Solar PV Development: Location of Economic Activity

R E P P

Renewable Energy Policy Project

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CONTENTS

Executive Summary

Chapter 1 – Location of Potential Manufacturing
- a) Using the NAICS to Locate Similar Manufacturing
- b) Potential PV Manufacturing, Throughout the U.S.

Chapter 2 – Economic Impact of Solar Photovoltaic Investment
- a) Impact of PV Industry Roadmap
- b) Solar PV Component Cost Breakdown
- c) Investment Allocation

Chapter 3 – Solar PV Components
- a) Module Components
- b) Balance of System Components
- c) US Manufacturing Census
- e) Subcomponent Data Sheets

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Executive Summary

Photovoltaic technologies can convert roughly 10% to 20% of energy from the sun directly into electricity. Since many areas of the United States have the potential to employ PV technologies to produce a significant portion of their electricity needs with little or no environmental pollution, the development of PV is recognized as a critical part of an environmentally responsible national energy policy. The "PV Roadmap", an industry led effort to assess the best mix of research and market development supports to accelerate PV development, predicts that with a reasonable set of incentives the solar photovoltaic market in the U.S. could grow more than 30% per year over the next 20 years, from 340MW of installed capacity to 9600 MW.

An increase in PV installations of this magnitude will produce substantial economic benefits for the states and regions that obtain the installations. Because PV technologies use more labor per MW installed than other renewable technologies, the direct job benefits to the regions that install systems are important. Nevertheless, the economic benefits extend well beyond the immediate installation and even beyond the regions where the installations occur. A program of the size documented in the PV Roadmap will create a substantial, new demand for the components and sub-components that go into a PV installation. In order to fully document the extent of the economic benefits offered by the PV Roadmap plan the total economic stimulus must be mapped. Manufacturing accounts for the largest portion of the cost of photovoltaics, and that manufacturing could occur in places other than the installation location, bringing economic benefits to other places in the country.

To assess the distribution of manufacturing, this Report first takes a modern solar photovoltaic system and reduces it to 14 separate component parts. Next, the Report integrates the market size and cost goals in the PV Industry Roadmap. Because a large national investment in PV would likely spread beyond existing active manufacturers, the Report identifies the number of companies with the technical potential to manufacture these components. To identify this potential, the North American Industrial Classification System (NAICS) codes for the 14 components are searched for companies operating in those industry codes. Based on this analysis the Report shows that the manufacturing activity related to the development of PV energy is substantial and widely dispersed. There are 10,179 firms currently operating in one or more of the NAICS codes related to the manufacturing of PV components. These firms are spread over every one of the 50 states.

Due to the typically distributed nature of PV, on-site construction and installation of the systems provides substantial local investment and employment and is considered in addition to manufacturing investment. To complete the overall picture of economic benefits this Report adds the likely location of construction and installation jobs to the manufacturing distribution. This results in a complete map of where jobs and economic investment could occur throughout the United States if the goals of the PV Roadmap are met.

PV Industry Roadmap

The PV Industry Roadmap document is an industry driven effort that attempts to balance likely trends with industry objectives. We summarize the document to outline the key objectives, policy drivers, and the anticipated size of the PV market. As explained, the size of the potential PV market is used as an input to the REPP Job Locator model in order to determine the number and geographic distribution of the jobs created as a result of the Roadmap being pursued. Here are the summary goals of that effort:

- Total installed capacity will increase from 340 MW now to 9,600 MW by 2015.
- The average installed cost in 2015 will be $3.68 per watt – $2.91 for manufacturing and $0.77 for construction and installation.
- This represents a $34 billion investment - $27 billion manufacturing and $7 billion construction and installation.
- Direct employment will increase from 20,000 now to 62,000 by 2015.

⇒ For comparison, if the PV Roadmap is not implemented and business-as-usual continues, baseline predictions show only 3,800 MW installed by 2015 and only 28,000 jobs.

Summary of The Industry-Developed PV Roadmap

In 2001, we, the U.S. photovoltaic industry, stated our vision in Solar Electric Power as "*providing consumers with competitive electricity generation products and services from a thriving, self-sustaining domestic solar power industry.*" And we laid out a plan to accomplish this vision.

Our goals for 2030 are solar power system costs of $2.33 per watt, solar electricity prices of 3.8 cents per kilowatt-hour (kWh) delivered to the customer, installed solar power generation of 200 gigawatts (GW), and direct employment of 260,000 people.

Our Plan for Reaching Tomorrow—
For the United States to realize the significant value and economic and employment benefits provided by solar power, we will need sustained, vigorous national leadership in market expansion and research and development (R&D).

Recommended actions for market expansion:
• Enact a residential and commercial tax credit that augments current state and federal support. The first 10 kW installed would receive a 50% tax credit capped at $3 per watt. Any amount above 10 kW would be eligible for a 30% tax credit capped at $2 per watt. Decreasing the caps by 5% per year will encourage a steady decline in prices and ease the transition to a market without tax credits.
• Modify the wind tax credit for solar so that it can be used in concert with the existing 10% investment tax credit.
• Establish uniform net metering and interconnection standards to give solar power owners simple, equitable access to the grid and fair compensation.
• Boost federal government procurement of solar power to $100 million per year to build public-sector markets for solar power.
• Support state public benefit charge programs and other state initiatives to advance solar power and build strategic alliances with public and private organizations to expand solar markets.

Recommended actions for R&D:

• Increase R&D investment to $250 million per year by 2010.

• Strengthen investments in crystalline silicon, thin film, and balance-of-systems components, as well as new system concepts, that are critical to the industry now—reducing the gap between their current cost and performance and their technical potential.

• Support higher-risk, longer-term R&D for all system components that can leapfrog beyond today's technology to new levels of performance and reduce installed system costs.

• Enhance funding for facilities and equipment at centers of excellence, universities, national labs (Sandia National Laboratories and the National Renewable Energy Laboratory)—as well as the Science and Technology Facility at NREL—to shorten by 50% the time between lab discoveries and industry use in manufacturing and products.

• Grow partnerships among industry, universities, and national laboratories to advance PV manufacturing and product technologies.

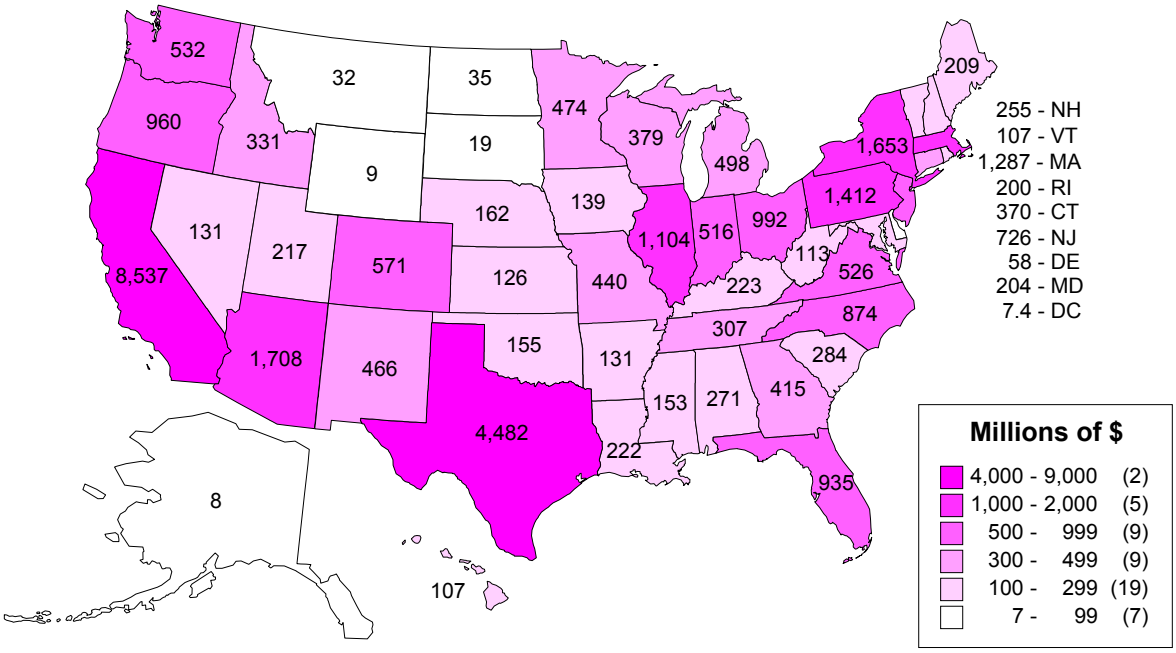
Table of Targets and Projections for Solar Power for 2004 to 2050

System Price and Electricity Cost, Commercial Systems		2004	2010	2015	2020	2030	2050
Best System Selling Price [a] ($/W)	Baseline	6.10	4.87	4.24	3.76	3.12	2.56
	Roadmap	6.10	4.65	3.68	3.01	2.33	1.93
Electricity Cost [b] (¢/kWh)	Baseline	18.2	13.4	11.5	10.0	8.2	6.8
	Roadmap	10.5	7.4	5.7	4.6	3.8	3.7
U.S. Solar Power Shipments, Installations, and Employment							
Annual U.S. Shipments (MW peak)	Baseline	120	240	480	950	2,400	5,500
	Roadmap	120	510	2,300	7,200	19,000	31,000
Cumulative U.S. Installations (MW peak)	Baseline	340	1,500	3,800	8,200	28,000	100,000
	Roadmap	340	2,100	9,600	36,000	200,000	670,000
Employment [c]	Baseline	20,000	23,000	28,000	37,000	59,000	95,000
	Roadmap	20,000	29,000	62,000	130,000	260,000	350,000
Performance Advances [d]							
Conversion Efficiency (%)	Cell	10–20	15–25	19–28	20–35	22–40+	Ultra-High Efficiency > 40
	Module	8–15	12–17	16–20	18–24	20–30	Ultra-Low Cost > 15
	System	6–12	9–14	13–18	14–20	18–25	

For an explanation of footnotes, and for the full PV Roadmap document, see:
http://www.seia.org/media/pdfs/pvroadmap.pdf

Total Investment and Jobs Map

For this Report, analysis of the 9,260 MW development proceeds in three steps. First we determine how the total cost of the new PV development will flow into demand for the various components of the systems. Second, we spread the total demand among the regions of the country. We allocate the manufacturing dollars according to the number of firms in each region with the technical potential to manufacture PV components, and the installation dollars according to the potential demand for PV installations. Third, we distribute the job allocation according to the same location information for manufacturing and installation. This results in a geographic "map" of investment and job location.



By investigating the location of potential PV component manufacturers and the location of demand for PV installations, this Report shows how economic benefits from pursuing the PV Roadmap would flow into the states. While California and Texas take a large portion of the investment, the rest is well distributed throughout the country. <u>All but 6 states would receive more than $100 million in investment.</u>

The PV Roadmap calculates that the number of jobs in PV will increase from 20,000 now to 62,000 by 2015. A recent REPP study showed that for PV, 80% of these jobs are in manufacturing, and the other 20% in construction and installation. The total employment resulting from the PV Roadmap is allocated to states based on the allocating investment.

These results indicate that investment in PV could provide economic benefit across the country, and particularly in places where it is needed. The 20 states that would receive the most investment from PV account for 75% of the manufacturing jobs lost in the last 3½ years. The table below shows the top 20 states ranked by received investment, along with job loss demographics.

