978	N- 15,700 R- 47,200	1,635	1,887	1,208	19,676	512	590	378	27,600	718	828	531
1979	N- 15,700 R- 47,200	1,635	1,887	1,208	N/A[6]				103,100	2,681	3,093	1,981
1980	N-125,600 R-246,500	9,675	11,163	7,851	144,132	3,747	4,324	2,890	238,200	6,193	7,146	4,775
1981	N-125,600 R-246,500	9,675	11,163	7,851	N/A				523,300	13,606	15,699	10,490
1982	N-121,500 R-220,800	9,394	10,839	7,230	N/A				864,500	22,477	25,935	17,331
1983	N-121,000 R-241,100	9,415	10,863	7,239	N/A				1,134,800	29,505	34,044	22,749
1984	N-121,500 R-240,400	9,409	10,857	7,240	N/A				1,445,200	37,575	43,356	28,972
1985	N-195,800 R-445,700	16,679	19,245	12,653	411,122	10,689	12,334	8,127	1,666,800	43,337	50,004	32,950
1986	N-191,600 R-440,100	16,424	18,951	12,448	N/A				1,797,000	46,722	53,910	35,357
1987	N-177,900 R-416,600	15,457	17,835	11,693	N/A				1,960,000	50,960	58,800	38,564
1988	N-177,900 R-416,600	15,457	17,835	11,693	N/A				2,067,000	53,742	62,010	40,669
1989	N-177,900 R-416,600	15,457	17,835	11,693	N/A				1,988,000	51,688	59,640	39,115
1990	N-190,600 R-464,400	17,030	19,650	12 833	853,289	22,186	25,599	16,710	1,656,000	43,056	49,680	32,429

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5. Derivation of Solar Jobs Per Year:

$$\text{Jobs Per Year} = \frac{\text{Market Penetration} \times \text{Collector ft}^2 \times \text{ph/ft}^2}{2{,}000 \text{ ph}}$$

(Note: one Job-year = 2,000 ph)
ph requirements: Navarro - 52.0 ph/ft^2; MITRE - 60.0 ph/ft^2;
CPPC = 52.35 ph/ft^2 (N), 33.78 ph/ft^2 (R)

6. N/A - Not Available
7. % breakdown into new and retrofit installations from Navarro-U.N.M. estimates.

TABLE 8
TOTAL SOLAR JOBS, DHW/SH SYSTEMS, 1978-1990

YEAR	U.N.M. Installations New - N Retro. - R	Navarro Jobs/Year[1]	MITRE Jobs/Year	CPPC Jobs/Year	MITRE Installations New & Retro.	Navarro Jobs/Year	MITRE Jobs/Year	CPPC Jobs/Year	SEIA Installations New & Retro.	Navarro Jobs/Year	MITRE Jobs/Year	CPPC Jobs/Year
1978	N- 3,100 R- 8,500	957	3,146	989	15,273	1,260	4,142	1,301	2,400	198	651	205
1979	N- 8,000 R- 18,000	2,145	7,051	2,196	N/A				4,900	404	1,329	415
1980	N- 13,300 R- 30,400	3,605	11,851	3,694	33,024	2,724	8,956	2,794	8,800	726	2,387	745
1981	N- 15,300 R- 30,900	3,811	12,529	3,881	N/A				18,700	1,543	5,071	1,571
1982	N- 24,900 R- 51,700	6,319	20,774	6,443	N/A				37,500	3,094	10,170	3,150
1983	N- 26,200 R- 54,200	6,633	21,804	6,762	N/A				76,200	6,286	20,655	6,402
1984	N- 34,200 R- 68,400	8,464	27,825	8,613	N/A				145,800	12,028	39,541	12,249
1985	N- 38,100 R- 74,600	9,298	30,564	9,451	90,152	7,438	24,449	7,557	285,200	23,529	77,346	23,905
1986	N- 47,000 R- 84,100	10,816	35,554	10,940	N/A				518,000	42,735	140,482	43,211
1987	N- 60,800 R-107,100	13,852	45,534	13,999	N/A				800,000	66,000	216,960	66,734
1988	N- 60,800 R-107,100	13,852	45,534	13,999	N/A				1,170,000	96,525	317,304	97,599
1989	N- 72,100 R-130,400	16,705	54,918	16,908	N/A				1,700,000	140,250	461,040	141,811
1990	N- 74,700 R-136,500	17,421	57,277	17,645	165,897	13,687	44,991	13,872	2,445,000	201,712	663,084	204,445

1. ph Requirements: Navarro - 165.0 ph/ft^2; MITRE - 542.4 ph/ft^2;
CPPC - 141.3 ph/ft^2 (N), 181.2 ph/ft^2 (R)