State Ranking by Total Investment and Job Creation

State	Manufacturing Jobs	Manufacturing $Millions	Const. & Install. Jobs	Const. & Install. $Millions	Totals Jobs	Totals $ Millions	Manufact. Jobs Lost, Jan. 2001 - August 2004
California	6,858	5,500	3,578	3,037	**10,437**	**8,538**	343,600
Texas	5,205	4,175	361	307	**5,567**	**4,481**	177,600
Arizona	1,987	1,594	134	114	**2,122**	**1,708**	39,300
New York	1,607	1,289	428	364	**2,035**	**1,652**	148,500
Pennsylvania	1,610	1,291	143	121	**1,752**	**1,412**	161,200
Massachusetts	1,275	1,023	311	264	**1,586**	**1,286**	84,800
Illinois	1,217	976	151	128	**1,368**	**1,104**	145,600
Ohio	996	799	227	193	**1,223**	**991**	173,000
Oregon	1,134	910	59	50	**1,193**	**960**	25,800
Florida	783	628	361	307	**1,144**	**935**	64,100
North Carolina	876	703	202	171	**1,078**	**874**	162,900
New Jersey	781	626	118	100	**899**	**726**	71,200
Colorado	624	500	84	71	**708**	**572**	36,100
Washington	609	489	50	43	**660**	**531**	66,700
Virginia	549	440	101	86	**649**	**526**	62,400
Indiana	589	473	50	43	**640**	**515**	70,900
Michigan	470	377	143	121	**613**	**498**	142,600
Minnesota	520	417	67	57	**587**	**474**	56,800
New Mexico	493	395	84	71	**577**	**467**	7,000
Missouri	469	376	76	64	**545**	**440**	37,000
20 State Total					35,381	28,690	2,077,100
% U.S. Total					**84%**	**84%**	**75%**

It is also interesting to examine which states receive the most job creation relative to the number of jobs lost. The table below examines the relative impact of job creation for the same top 20 states listed above, this time ranking them by job creation as a percentage of job loss.

State Ranking by Job Creation as a Percentage of Job Loss

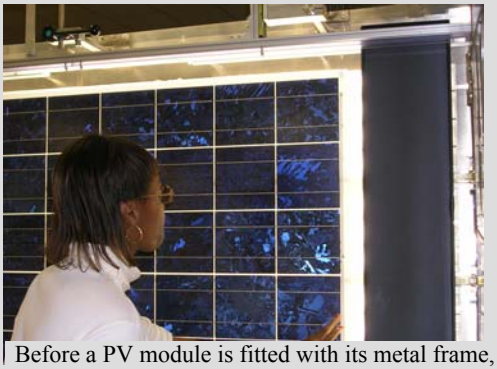
State	New Jobs	$ Millions	Manuf. Job Loss Jan. '01 – Aug. '04	New Jobs as % of Manuf. Job Loss
New Mexico	577	467	7,000	**7.04%**
Arizona	2,122	1,708	39,300	**5.06%**
Oregon	1,193	960	25,800	**4.40%**
Texas	5,567	4,481	177,600	**2.93%**
California	10,437	8,538	343,600	**2.00%**
Colorado	708	572	36,100	**1.73%**
Massachusetts	1,586	1,286	84,800	**1.50%**
Missouri	545	440	37,000	**1.27%**
Florida	1,144	935	64,100	**1.22%**
New Jersey	899	726	71,200	**1.10%**
New York	2,035	1,652	148,500	**1.08%**
Pennsylvania	1,752	1,412	161,200	**1.00%**
Minnesota	587	474	56,800	**0.92%**
Washington	660	531	66,700	**0.91%**
Virginia	649	526	62,400	**0.88%**
Illinois	1,368	1,104	145,600	**0.84%**
Indiana	640	515	70,900	**0.83%**
Ohio	1,223	991	173,000	**0.58%**
North Carolina	1,078	874	162,900	**0.54%**
Michigan	613	498	142,600	**0.33%**

Sharp Solar Photovoltaic Module Assembly Facility, Memphis, TN

In October 2003, Sharp opened a solar panel manufacturing facility in Memphis, TN to meet the increasing demand for solar energy in the U.S. Sharp, which had previously used the facility to manufacture consumer electronics, retooled the factory with machinery built in-house to produce modules. The vast majority of the employees stayed on in the retooled plant.

Sharp's Memphis plant has doubled production in less than two years and plans another increase in 2005. *Credit:* Sharp Manufacturing Company of America.

The plant assembles 165-, 167- and 185-watt solar panels for residential and commercial installations, all focused on the domestic solar market. From its original capacity of 20 MW, the plant has doubled to 40 MW and plans another large increase in 2005. This transformation has taken place in less than two years.


Before a PV module is fitted with its metal frame, this post-lamination inspector must test the quality using sophisticated vision instruments. *Credit:* Sharp Manufacturing Company of America.

Currently, the factory employs approximately 130 people, with 75 percent of employees in direct materials handling on the assembly line. The remaining employees are mostly involved in product engineering and line management. With the upcoming expansion, employment should rise considerably. The company is also developing several new module products.

The company estimates that the Memphis factory supports between 1,000 – 2,000 jobs in the solar industry (i.e. system installers, product distributors).

Location of Manufacturing

This Report proceeds in three steps to trace the distribution of benefits from manufacturing of PV components. First we determine how the total installed cost of the new PV development will flow into demand for each of the 14 separate components of the system (grouped into 5 categories). Second, we spread the total demand among the regions of the country by allocating the $27 billion manufacturing investment according to the number of employees at firms identified by the NAICS codes. The number of employees is used rather than number of firms to account for the different impact of large vs. small companies, and hence to more accurately distribute the investment. This produces a "map" of manufacturing activity across the United States based on firms that have the technical potential to become active manufacturers of PV components. Third, we distribute manufacturing job creation according to this same map. The Roadmap projects direct employment increasing by 42,000 jobs by 2015 – 80% of these jobs will be in manufacturing.

The 14 identified components fall into 11 distinct industries, as shown in the table below. The results of this initial research into the distribution of manufacturing activity are encouraging; there are currently over 10,000 firms in the United States operating in these 11 industries.

U.S. Summary Table – Manufacturing Firms with Technical Potential to Enter Solar PV Market

NAICS code	Code Description	Total Employees	Annual Payroll ($1000s)	Number of Establish-ments
325211	Plastics Material and Resin Manufacturing	61,065	3,613,242	621
326113	Unlaminated Plastics Film and Sheet (Except Packaging) Manufacturing	53,385	2,092,790	787
327211	Flat Glass	11,628	582,045	80
331422	Copper Wire (except Mechanical) Drawing	4,264	146,575	61
332322	Sheet Metal Work Manufacturing	142,604	4,704,414	4,479
334413	Semiconductors and Related Devices	225,078	15,016,106	1,177
334515	Instrument Manufacturing for Measuring and Testing Electricity and Electrical Signals	62,447	4,267,812	769
335313	Switchgear and Switchboard Apparatus Manufacturing	44,506	1,784,286	580
335911	Storage Batteries	22,995	837,254	138
335931	Current-Carrying Wiring Device Manufacturing	43,665	1,457,096	508
335999	Electronic Equipment and Components, NEC	42,546	1,780,246	979
Total		**714,183**	**36,281,866**	**10,179**

Location of Construction and Installation

The location of construction and installation depends on the number of PV systems installed in a geographic region. To determine the distribution by state, this Report uses a study conducted for the Energy Foundation that predicts the "potential demand" in MW by state for the year 2010. The prediction is a function of the available roof area and the projected payback period – itself a function of projected price of the system, local utility electric rates, and other factors such as rebate and buydown programs.

This Report takes the $7 billion for construction and installation from the PV Roadmap goals for 2015, and allocates it to each state according to the predicted demand. Job creation is again allocated in the same manner as investment.

Solar PV Components

For this Report we broke solar PV systems down into 14 separate components. Each component is identified with a ten-digit and therefore a six-digit North American Industrial Classification System (NAICS) code.

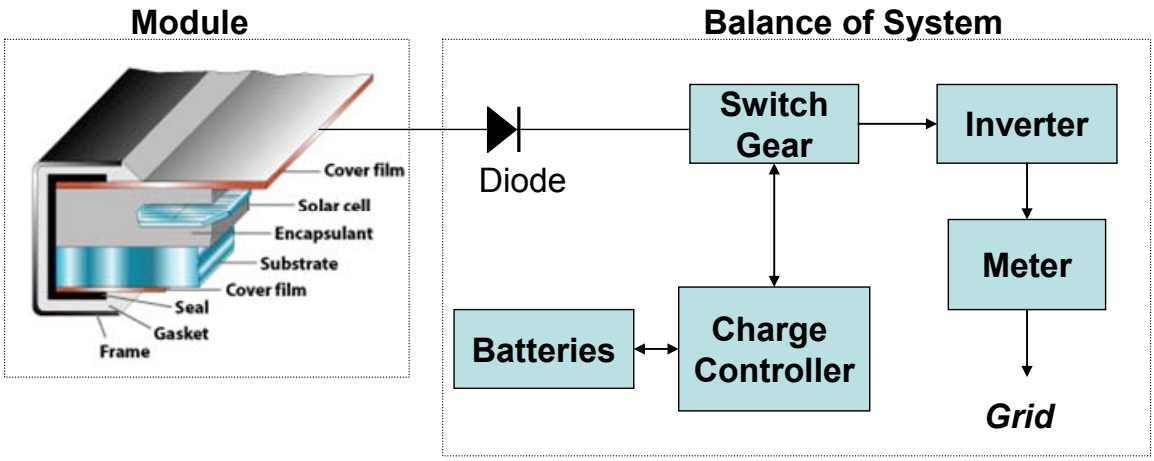
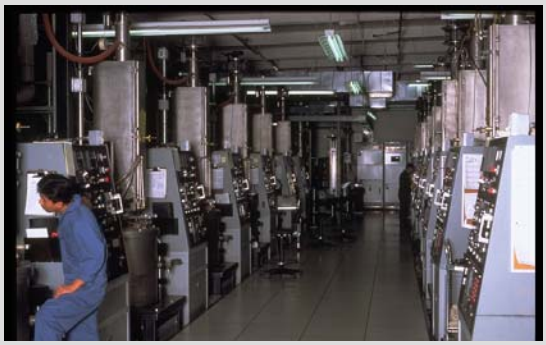


Figure 1 – Photovoltaic System Components

Description of Module Components

Subcomponent	Description
Solar Cell	A photovoltaic cell is any device that transforms light energy into electric energy. Current cells consist primarily of a semiconductor material, in which photons are absorbed from the incoming light to create free electrons.
Top Surface	The top surface, usually glass or transparent plastic, allows light to enter the cell while protecting the delicate cells from damage. The top surface often has an antireflective coating as well, to increase the fraction of light transmitted.
Encapsulant	The encapsulant protects the cells, and holds together the top surface, PV cells and rear surface. Ethyl vinyl acetate (EVA) is the most common encapsulant used in flat plate modules.
Rear Layer	The rear layer protects the back surface of the module, and prevents water and gases from entering the module. Tedlar (a thin polymer sheet) is a common material for the rear layer.
Electrical Connections	Metal conductors carry electrons out of the cells, connecting the cells in the module in series or parallel, and carry electricity out of the module.
Frame	The frame adds structure to the module, and can attach to the mounting structure.

Shell Solar Silicon Ingot Production Facility, Vancouver, WA



Sixty-nine Czochralski pullers melt silicon at 1400 degrees and slowly crystallize the silicon to form a single crystal ingot. *Credit: Shell Solar Industries.*

Shell Solar Industries produces silicon ingots from their factory in Vancouver, Washington, for use in solar photovoltaic modules. The plant has been producing ingots for over 20 years. There are a total of 69 crystal pullers, which produce approximately 15 miles of ingots per year.

Ingot production can be broken down into three steps: cleaning the silicon, growing single crystals at high temperatures, and shaping the ingot to dimensions usable for wafer production. Two or three boxes of 400-millimeter ingots are shipped from the factory daily.

There are roughly 110 employees in Vancouver, the majority of which are devoted to materials handling. The breakdown of employment is as follows:

Silicon cleaning	10 people
Crystal growing	60 people
Ingot shaping	15 people
Maintenance	15 people
Management	10 people

This worker is transforming the round ingot into a rectangular form that can be sliced into thin wafers. *Credit*: Shell Solar Industries.

Description of Balance of System Components

Subcomponent	**Description**
Batteries	Used to store the electricity produced by the solar module, and then to provide power during times of insufficient sun. (Batteries and charge controllers are currently installed in only 1-2% of new systems due to high cost.)
Blocking Diode	The blocking diode is a semiconductor that keeps the battery from discharging through to the solar cells when there is no output from the cells to the battery.
Charge Controller	Regulates the flow of electricity to and from the battery in order to charge efficiently, and to protect the batteries from overcharging.
Circuit Breaker and Fuses	Both of these devices serve to protect the electronic circuitry, by breaking the connection to the system in the case of a current surge.
Inverter	The inverter converts direct-current (DC) electricity produced by the solar modules into alternating-current (AC) electricity. They are designed to meet utility requirements for system and user protection.
Meter	Used particularly in grid connected systems to track the amount of energy produced by the PV system.
Switch Gear	Used to open and close the route that the electricity can flow through. Allows components of the system to be disconnected from one another.
Wiring	Necessary for connecting the PV system to the utility grid or battery and load and controlling the movement of electricity.

This Report identifies firms not currently active in domestic PV manufacturing but reasonably capable of providing components. The Report relied on the NAICS codes to identify the companies that could supply an expanded US PV industry. This required associating each component with the correct NAICS code, which was first done at the 10-digit (highest) level of detail to ensure that the codes were accurately identified. The six-digit codes are the standard level of reporting for industry classification, and hence were more useful for this study. For the 14 10-digit component codes there are 11 different 6-digit codes – some of the parts are similar and fall under the same code. For these components that go into a modern PV system, this analysis revealed that there are 10,179 firms that currently operate in one or more of these Industrial classifications. In other words, there are 10,179 firms in 50 states that are now engaged in manufacturing parts or components that are equivalent in terms of manufacturing skills and equipment needs to those required to manufacture components for PV systems. Our analysis of course does not draw the conclusion that all these firms will benefit. Rather, it shows where a technical potential to benefit from a major development of PV exists.

BP Solar Manufacturing Facility, Frederick, MD

Frederick, Maryland-based BP Solar is a unique example of a "vertically integrated" PV module manufacturing facility. The plant controls the intermediate processes of its module production, including silicon ingot casting, silicon cell fabrication, solar cell metallization, lamination and assembly. The end products are multicrystalline and monocrystalline PV modules for use in commercial and residential buildings.

This 194,000 ft^2 BP Solar plant will double PV module output and add 115 workers in 2005. *Credit*: BP Solar.

BP Solar (formerly Solarex) opened its Frederick operations in 1982. The 194,400-square-foot plant currently employs 420 workers. About 90 percent of the jobs are on the floor in line production and management.

Recently, the company announced that it is spending $25 million to enlarge the Frederick plant by about 1,500 square feet, acquire new equipment, and add about 115 workers by the end of 2005. Plans primarily call for hiring factory workers, but some sales and marketing employees may be hired, too.

Credit: BP Solar.

The Frederick plant expansion ensures that BP Solar will remain the largest North American producer of solar silicon wafers, expanding its casting and wafering capacity. Cell, module, casting and wafering growth will be complete by the end of 2005. The expansion supports BP Solar's strategic growth plan to increase its global production capacity from 90 MW to 200 MW by the end of 2006. The company also announced a distribution agreement with Home Depot to carry its new ready-to-install PV kit, BP Solar Home Solutions.

CHAPTER ONE – LOCATION OF POTENTIAL MANUFACTURING ACTIVITY

If the goals outlined in the PV Roadmap are pursued, the economic impact will spread far beyond the current active firms. Companies currently engaged in manufacturing processes similar to the manufacturing of photovoltaic system components could potentially transfer their capabilities to this new market. For example, a company that makes glass plate could potentially begin making top surface glass for PV modules; a silicon semiconductor company could begin making silicon solar cells. In order to take a look at the size and location of this potential market, REPP uses an approach based on the North American Industrial Classification System, or NAICS, which the U.S. Census Bureau adopted in 1997. The results of this study indicate that 10,179 firms, located across all 50 states, operate in industries similar to the manufacturing of PV components.

Using the NAICS to Locate Similar Manufacturing Companies

In the Economic Census conducted by the U.S. Census Bureau, every firm operating in North America reports one or more NAICS codes, indicating what types of products or services they provide. Companies reporting the same NAICS code are involved in similar activities, for example every company that reports "334413" manufactures some type of semiconductor. Using this system, REPP was able to tabulate the companies involved in activities similar to the manufacturing of PV components.

The NAICS codes have several levels of detail, up to ten digits, with each digit indicating a higher level of detail. For example, a first digit of 3 indicates Manufacturing, 334 is Computer and Electronic Product Manufacturing, 334413 is Semiconductor and Related Device Manufacturing, and 334413A005 is Solar Cells. This system replaced the older System of Industrial Classification, or SIC codes. Each PV component can be matched with a 10-digit code, and hence also a 6-digit code, as shown in Table 1.1.

Table 1.1 - Solar Component NAICS Codes

Com-ponent	Sub Component	NAICS 6-digit	Code description	NAICS 10-dig.	Code description
Module	Complete Module	334413	Semiconductors and Related Devices	-A010	Photovoltaic modules
	Solar Cell	334413	Semiconductors and Related Devices	-A005	Solar Cells
	Top Surface	327211	Flat Glass	-1041	Flat glass, nonautomotive, other than pyrolytically coated, clear, less than 5.0 mm thick
	Encapsulant	325211	Plastic Material and Resin Manufacturing	-1160	Other thermoplastic resins and plastics materials
	Rear Layer	326113	Unlaminated Plastics Film and Sheet Manufacturing	-0453	Other unlaminated plastics film and sheet
	Electrical Connections	335931	Current-Carrying Wiring Device Manufacturing	-7100	Current-carrying metal contacts, including precious metal
	Frame	332322	Sheet Metal Work Manufacturing	-G331	Other aluminum sheet metal work
Balance of System	Batteries	335911	Storage Batteries	-4207	All other lead acid storage batteries, larger than BCI dimensional size group 8D (1.5 cu ft or .042 cu m and smaller), including starting, lighting, and ignition
	Blocking Diode	334413	Semiconductors and Related Devices	-7015	Semiconductor rectifiers - power diodes and assemblies
	Charge Controller	335999	Electronic Equipment and Components, NEC	-3104	Semiconductor battery chargers, industrial and railroad
	Circuit Breaker	335313	Switchgear and Switchboard Apparatus Manufacturing	-1100	Power circuit breakers, all voltages
	Inverter	335999	Electronic Equipment and Components, NEC	-3219	Other rectifying (power conversion) apparatus (except for electronic circuitry)
	Meter	334515	Instrument Manufacturing for Measuring and Testing Electricity and Electrical Signals	-1105	Integrating instruments, electrical, demand meters, kW and kVA, combined watt-hour and demand meters (single phase and polyphase), and combined watt-hour and time switch meters
	Switch Gear	335313	Switchgear and Switchboard Apparatus Manufacturing	-A100	Switchgear, except ducts and relays
	Wiring	331422	Copper Wire (Except Mechanical) Drawing	-4213	Insulated copper wire and cable for electrical transmission, made in plants that draw wire

Advantages to Using the 6-digit Codes
The 6-digit NAICS codes replaced the 4-digit SIC codes, which were the highest level of detail available in the SIC. Hence the 6-digit NAICS are the standard level reported by all companies in North America, with the 10-digit codes providing additional detail. The U.S. Census Bureau itself provides data primarily at the 6-digit level, reporting 10 only at the request of a special study. Furthermore, for a given NAICS code and a given geographical area, such as a county, if there are less than 2 companies operating or if one company is dominant, disclosure rules require the Census to not report information for that particular code and for that area, to avoid disclosing private company information. The small number of companies reporting in a given 10-digit code makes it unlikely that information would be available for all codes and states. Therefore, for this study we had to rely on the 6-digit codes. Additionally, the specificity of a 10-digit code could have excluded companies with good potential for entering the PV market, which the 6-digit industry code includes.

Table 1.2 – NAICS 6-digit Codes Associated with PV Components

NAICS 6-digit	NAICS Description	Components
325211	Plastics Material and Resin Manufacturing	Encapsulant
326113	Unlaminated Plastics Film and Sheet (Except Packaging) Manufacturing	Rear Layer
327211	Flat Glass	Top Surface
331422	Copper Wire (except Mechanical) Drawing	Wiring
332322	Sheet Metal Work Manufacturing	Frame
334413	Semiconductors and Related Devices	Solar Cells, Blocking Diode
334515	Instrument Manufacturing for Measuring and Testing Electricity and Electrical Signals	Meter
335313	Switchgear and Switchboard Apparatus Manufacturing	Circuit Breakers and Fuses
335911	Storage Batteries	Batteries
335931	Current-Carrying Wiring Device Manufacturing	Module Electrical Connections, Switch Gear
335999	Electronic Equipment and Components, NEC	Charge Controller, Inverter

Caveat to Using the 6-digit Codes
When interpreting the results of a 6-digit code search, it is important to be aware of the potential broadness of companies included. For example, under the 6-digit NAICS, charge controllers and inverters fall under "Electronic Equipment and Components, Not Easily Classified." Along with rectifying equipment, such as inverters, this also includes laser power supplies and ultrasound equipment. However, this is mostly a problem for this particular code, the other 10 NAICS codes used in this study, shown in Table 1.2, have much less variation of product type. Furthermore, even a company that makes laser power supplies has a significant advantage over a company starting from scratch, as they have basic knowledge and capabilities for making sophisticated electrical equipment.

Potential for PV System Component Manufacturing, Throughout the United States
In the United States, there are more than 10,000 companies operating in the NAICS codes identified for PV components. These companies employ over 700,000 employees, with an annual payroll of more than $36 billion.

Table 1.3 – Manufacturing Activities Similar to PV Components – Summary for Entire United States

NAICS code	Code Description	Total Employees*	Annual Payroll ($1000s)	Number of Establish-ments
325211	Plastics Material and Resin Manufacturing	61,065	3,613,242	621
326113	Unlaminated Plastics Film and Sheet (Except Packaging) Manufacturing	53,385	2,092,790	787
327211	Flat Glass	11,628	582,045	80
331422	Copper Wire (except Mechanical) Drawing	4,264	146,575	61
332322	Sheet Metal Work Manufacturing	142,604	4,704,414	4,479
334413	Semiconductors and Related Devices	225,078	15,016,106	1,177
334515	Instrument Manufacturing for Measuring and Testing Electricity and Electrical Signals	62,447	4,267,812	769
335313	Switchgear and Switchboard Apparatus Manufacturing	44,506	1,784,286	580
335911	Storage Batteries	22,995	837,254	138
335931	Current-Carrying Wiring Device Manufacturing	43,665	1,457,096	508
335999	Electronic Equipment and Components, NEC	42,546	1,780,246	979
Total		**714,183**	**36,281,866**	**10,179**

* Number of Employees reported for the middle of March, 2001.