TABLE 9
TOTAL SOLAR JOBS, DHW AND DHW/SH SYSTEMS, 1978-1990

YEAR	U.N.M. TOTAL Installations	Navarro TOTAL Jobs/Year	MITRE TOTAL Jobs/Year	CPPC TOTAL Jobs/Year	MITRE TOTAL Installations	Navarro TOTAL Jobs/Year	MITRE TOTAL Jobs/year	CPPC TOTAL Jobs/Year	SEIA TOTAL Installations	Navarro TOTAL Jobs/Year	MITRE TOTAL Jobs/Year	CPPC TOTAL Jobs/Year
1978	74,500	2,592	5,033	2,197	34,949	1,772	4,732	1,679	30,000	916	1,479	736
1979	88,900	3,780	8,938	3,404	N/A				108,000	3,085	4,422	2,396
1980	415,800	13,280	23,014	11,145	177,156	6,471	13,280	5,684	247,000	6,919	9,533	5,520
1081	418,300	13,486	23,692	11,332	N/A				542,000	15,149	20,770	12,061
1982	437,900	15,713	31,613	13,673	N/A				902,000	25,571	36,105	20,481
1983	442,500	16,048	32,667	14,001	N/A				1,211,000	35,791	54,699	29,151
1984	464,500	17,873	38,682	15,853	N/A				1,591,000	49,603	82,897	41,221
1985	754,200	25,977	49,809	22,104	501,274	18,127	36,783	15,684	1,952,000	66,866	127,350	56,855
1986	762,800	27,240	54,505	23,338	N/A				2,315,000	89,457	194,392	78,568
1987	762,400	29,309	63,369	25,692	N/A				2,760,000	116,960	275,760	105,298
1988	762,400	29,309	63,369	25,692	N/A				3,237,000	150,267	379,314	138,268
1989	797,000	32,163	72,753	28,601	N/A				3,688,000	191,938	520,680	180,926
1990	866,200	34,454	76,927	30,478	1,019,186	35,873	70,590	30,582	4,101,000	244,768	712,764	236,874

IV. SUMMARY AND CONCLUSIONS

As indicated by the preceding discussion, there is considerable divergence among estimates of direct labor requirements for solar energy technologies. This is not a surprising result for at least two reasons. First, available research varies widely in terms of objectives and methodologies. Second, and perhaps more important, is the nascent position of the solar industry. In an industry with relatively little market experience, impact projections are based largely on conjecture rather than observation. This lack of experience is particularly important in attempting to estimate maintenance requirements, since few systems have been functioning for their expected service life under normal operating circumstances. As the solar industry gains momentum and market acceptance, analysis based on actual observation of labor requirements will enable researchers to refine estimates beyond the speculative stage.

Several limitations of existing studies suggest that additional research on employment requirements and impacts is warranted. One major limitation of previous research is that it generally examines only one type of solar energy technology--liquid flat-plate collectors for DHW and SH. Several other technologies need to be examined, such as passive solar heating and cooling, thermal electricity conversion, biomass, geothermal, agricultural and commercial process heating applications, wind, and photovoltaics.

A second limitation is that labor requirement estimates do not incorporate learning effects or potential technological advances. At this stage of development, the design, manufacture, installation and maintenance of solar energy systems appear to be quite labor-intensive. As workers become familiar with solar

technologies, labor efficiencies will undoubtedly be realized. Moreover, if solar technologies are to be competitive with conventional energy sources, labor inputs will probably be decreased due to system packaging, mass production, and other technological changes. The MITRE study does attempt to incorporate these learning factors into their cost estimates. It is assumed, however, throughout MITRE's market penetration analysis that labor costs will remain constant at $3 (in real terms) per square foot of collector. This approach does not indicate a substantial learning process.

A third limitation of existing research is that little consideration has been given to labor requirements for manufacturing ancillary components necessary for complete solar systems. Manufacturing pipes, pumps, heat exchangers, thermostats, blowers and ducts will all require significant labor input. The CPPC study did examine labor requirements for storage tanks, controls, and pumps, but excluded several other potentially important ancillary components. To provide a comprehensive picture of labor requirements for solar systems, it is necessary to derive labor requirements for these components and determine if the labor quantity and skill needs differ substantially from existing heating, ventilation, and air conditioning components.

Fourth, most of the previous studies do not examine the indirect and displacement effects of solar technology diffusion.[17] If solar technologies provide a significant portion of energy supplies, new employment opportunities will probably be created. These new jobs--and the income they generate--will create secondary employment impacts, particularly in the service industries. But this job creation will be offset, at least partially, by reduction in employment opportunities in conventional energy industries. The direction and magnitude of these employment shifts require careful analysis.

Finally, policies to advance solar energy commercialization are often advocated on the basis that solar technologies will create job opportunities for individuals currently under- or unemployed. Despite this enthusiasm, several issues remain unanswered which will determine whether the employment impacts are beneficial from a policy perspective. The types and geographic dispersion of jobs created by a solar industry are important concerns. Will they be low-skill (and low-wage) jobs suitable for the structurally unemployed, or will the solar industry require highly skilled and relatively scarce trades? Moreover, demographic projections suggest that, as the post-War "baby bubble" moves through the

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[17] A national input-output study by H. Craig Peterson did attempt to examine the direct and indirect employment effects of increased solar utilization. Assuming that final demand for solar space and water heating systems will be $1 billion (in terms of 1963 dollars) in 1985, Peterson estimated that only three sectors (copper ore mining, primary copper metals, and copper melting and rolling) would experience employment increases of more than one percent, with none greater than four percent. Employment in the electric utility industry was projected to decline by one percent due to solar development. Since Peterson utilized the Bureau of Labor Statistics input-output matrix, it was not possible to identify impacts on specific trades. (H. Craig Peterson, Sector-Specific Output and Employment Impacts of a Solar Space and Water Heating Industry, Washington, D.C.: National Science Foundation (RANN), Report No. APR 75-18004, (December 1977).

labor market, labor shortage rather than surplus may be the dominant policy concern of the future. It is imperative that these questions be addressed before programs and policies are pursued which tout the purported labor intensity of solar energy technologies.

In conclusion, there is need for careful research which examines all of the following issues in a concerted manner: 1) direct job requirements for a wide variety of solar technologies; 2) how these skill requirements differ from existing occupational pools and how they relate to regional manpower supplies; 3) indirect and displacement effects on a regional basis; and 4) the sensitivity of these results to alternative economic and policy scenarios and the market penetration estimates that result from these scenarios.

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