These 10,179 companies are well distributed throughout the United States, with every one of the 50 states involved in some manufacturing activity that is similar to the production of PV components. A significant number of potential entrants to the PV market are situated in each census division of the country, as shown in Table 1.4.

Table 1.4 – Distribution of Potential Manufacturing Activity, by Division

Region	Division	325211 Plastics Material and Resin Manufacturing	326113 Unlaminated Plastics Film and Sheet (Except Packaging) Manufacturing	327211 Flat Glass	331422 Copper Wire (except Mechanical) Drawing	332322 Sheet Metal Work Manufacturing	334413 Semiconductors and Related Devices	334515 Instrument Manufacturing for Measuring and Testing Electricity …	335313 Switchgear and Switchboard Apparatus Manufacturing	335911 Storage Batteries	335931 Current-Carrying Wiring Device Manufacturing	335999 Electronic Equipm Components, NEC	Totals
Midwest	East North Central	126	149	15	12	701	67	93	137	20	114	168	**1,602**
	West North Central	36	105	11	1	364	51	45	55	20	42	63	**793**
Northeast	Middle Atlantic	82	158	10	10	696	160	115	83	23	110	179	**1,626**
	New England	24	39	2	12	215	96	62	18	3	30	59	**560**
South	East South Central	37	27	6	1	147	7	8	27	9	10	22	**301**
	South Atlantic	112	123	14	8	704	93	78	100	22	77	122	**1,453**
	West South Central	110	63	6	6	589	150	69	63	13	40	112	**1,221**
West	Mountain	6	26	2	0	189	78	40	18	5	14	48	**426**
	Pacific	88	97	14	11	874	475	259	79	23	71	206	**2,197**
	Component Total:	**621**	**787**	**80**	**61**	**4479**	**1177**	**769**	**580**	**138**	**508**	**979**	**10,179**

Table 1.5 ranks the states in order of total number of firms operating in the state in all 11 of the NAICS industries associated with PV. While looking at the number of firms gives a rough idea of the current size of an industry, it does not account for the size of the firms themselves. A firm with 1,000 employees entering the PV manufacturing market would likely have a larger financial impact than one with 10 employees. To get a more accurate picture of the size of each industry in the potential PV manufacturing market, Table 1.6 ranks the states by total number of employees.

A Note about Disclosure Rules and Employment Numbers

Federal disclosure rules prohibit census data from being released if there are too few companies in a given area, or if one company dominates such that a person looking at the information could determine information for a specific company. However, even in these cases the total number of establishments is still published, as well as the number of establishments in each size class (i.e. number of companies with 1-4 employees, 5-9 employees, and so on). These size class numbers can be used to calculate an average guess at the number of employees working in a given region. Numbers that are italicized in the employment tables indicate a case where this method was used. Numbers in regular type did not fall under the disclosure rules and are the number of employees reported for mid-March 2001 by the Census bureau. Slight variation in total employment stated for the entire U.S. and for the sum of the 50 states is due to use of this method.

Table 1.5 – Number of Establishments – by State

State	325211 Plastics Material and Resin Manufacturing	326113 Unlaminated Plastics Film and Sheet (Except Packaging) Manufacturing	327211 Flat Glass	331422 Copper Wire (except Mechanical) Drawing	332322 Sheet Metal Work Manufacturing	334413 Semiconductors and Related Devices	334515 Instrument Manufacturing for Measuring and Testing Electricity …	335313 Switchgear and Switchboard Apparatus Manufacturing	335911 Storage Batteries	335931 Current-Carrying Wiring Device Manufacturing	335999 Electronic Equipme Components, NEC	Totals
California	65	80	11	8	664	422	215	58	19	68	181	**1,791**
Texas	73	38	3	4	369	94	43	39	8	27	71	**769**
Ohio	46	50	4	-	224	15	33	50	6	33	39	**500**
New York	13	40	2	5	227	47	39	28	8	28	57	**494**
Illinois	37	41	7	5	176	26	27	45	8	40	64	**476**
Pennsylvania	29	39	5	-	211	47	26	27	7	35	42	**468**
Florida	19	24	2	1	197	34	28	18	2	26	55	**406**
New Jersey	24	50	2	2	156	43	35	19	4	27	42	**404**
Massachusetts	20	31	1	9	147	67	44	12	3	23	38	**395**
Michigan	29	28	3	1	171	15	22	35	3	18	34	**359**
Indiana	14	30	1	6	130	11	11	7	3	23	31	**267**
North Carolina	28	28	6	2	112	19	7	15	3	12	16	**248**
Georgia	23	26	1	1	115	5	9	19	9	11	8	**227**
Minnesota	6	25	2	-	101	20	16	13	3	11	21	**218**
Wisconsin	15	31	4	1	96	10	13	15	3	10	19	**217**
Connecticut	7	21	1	3	90	19	11	9	4	16	34	**215**
Washington	9	8	1	2	114	23	21	11	1	1	18	**209**
Arizona	5	5	-	1	80	49	14	8	1	6	20	**189**
Colorado	2	13	-	-	67	38	27	10	4	6	22	**189**
Oregon	14	8	2	1	84	29	22	9	3	2	7	**181**
Missouri	8	21	-	-	88	8	6	12	5	12	11	**171**
Virginia	5	13	-	1	77	17	10	11	2	6	11	**153**
Alabama	9	7	1	-	83	6	9	13	1	12	10	**151**
Tennessee	10	16	4	1	59	6	3	13	6	5	13	**136**
Oklahoma	3	11	2	-	67	4	9	7	1	2	10	**116**
Kentucky	17	8	2	-	60	1	3	10	2	3	5	**111**
Maryland	4	4	1	1	54	11	9	7	2	4	10	**107**
New Hampshire	3	5	-	1	37	22	16	4	-	5	14	**107**
South Carolina	13	14	1	1	39	-	3	12	1	4	8	**96**
Louisiana	25	6	1	-	36	1	2	7	2	1	6	**87**
Utah	2	4	1	-	45	9	1	1	-	2	9	**74**
Kansas	2	6	1	-	30	4	5	5	6	3	7	**69**
Arkansas	4	3	-	1	37	2	1	2	1	4	5	**60**
Iowa	3	11	3	-	26	4	3	4	3	1	2	**60**
Mississippi	10	3	-	-	28	-	2	4	1	2	4	**54**
Nevada	-	4	-	-	29	5	6	3	1	1	4	**53**
New Mexico	1	1	-	-	18	15	2	2	-	3	7	**49**
Rhode Island	9	8	-	-	12	4	4	-	-	4	4	**45**
Idaho	1	1	-	-	23	9	-	1	-	1	3	**39**
Maine	1	1	1	-	21	5	2	1	-	1	2	**35**
Nebraska	-	6	1	-	14	1	1	4	-	5	3	**35**
West Virginia	5	1	2	1	14	1	3	2	1	1	2	**33**
Delaware	6	6	-	-	12	-	-	3	1	-	2	**30**
Vermont	-	2	-	2	10	2	-	1	-	1	5	**23**
South Dakota	2	4	-	-	6	3	1	2	-	-	-	**18**
Montana	-	2	1	-	4	2	2	1	-	1	2	**15**
Alaska	-	-	-	-	7	-	-	1	-	-	-	**8**
Hawaii	-	1	-	-	5	1	1	-	-	-	-	**8**
Wyoming	-	1	-	-	3	-	2	-	-	-	1	**7**
North Dakota	-	1	-	-	3	1	-	-	-	-	-	**5**
D.C.	-	-	-	-	1	-	-	-	-	1	-	**2**
U.S. Total	621	787	80	61	4,479	1,177	769	580	138	508	979	**10,179**

Table 1.6 – Number of Employees – by State

State	325211 Plastics Material and Resin Manufacturing	326113 Unlaminated Plastics Film and Sheet (Except Packaging) Manufacturing	327211 Flat Glass	331422 Copper Wire (except Mechanical) Drawing	332322 Sheet Metal Work Manufacturing	334413 Semiconductors and Related Devices	334515 Instrument Manufacturing for Measuring and Testing Electricity …	335313 Switchgear and Switchboard Apparatus Manufacturing	335911 Storage Batteries	335931 Current-Carrying Wiring Device Manufacturing	335999 Electronic Equipment Components, NEC	Totals
California	1,840	2,986	1,167	928	22,971	50,901	23,037	2,136	2,054	3,012	10,736	**121,768**
Texas	16,285	4,723	752	382	12,057	44,974	1,502	3,084	157	1,382	2,200	**87,498**
Pennsylvania	3,332	2,880	1,336	-	7,239	10,046	899	1,854	2,308	3,302	924	**34,119**
Illinois	3,400	1,999	793	473	6,400	681	1,001	6,180	786	7,669	2,968	**32,350**
New York	1,141	1,602	409	245	6,889	10,378	2,313	565	413	2,285	2,690	**28,930**
Ohio	3,808	2,778	394	-	7,469	1,510	1,929	3,292	943	2,390	3,195	**27,708**
Massachusetts	1,148	2,729	3	688	4,079	6,930	4,349	1,187	84	1,851	2,826	**25,873**
Arizona	194	229	-	7	2,856	20,213	535	127	7	51	751	**24,969**
North Carolina	2,151	2,160	571	37	3,678	4,190	810	1,698	1,159	3,216	535	**20,203**
Oregon	444	484	109	35	2,399	10,673	3,992	236	180	5	238	**18,793**
New Jersey	1,896	2,589	177	77	4,773	3,734	962	698	638	1,521	1,087	**18,152**
Indiana	1,977	2,881	35	375	4,668	404	1,603	979	486	1,584	2,043	**17,033**
Florida	648	526	42	7	4,707	3,660	627	1,587	1,124	1,776	1,726	**16,430**
Michigan	3,570	1,421	556	35	3,811	431	560	1,085	40	1,792	904	**14,204**
Washington	172	514	175	177	3,752	4,338	3,303	273	7	175	481	**13,366**
Wisconsin	715	1,687	571	7	5,362	606	344	1,347	416	997	411	**12,463**
Georgia	1,343	2,357	3	75	2,930	16	448	1,938	1,859	586	253	**11,806**
Missouri	272	1,418	-	-	2,194	2,354	528	1,134	2,223	1,026	500	**11,648**
Virginia	238	2,836	-	35	2,772	3,768	300	678	10	123	564	**11,323**
Minnesota	140	1,916	17	-	3,728	2,812	872	470	44	212	1,093	**11,304**
Colorado	29	312	-	-	1,996	5,391	2,514	141	286	44	386	**11,099**
South Carolina	2,452	1,971	375	375	945	-	764	2,058	750	618	316	**10,621**
Tennessee	1,033	880	2,127	15	2,188	92	56	1,556	376	414	381	**9,115**
Kentucky	2,962	780	209	-	1,711	7	17	1,904	924	284	97	**8,894**
Connecticut	398	824	7	180	1,442	924	365	875	258	1,040	2,007	**8,319**
Louisiana	4,366	896	3	-	966	3	49	266	409	3	179	**7,138**
New Mexico	3	35	-	-	290	4,968	22	764	-	17	247	**6,344**
New Hampshire	104	201	-	15	1,100	1,405	1,303	359	-	1,173	384	**6,041**
Alabama	1,119	236	3	-	2,214	431	264	203	35	1,035	246	**5,784**
Iowa	384	950	452	-	720	51	216	2,099	724	7	29	**5,631**
Kansas	42	727	375	-	1,220	48	789	164	1,616	324	46	**5,350**
Maryland	79	416	15	7	1,734	771	564	1,225	5	34	271	**5,120**
West Virginia	3,349	15	409	175	669	3	116	249	75	3	49	**5,110**
Idaho	3	7	-	-	857	3,665	-	3	-	175	152	**4,860**
Oklahoma	104	1,138	752	-	1,592	218	300	317	35	17	296	**4,768**
Mississippi	1,053	483	-	-	1,365	-	177	426	375	249	358	**4,486**
Utah	69	214	7	-	1,485	1,739	175	35	-	177	359	**4,259**
Rhode Island	103	1,040	-	-	452	1,001	158	-	-	1,091	391	**4,235**
Maine	3	375	75	-	1,461	1,789	37	3	-	175	77	**3,993**
Arkansas	146	439	-	175	888	10	3	249	375	934	161	**3,378**
Nebraska	-	44	7	-	326	15	35	961	-	621	1,243	**3,250**
Nevada	-	413	-	-	1,034	261	1,126	52	3	15	182	**3,084**
Delaware	747	363	-	-	688	-	-	49	375	-	89	**2,310**
Vermont	-	49	-	37	479	1,003	-	15	-	7	233	**1,822**
South Dakota	77	186	-	-	128	32	175	10	-	-	-	**607**
Montana	-	37	7	-	59	37	382	3	-	3	17	**543**
Hawaii	-	3	-	-	121	3	375	-	-	-	-	**500**
North Dakota	-	7	-	-	44	375	-	-	-	-	-	**426**
Wyoming	-	35	-	-	44	-	10	-	-	-	3	**90**
Alaska	-	-	-	-	52	-	-	3	-	-	-	**55**
D.C.	-	-	-	-	15	-	-	-	-	3	-	**17**
U.S. Total	63,331	53,786	11,925	4,556	143,000	206,857	59,901	44,531	21,550	43,408	44,318	**697,161**

CHAPTER TWO – ECONOMIC IMPACT OF SOLAR PHOTOVOLTAIC INVESTMENT

To fully measure the potential economic impact of solar PV development, the economic stimulus related to the investment must be traced beyond the Installation and Operations and Maintenance phases back to the manufacturing activity related to the components that go into the systems. If PV development is seen solely as an effort to put new systems on-line, then the benefits of development will be seen as largely accruing to the communities and states that have good resources and can host the developments. However, the benefits of investment in PV are not limited to the localities where the installations occur.

A large solar development program will also stimulate manufacturing activity in communities distant from where the actual installations occur. This Chapter traces the potential boost a major solar development effort would provide to both investment and job creation stimulus in regions and specific states.

Impact of PV Industry Roadmap

To provide an aggressive but acheivable estimate of market development, REPP relied on the PV Industry Roadmap Document. This document estimates that 9,600 MW total PV capacity will exist in the United States by 2015, up from 340 MW in 2004. According to the roadmap, the installed system price in 2015 will be $3.68/W. Based on this cost estimate, the 9,260 MW of new capacity represents $34 billion worth of investment. In actuality the investment would be somewhat higher as some systems would be installed at a higher cost prior to 2015. For simplicity, this Report uses the $34 billion as a conservative estimate of the investment.

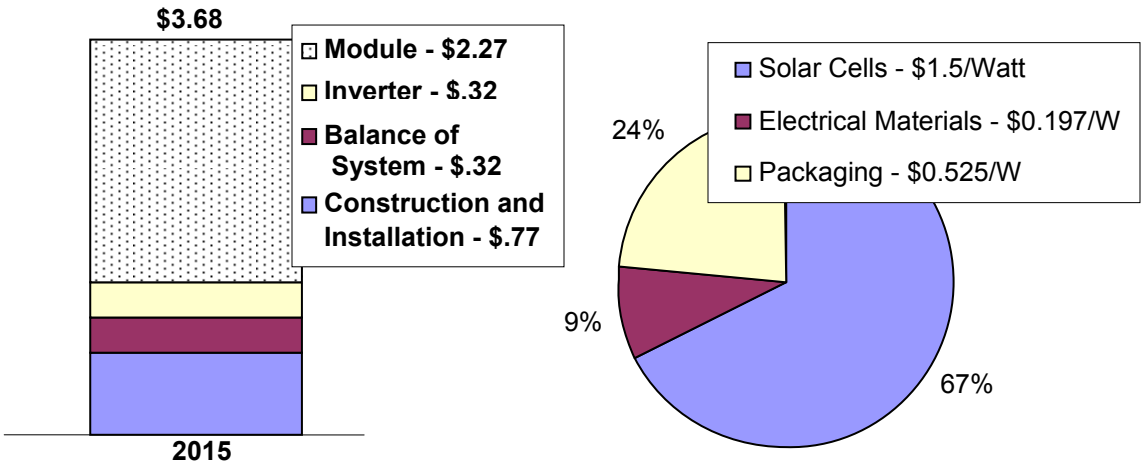
The PV Roadmap also predicts that by 2015 there will 62,000 annual full-time jobs created in the U.S. PV industry. According to several recent REPP analyses, roughly 80% of the new job creation potential related to solar development is in the manufacturing sector, and most of the remaining 20% is in construction and installation of the systems. Operation and maintenance also account for a very small percentage not considered for this Report. This same 80-20 breakdown is assumed in the PV Roadmap, meaning that 33,600 jobs would be created in manufacturing, and 8,400 in construction and installation.

For this Report, analysis of the 9,260 MW development proceeds in three steps. First we determine how the total cost of the new PV development will flow into demand for the various components of the systems. Second, we spread the total demand among the regions of the country. We allocate the manufacturing dollars according to the number of firms in each region with the technical potential to manufacture PV components, and the installation dollars according to the potential demand for PV installations. Third, we distribute the job allocation according to the same location information for manufacturing and installation. This results in a geographic "map" of investment and job location.

Solar PV System Cost Breakdown

The allocation of investment among regions and states is based in part on the determination of how the capital cost of an installed project breaks down into the various cost categories. For this report the system cost breakdown from the PV Roadmap is used. As shown in the chart below, the PV Roadmap provides a predicted cost of each component for the year 2015. In order to obtain a higher level of detail, this Report then further breaks down the cost of the module according to a cost study from the National Renewable Energy Lab's Solar Energy Technologies Program. As shown below the NREL cost breakdown shows the fraction of the total module cost that goes into different module components. Both the PV Roadmap and the NREL cost assumptions are based on grid-connected systems.

Figure 2.1 – Solar PV System and Module Manufacturing Cost Breakdown



As a result of these two cost breakdowns, we have cost information for 5 part categories plus construction and installation. In order to use this cost data, the 14 individual PV components are grouped into these 5 categories. The "Module Solar Cells" group consists of the solar cells, "Module Electrical Materials" consists of the electrical connections within the module, and "Module Packaging" consists of the top surface, encapsulant, rear layer and frame. The "Inverter" group consists of the inverter. The "Balance of System" has the most components, consisting of the batteries (where applicable), blocking diode, charge controller, circuit breakers and fuses, meter, switch gear, and wiring. According to the above cost information, $27 billion of the total $34 billion investment goes into manufacturing the components, and $7 billion goes into construction and installation. The manufacturing investment is further broken down as shown in the following table.

Table 2.1 – Manufacturing Investment Allocation into Component Groups

Description	Module			Inverter	Balance of System	All Components
Component Cost Fraction[1]	78.0%			11.0%	11.0%	100%
Subcomponent Description	Solar Cells	Electrical Materials	Packaging			
Subcomponent Fraction of Component Cost[2]	67.5%	8.9%	23.6%	100.0%	100.0%	
Subcomponent Overall Cost Fraction	**52.7%**	**6.9%**	**18.4%**	**11.0%**	**11.0%**	**100%**
Investment Allocation (in Millions of $)	**$14,187**	**$1,871**	**$4,960**	**$2,964**	**$2,964**	**$26,946**

Manufacturing Investment Allocation

The $27 billion total manufacturing investment is allocated among the component groups according to the relative cost of the component to the total cost. The cost allocated to each component group is then allocated to states and geographic regions according to the number of employees working for companies with the technical potential to manufacture components in that component group. The number of employees is used rather than number of firms to account for variation in size of the firms. A firm employing 1,000 people will bring a larger investment to a region than one employing 10. To illustrate the allocation, consider the Inverter group which accounts for 11% of the manufacturing cost of PV, so $2.96 billion of the $26.95 billion total is then allocated to inverters. According to the NAICS data there 5,368 employees in California working for companies in the NAICS industry associated with inverters, and 22,159 working in that industry in the entire U.S. So California has 24% of the employees in the nation in NAICS codes related to inverters, and so gets 24% of the $2.96 billion allocated to inverters, or $710 million.

This same allocation is done for each component group, and to find the total investment in a given state, we simply add the resulting investment from each of the 5 component groups. This allocation produces a "map" of manufacturing activity across the United States based on firms that have the technical potential to become active manufacturers of PV components. As mentioned above, 33,600, or 80% of the total 42,000 new jobs predicted by the PV Roadmap by 2015 would be in manufacturing. This Report assumes that the manufacturing job allocation will follow the investment allocation, and uses the same component cost breakdown to allocate the 33,600 jobs geographically according to the same formula shown in the example above for California.

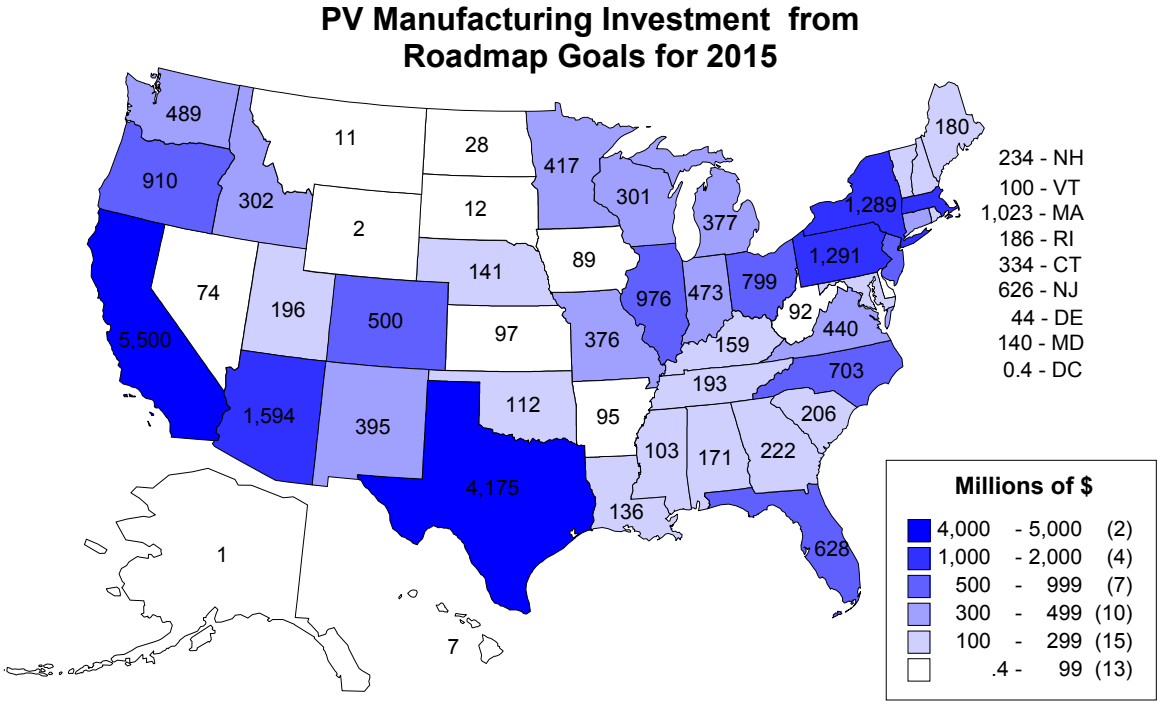


Figure 2.2 – Manufacturing Map

Some of the 11 NAICS codes considered are associated with more than one component group. To maintain the integrity of the data in this case, the amount of manufacturing activity for a given code is divided evenly amongst the applicable component groups. For example, 335999 applies to both the Inverter group (inverter) and the Balance of System group (charge controller). Hence, for a given geographic region such as a state, half the companies would be counted in Inverter,

and half in Balance of System. A code applying to 3 component groups would be divided in thirds.

Construction and Installation Investment Allocation

Based on the PV Roadmap goals for 2015, $7 billion worth of investment and 12,400 annual jobs would go to construction and installation of PV systems. This economic development will go to locations where the systems are installed. To obtain a geographic map of installations similar to the one for manufacturing, this Report uses the results of a study conducted by Navigant Consulting for the Energy Foundation. The EF report predicts the potential demand for PV by state in 2010. Their calculation of potential demand depends on two factors: the technical market – which is the absolute maximum potential based on available roof space and power density, and the payback period – which is the number of years it would take for a PV system to pay for itself. The payback period is based on a number of factors, primarily the cost of the system and the local utility electric rates. The calculations result in a potential demand in MW for each state and for several system price predictions. This Report uses the demand figures for a system price of $3.00 - $3.75 per Watt to match the PV Roadmap predicted cost of $3.68/W.

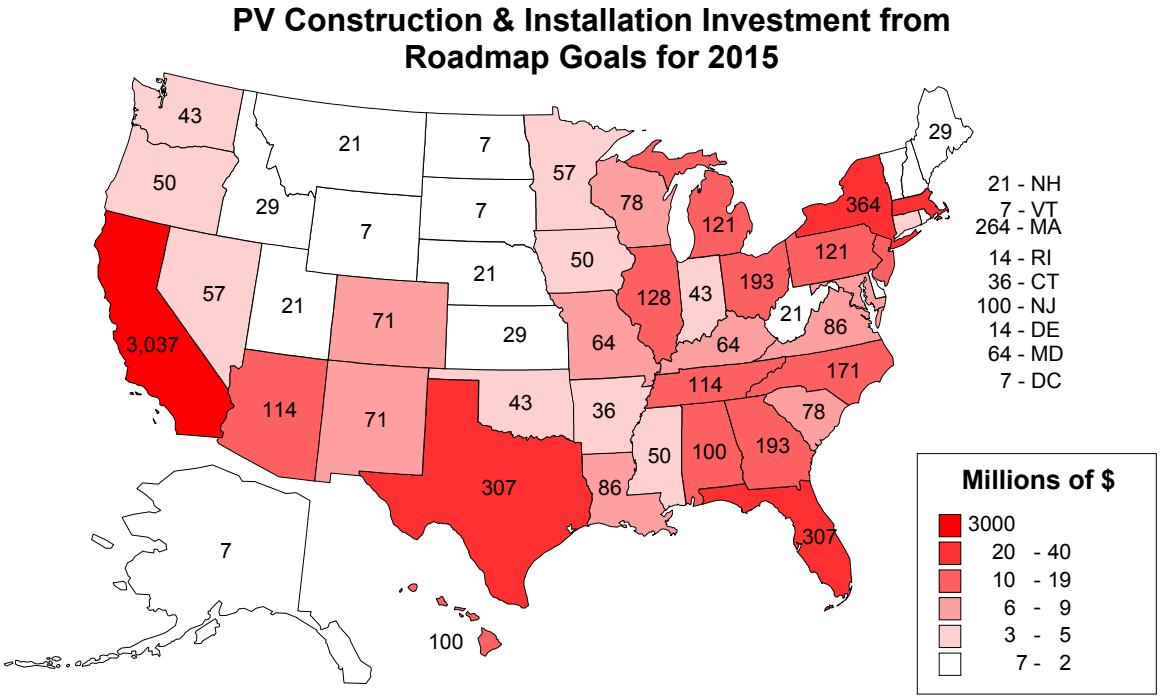


Figure 2.3 – Construction and Installation Map

Total Investment and Jobs, by State

To arrive at a complete picture of how the $34 billion and 42,000 annual jobs would be distributed throughout the country, we simply add the results for manufacturing and for construction and installation. The results for all 50 states are shown in the following table.

Table 2.2 – Total Investment and Jobs by State

State	Manufacturing		Const. & Install.		Totals	
	Jobs	$ Millions	Jobs	$ Millions	Jobs	$ Millions
California	6,858	5,500	3,578	3,037	**10,437**	**8,538**
Texas	5,205	4,175	361	307	**5,567**	**4,481**
Arizona	1,987	1,594	134	114	**2,122**	**1,708**
New York	1,607	1,289	428	364	**2,035**	**1,652**
Pennsylvania	1,610	1,291	143	121	**1,752**	**1,412**
Massachusetts	1,275	1,023	311	264	**1,586**	**1,286**
Illinois	1,217	976	151	128	**1,368**	**1,104**
Ohio	996	799	227	193	**1,223**	**991**
Oregon	1,134	910	59	50	**1,193**	**960**
Florida	783	628	361	307	**1,144**	**935**
North Carolina	876	703	202	171	**1,078**	**874**
New Jersey	781	626	118	100	**899**	**726**
Colorado	624	500	84	71	**708**	**572**
Washington	609	489	50	43	**660**	**531**
Virginia	549	440	101	86	**649**	**526**
Indiana	589	473	50	43	**640**	**515**
Michigan	470	377	143	121	**613**	**498**
Minnesota	520	417	67	57	**587**	**474**
New Mexico	493	395	84	71	**577**	**467**
Missouri	469	376	76	64	**545**	**440**
Georgia	277	222	227	193	**504**	**414**
Wisconsin	375	301	92	78	**467**	**379**
Connecticut	416	334	42	36	**458**	**370**
Idaho	376	302	34	29	**410**	**330**
Tennessee	240	193	134	114	**375**	**307**
South Carolina	257	206	92	78	**350**	**285**
Alabama	214	171	118	100	**331**	**271**
New Hampshire	291	234	25	21	**317**	**255**
Kentucky	199	159	76	64	**274**	**224**
Louisiana	169	136	101	86	**270**	**221**
Utah	245	196	25	21	**270**	**217**
Maine	224	180	34	29	**257**	**208**
Maryland	175	140	76	64	**251**	**204**
Rhode Island	232	186	17	14	**249**	**200**
Nebraska	176	141	25	21	**201**	**163**
Oklahoma	139	112	50	43	**190**	**154**
Mississippi	129	103	59	50	**187**	**153**
Iowa	111	89	59	50	**170**	**139**
Nevada	92	74	67	57	**159**	**131**
Arkansas	118	95	42	36	**160**	**131**
Kansas	121	97	34	29	**155**	**126**
West Virginia	115	92	25	21	**140**	**114**
Vermont	125	100	8	7	**134**	**108**
Hawaii	9	7.0	117.6	100	**126**	**107**
Delaware	55	44	17	14	**72**	**59**
North Dakota	35	28	8	7	**43**	**35**
Montana	13	10.6	25.2	21	**38**	**32**
South Dakota	15	11.7	8.4	7	**23**	**19**
Wyoming	2	1.7	8.4	7	**11**	**9**
Alaska	1	1.0	8.4	7	**10**	**8**
D.C.	0	0.4	8.4	7	**9**	**8**
U.S. Total:	33,600	26,947	8,392	7,123	**41,992**	**34,070**

AFG Industries Solar Glass Manufacturing Facility, Kingsport, Tennessee

Photovoltaics is a significant part of our current business and is growing as the solar electric industry expands in response to the demands for its products and services. This is especially true with the impacts of the building-integrated PV and architectural glass markets that are just beginning.
—*Chris Cording, 2001, AFG Glass, Inc.*

AFG's Blue Ridge Plant is the largest supplier of photovoltaic glass to the US solar industry.

Headquartered in Kingsport, Tennessee at its Blue Ridge Plant, AFG is the second largest flat glass manufacturer in North America. AFG operates 11 glass production lines at nine plants and employs about 7,000 people in North America, including 2,000 people in Northeast Tennessee.

Since 1978, AFG has been a major supplier of solar glass in the US and overseas. By 2001, the Blue Ridge Plant's fastest-growing product was its high-tech photovoltaic glass, which converts light to energy. Plant sales totaled $70 million a year, and its customers included Shell Solar, BP Solar, and GE Energy. The plant employed 330 people, and had an employee turnover rate that was half the industry average, with the average length of employee service about 13 years. Currently, roughly 40-50% of the capacity of the plant is devoted to solar glass production on a specialty line.

Availability of County Level Data for Manufacturing

Another advantage to examining potential manufacturing activity through the NAICS codes is the availability of information for every county in the U.S. This information makes it possible to determine how any local community would potentially benefit from a national investment in PV. For example, the Kingsport, TN and the float glass factory mentioned in the box above, is located in Sullivan County. A sample of county results for Tennessee, including Sullivan County, is shown in Table 2.3. Using this county information, it is then further possible to consider how pursuing the Roadmap goals, would benefit a given county. For example, Sullivan County would receive 9 new jobs and $6.9 million in manufacturing investment as a result of the PV Roadmap. The methodology used is the same as at the state level, simply using the geographic location information for the county level.

Table 2.3 – Number of Employees, Partial List of Tennessee Counties

County	**Employees at Potential Companies**	Solar Cells	Module Electrical Materials	Module Packaging	Inverter	Solar Balance of System	**Number of Jobs**	**Average Investment ($ Millions)**
Shelby, TN	**954**	3	-	917	15	19	**24**	**19.23**
Smith, TN	**-**	-	-	-	-	-	**-**	**-**
Statewide, TN	**-**	-	-	-	-	-	**-**	**-**
Stewart, TN	**-**	-	-	-	-	-	**-**	**-**
Sullivan, TN	**377**	-	-	377	-	-	**9**	**6.87**
Sumner, TN	**22**	-	-	15	-	7	**0**	**0.35**
Tipton, TN	**284**	-	-	35	-	249	**5**	**3.66**

CHAPTER THREE – SOLAR PHOTOVOLTAIC COMPONENTS

Major Components

Photovoltaic systems are essentially divided into two major parts: the photovoltaic module and the balance of system. The photovoltaic module includes the solar cells, and the packaging and electrical connections required by the cells. The balance of system includes components for managing the power provided by the cells, either storing it for later use in a battery system, or adapting the power to a form that can be interfaced with the existing electric grid, or often both.

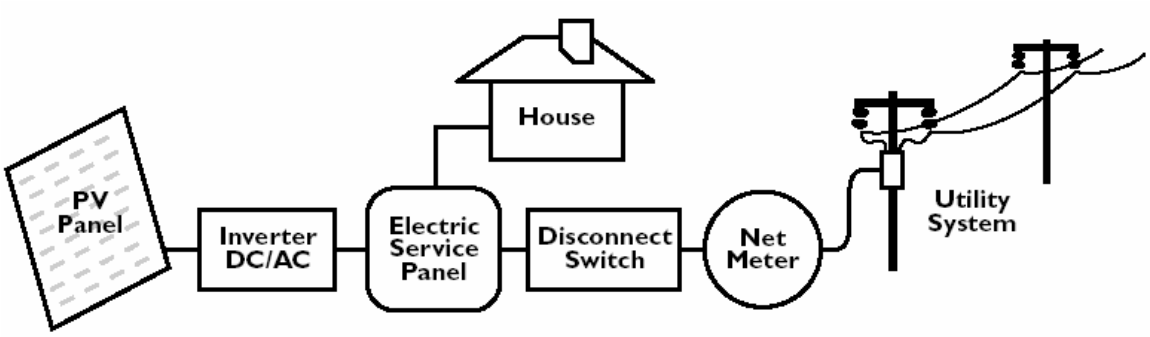


Figure 3.1 - Diagram of PV System Major Components

Module Components

There are currently two major types of solar modules: conventional and thin-film. In the United States, conventional modules account for more than 90% of the market and will be the main focus of this discussion. However, thin-film modules have most of the same components as conventional modules, so much of this component breakdown is applicable to thin-film as well.

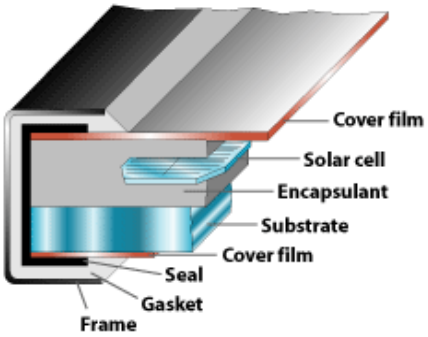


Image Source: EERE

Figure 3.2 - Schematic of Flat Plate Photovoltaic Module Components

Table 3.1 - Description of Module Components

Subcomponent	Description
Solar Cell	A photovoltaic cell is any device that transforms light energy directly into electric energy. Current cells consist primarily of a semiconductor material, in which photons are absorbed from the incoming light to create free electrons..
Top Surface	The top surface, usually glass or transparent plastic, allows light to enter the cell, while protecting the delicate cells from damage. The top surface often has an antireflective coating as well, to increase the fraction of light transmitted.
Encapsulant	The encapsulant protects the cells, and holds together the top surface, PV cells and rear surface. Ethyl vinyl acetate (EVA) is the most common material used for the encapsulant in flat plate modules.
Rear Layer	The rear layer protects the back surface of the module, and prevents water and gases from entering the module.
Electrical Connections	Metal conductors carry electrons out of the cells, connecting the cells in the module in series or parallel, and carry electricity out of the module.
Frame	The frame adds structure to the module, and can attach to the mounting structure.

Balance of System Components

The balance of system is a significant part of the cost of an installed photovoltaic system, and is responsible for controlling and managing the power output of the PV array. It primarily consists of an inverter to transform the direct-current (DC) output from the PV array into a form of alternating-current (AC) electricity that can be synchronized with and connected to the electric grid. Other equipment includes wiring, switches, an electric meter, and circuit breakers and fuses. Some systems are equipped with a charge controller and battery to provide backup power, but due to the large expense of batteries, they are currently included in only 1-2% of new installations.

Table 3.2 - Description of Balance of System Components

Subcomponent	Description
Batteries	Used to store the electricity produced by the solar module, and then to provide power during times of insufficient sun. For grid connected systems batteries can provide backup electricity in case of grid failure.
Blocking Diode	The blocking diode is a semiconductor that keeps the battery from discharging through to the solar cells when there is no output from the cells to the battery.
Charge Controller	Regulates the flow of electricity to and from the battery in order to charge efficiently, and to protect the batteries from overcharging.
Circuit Breaker	Both of these devices serve to protect the electronic circuitry, by breaking the connection to the system in the case of a current surge.
Inverter	The inverter converts direct-current (DC) electricity produced by the solar modules into alternating-current (AC) electricity. They are designed to meet utility requirements for system and user protection.
Meter	Used particularly in grid connected systems to track the amount of energy produced by the PV system.
Switch Gear	Used to open and close the route that the electricity can flow through. Allows components of the system to be disconnected from one another.
Wiring	Necessary for connecting the PV system to the utility grid or battery and load and controlling the movement of electricity.

U.S. Manufacturing Census
The U.S. Census Bureau conducts an Economic Census every 5 years that profiles the US economy, from the national to the local level. At the time of writing this Report, the 2002 Economic Census data was not yet fully released, and this Report uses data from the 1997 Census. The Census data is reported by economic sector. Data from the Manufacturing Sector report can potentially be used to geographically track the manufacturing and economic activity associated with PV systems and their subcomponents.

SIC Codes
Manufacturing activity has historically been tracked by Standard Industrial Classification (SIC) codes. The four-digit SIC code was developed in the 1930's to classify businesses by the type of activity in which they are primarily engaged and to promote the comparability of business data to describe various aspects of the U.S. economy. In 1997 the SIC was replaced by the North American Industry Classification System (NAICS). This six digit code constitutes a major revision in economic activity tracking, and uses a production-oriented, or supply-based, conceptual framework to group together producing units that use identical or similar production processes so that their economic activity can be tracked in a consistent manner over time and across industries.

NAICS Codes
A typical NAICS code ranges from two to ten digits, where a two digit code indicates the economic sector, a three digit code specifies a sub-sector, a four-digit code indicates the industry group, the six-digit code specifies the U.S. industry sector, and additional digits indicate increasing specificities within the sub-sector. As an example, the three-digit NAICS code 334 signifies "Computer and Electronic Product Manufacturing", whereas the ten digit NAICS code 334413A005 pertains to "Solar cells."

Table 3.3 - North American Industry Classification System (NAICS) Hierarchy

	Example 1		Example 2	
NAICS Level	**NAICS Code**	**Description**	**NAICS Code**	**Description**
Sector	31-33	Manufacturing	51	Information
Subsector	334	Computer and electronic manufacturing	513	Broadcasting and telecommunications
Industry Group	3346	Manufacturing and reproduction of magnetic and optical media	5133	Telecommunications
Industry	33461	Manufacturing and reproduction of magnetic and optical media	51332	Wireless telecommunications carriers, except satellite
U.S. Industry	334611	Reproduction of software	513321	Paging

Source: U.S. Census Bureau

Component Sheets
The following pages provide more detailed description of the components considered in this report, as well as the NAICS codes associated with each part.

Batteries

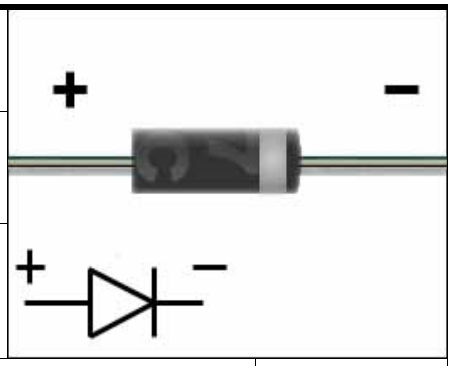
NAICS Codes:	NAICS Descriptions:
Subsector Code: 335	Electrical Equipment, Appliance, and Component Manufacturing
Industry Code: 335911	Storage Batteries
Detailed Code: 3359114207	All other lead acid storage batteries, larger than BCI dimensional size group 8D (1.5 cu ft or .042 cu m and smaller), including starting, lighting, and ignition
Description of Subcomponent:	Used to store the electricity produced by the solar module, and then to provide power during times of insufficient sun.

Source: http://www.nrel.gov/data/pix/Jpegs/11663.jpg

For grid connected systems batteries can provide backup electricity in case of grid failure. For off-grid systems, batteries are necessary to provide energy during the night, or when it is cloudy and the sun is not shining. The vast majority of systems being installed currently are grid-tied, and batteries are only installed in approximately 2% of systems. Given the nature of solar panels, only batteries designed for frequent charging and discharging (called deep-cycle batteries) will provide optimal performance. The most commonly used deep-cycle batteries are lead-acid and nickel-cadmium batteries.

Blocking Diode

NAICS Codes:	NAICS Descriptions:
Subsector Code: 334	Computer and Electronic Product Manufacturing
Industry Code: 334413	Semiconductors and Related Devices
Detailed Code: 3344137015	Semiconductor rectifiers - power diodes and assemblies
Description of Subcomponent:	The blocking diode is a semiconductor that keeps the battery from discharging through to the solar cells when there is no output from the cells to the battery.



Source: http://mediatheek.thinkquest.nl/~kl010/elektro/diodes.JPG

Blocking diodes are also referred to as "isolation diodes" when used to isolate cells from other cells in the array. This isolation allows the array to continue producing power when some of the cells are shaded.

Charge Controller

NAICS Codes:	NAICS Descriptions:
Subsector Code: 335	Electrical Equipment, Appliance, and Component Manufacturing
Industry Code: 335999	Electronic Equipment and Components, NEC
Detailed Code: 3359993104	Semiconductor battery chargers, industrial and railroad
Description of Subcomponent:	Regulates the flow of electricity to and from the battery in order to charge efficiently, and to protect the batteries from overcharging.

Source: http://www.nrel.gov/data/pix/Jpegs/06852.jpg

Applying a charging current to an already full battery produces gases in the battery that build up pressure and can damage the battery. Also, a mismatch in the voltage output from the solar array and the charging requirements of the battery can reduce the charging efficiency - requiring more time to reach full charge. The charge controller regulates the voltage and current to charge the battery quickly and efficiently. It also detects when the battery is full and switches to a trickle charge mode, which maintains the battery's full state without causing damage. Like batteries, charge controllers are only used in about 2% of systems today, but are included in this report for completeness.

Circuit Breakers and Fuses

NAICS Codes:	NAICS Descriptions:
Subsector Code: 335	Electrical Equipment, Appliance, and Component Manufacturing
Industry Code: 335313	Switchgear and Switchboard Apparatus Manufacturing
Detailed Code: 3353131100	Power circuit breakers, all voltages
Description of Subcomponent:	Both of these devices serve to protect the electronic circuitry, by breaking the connection to the system in the case of a current surge.

Source: http://www.nrel.gov/data/pix/Jpegs/07792.jpg

In a circuit breaker the current flows through an electromagnetic switch; when the current rises above a certain lever the electromagnet pulls the switch, breaking the circuit. The circuit breaker can then be reset.

Complete Module

NAICS Codes:	NAICS Descriptions:	
Subsector Code: 334	Computer and Electronic Product Manufacturing	
Industry Code: 334413	Semiconductors and Related Devices	
Detailed Code: 334413A010	Photovoltaic modules	
Description of Subcomponent:	The module consists of the PV cells, top surface, encapsulant, substrate, rear layer and frame. A photovoltaic module is a complete unit ready to be mounted and connected to the electrical equipment.	Source: http://www.nrel.gov/data/pix/Jpegs/09059.jpg

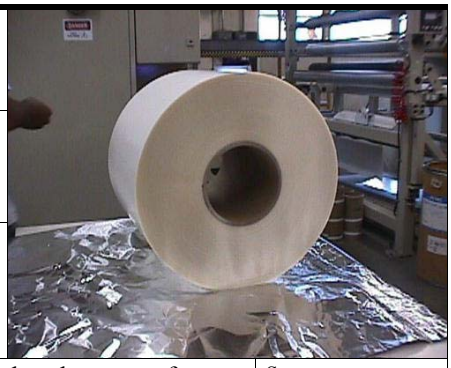
A module typically consists of several cells, connected in a combination of serial and/or parallel connections to achieve the desired current-voltage characteristics. Multiple modules are often connected together to create the complete PV system.

Electrical Connections

NAICS Codes:	NAICS Descriptions:	
Subsector Code: 335	Electrical Equipment, Appliance, and Component Manufacturing	
Industry Code: 335931	Current-Carrying Wiring Device Manufacturing	
Detailed Code: 3359317100	Current-carrying metal contacts, including precious metal	
Description of Subcomponent:	Metal conductors carry electrons out of the cells, connecting the cells in the module in series or parallel, and carry electricity out of the module to the rest of the system.	Source: http://www.partsonsale.com/pw1000boxsmall.jpg

Encapsulant

NAICS Codes:	NAICS Descriptions:
Subsector Code: 325	Chemical Manufacturing
Industry Code: 325211	Plastics Material and Resin Manufacturing
Detailed Code: 3252111160	Other thermoplastic resins and plastics materials
Description of Subcomponent:	The encapsulant protects the cells, and holds together the top surface, PV cells and rear surface.



Source: http://www.nrel.gov/data/pix/Jpegs/13424.jpg

Ethyl vinyl acetate (EVA) is the most common material used for the encapsulant. According to the Department of Energy, "thin sheets of EVA are inserted between the solar cells and the top and rear surfaces. Heating this "sandwich" causes the EVA to polymerize, thus bonding the module into one piece."

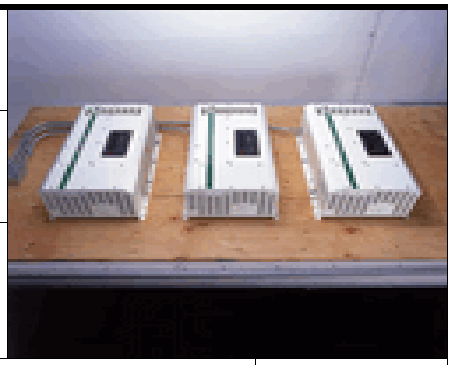
Frame

NAICS Codes:	NAICS Descriptions:
Subsector Code: 332	Fabricated Metal Product Manufacturing
Industry Code: 332322	Sheet Metal Work Manufacturing
Detailed Code: 332322G331	Other aluminum sheet metal work
Description of Subcomponent:	The frame adds structure, and can attach to the mounting structure.

Source: http://www.nrel.gov/data/pix/Jpegs/13384.jpg

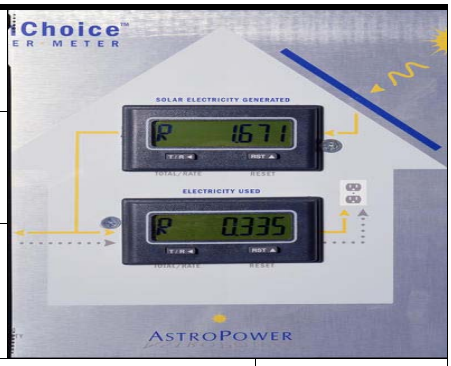
Aluminum is a common material used for the frame. Thin-film modules are often flexible, having no frame, and are applied directly to the supporting structure. In building-integrated systems, the frame serves as roofing material and in other applications as well.

Inverter

NAICS Codes:	NAICS Descriptions:	
Subsector Code: 335	Electrical Equipment, Appliance, and Component Manufacturing	
Industry Code: 335999	Electronic Equipment and Components, NEC	
Detailed Code: 3359993219	Other rectifying (power conversion) apparatus (except for electronic circuitry)	
Description of Subcomponent:	The inverter converts direct-current (DC) electricity produced by the solar modules into alternating-current (AC) electricity to match the transmission grid.	Source: http://www.nrel.gov/data/pix/Jpegs/10544.jpg

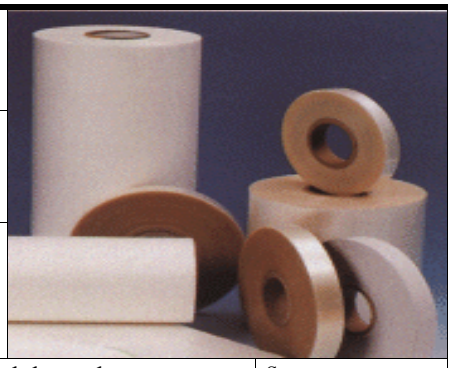
Inverters are sophisticated electronic devices, and account for a large part of the balance of system cost in grid-connected PV systems. They must be able to synchronize to the grid and meet interconnection requirements, as well as provide power to AC equipment such as appliances in a typical residential installation.

Meter

NAICS Codes:	NAICS Descriptions:	
Subsector Code: 334	Computer and Electronic Product Manufacturing	
Industry Code: 334515	Instrument Manufacturing for Measuring and Testing Electricity and Electrical Signals	
Detailed Code: 3345151105	Integrating instruments, electrical, demand meters, kW and kVA, combined watt-hour and demand meters (single phase and polyphase)	
Description of Subcomponent:	Used particularly in grid connected systems to track the amount of energy produced by the PV system.	Source: http://www.nrel.gov/data/pix/Jpegs/12244.jpg

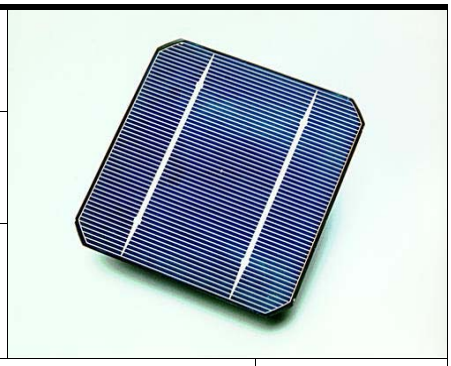
Some systems interface through a customer's existing utility meter, while others have additional equipment to display or report additional information or meet utility requirements.

Rear Layer

NAICS Codes:	NAICS Descriptions:	
Subsector Code: 326	Plastics and Rubber Products Manufacturing	
Industry Code: 326113	Unlaminated Plastics Film and Sheet (Except Packaging) Manufacturing	
Detailed Code: 3261130453	Other unlaminated plastics film and sheet	
Description of Subcomponent:	The rear layer protects the back surface of the module, and prevents water and gases from entering the module.	Source: http://www.fluortek.se/Old%20homepage/bilder/tedlarg.gif

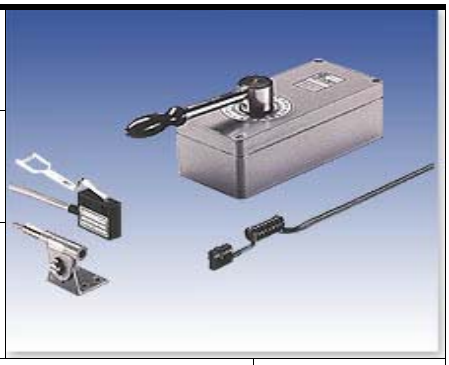
The rear layer must have low thermal resistance because the cell loses efficiency if its temperature is raised. Tedlar (a thin polymer sheet) is a common material for the rear layer.

Solar cells

NAICS Codes:	NAICS Descriptions:	
Subsector Code: 334	Computer and Electronic Product Manufacturing	
Industry Code: 334413	Semiconductors and Related Devices	
Detailed Code: 334413A005	Solar cells	
Description of Subcomponent:	A photovoltaic cell is any device that transforms light energy into electric energy. Current cells consist primarily of a semiconductor material, in which photons are absorbed from the incoming light to create free electrons.	Source: http://www.nrel.gov/data/pix/Jpegs/04065.jpg

Silicon solar cells are currently the most common, and can be single-crystal or multicrystalline. Single crystal silicon cells are the oldest commercial technology, and also the most efficient. Multicrystalline cells are less efficient due to grain boundaries between crystals blocking electron flow, but are also cheaper to produce. Amorphous silicon cells can be made in a thin, flexible film, making them ideal for building-integrated applications. They are less efficient than crystalline cells, and experience an initial decrease in performance, which later stabilizes. Thin-film cells made from copper indium diselenide (CIS) or cadmium telluride (CdTe) are also coming into use, because thin-film deposition can potentially be cheaper than silicon ingot growth. Several companies are also developing organic solar cells made using a dye-sensitizing process, or made from semiconducting polymers.

Switch Gear

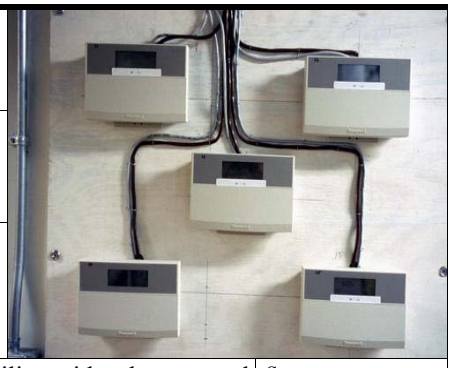
NAICS Codes:	NAICS Descriptions:	
Subsector Code: 335	Electrical Equipment, Appliance, and Component Manufacturing	
Industry Code: 335931	Current-Carrying Wiring Device Manufacturing	
Detailed Code: 3359315100	Current-carrying switches for electrical circuitry (including vehicular switches)	
Description of Subcomponent:	Used to open and close the route that the electricity can flow through. Allows components of the system to be disconnected from one another.	Source: http://www.asa-schalttechnik.de/jpgs/prod_spe.jpg

Top surface

NAICS Codes:	NAICS Descriptions:	
Subsector Code: 327	Nonmetallic Mineral Product Manufacturing	
Industry Code: 327211	Flat Glass	
Detailed Code: 3272111041	Flat glass, nonautomotive, other than pyrolytically coated, clear, less than 5.0 mm thick	
Description of Subcomponent:	The top surface allows light to enter the cell, while protecting the delicate cells from damage.	Source: http://www.sunarc.net/englisch/images/AR_Model01.jpg

Based on the materials used for the cell, the necessary wavelengths need to be able to pass through the top surface. Reflection from the top surface should be minimized either by adding texture to the material, or adding an antireflection coating. The top cover needs to be resistant to weather damage including rain, hail, strong winds and ultraviolet radiation and needs to be strong enough to protect the inside of the module from damage. Generally made of glass or plastic.

Wiring

NAICS Codes:	NAICS Descriptions:	
Subsector Code: 331	Primary Metal Manufacturing	
Industry Code: 331422	Copper Wire (except Mechanical) Drawing	
Detailed Code: 3314224218	Copper apparatus wire and cord and flexible cord sets (except wiring harnesses and fiber optic), made in plants that draw wire	
Description of Subcomponent:	Necessary for connecting the PV system to the utility grid or battery and load and controlling the movement of electricity.	Source: http://www.nrel.gov/data/pix/Jpegs/13159.jpg