CHAPTER 4

Concentrating Solar Power

Clean Energy for the Electric Grid

by

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Summary

Concentrating solar power (CSP), also referred to as concentrating solar thermal power, represents a powerful, clean, endless, and reliable source of energy with the capacity to entirely satisfy the present and future electricity needs of the United States. Concentrating solar power plants produce no carbon dioxide (CO_2), thus reducing carbon emissions from electricity generation by approximately 600 pounds per megawatt-hour (BrightSource Energy, 2008).[4] The evolution of CO_2 emissions regulations, the pressure of international fossil fuel prices, and the experience, knowledge, and technological readiness amassed during several decades of CSP research have launched the technology into a new era of commercial reality.

The United States and Spain have integrated CSP into their national electricity supply grids through large-scale commercial plants. Eight of the 13 biggest planned CSP projects in the world will be located in California and Arizona. The Sun Belt region of the United States, particularly the Southwest, is one of the largest areas in the world for CSP exploitation because of its abundant sunshine. In addition to generating a new clean source of energy, expansion of the industry promises to create economic opportunity for many different businesses along multiple stages of the value chain, including thousands of new construction jobs and hundreds of skilled jobs in the operation and maintenance of the new plants.

Introduction

After several decades of research and pilot testing, concentrating solar power (CSP) is now commercially viable. For more than 50 years researchers, universities, laboratories, inventors, and scientists experimented with ways to produce electricity using steam generated from the heat of concentrating solar rays. The U.S. government has been collaborating with private research corporations over the last 20 years to scale up CSP technology for the energy markets. Government investment in this technology continues to increase. In April 2008, the U.S. Department of Energy announced $60 million in funding over the next five years to support further development of low-cost CSP technology (U.S. Department of Energy, 2008).

CSP plants concentrate beams of light from the sun to heat a fluid and produce steam. The steam rotates a turbine connected to a generator, producing electricity to run a traditional power plant. There are four types of CSP technologies: parabolic troughs, power towers, dish/engine systems, and linear Fresnel reflectors. The parabolic trough system was the first CSP technology, thus it is the most developed and most commonly replicated system. Deployment of the other technologies is relatively new and in some cases, as with the linear Fresnel reflector technology, projects currently being developed are the first to reach utility-scale magnitude. Parabolic trough technology uses parabolic reflectors to concentrate the sun's rays into a receiver pipe along the reflector's focal line. The receiver heats a liquid which generates steam for power. This collector system rotates with the sun's movement to optimize solar energy generation (Solar Energy Technologies Program, 2008a). Power tower systems use flat mirrors to reflect the sun's rays onto a water-filled boiler atop a central tower. The liquid is heated to a very high temperature and runs the turbine to create electricity (BrightSource Energy, 2007). Dish/engine systems use parabolic reflectors to direct the sun's rays at a receiver placed at the reflector's focal point. The liquid in the receiver is heated and runs a Stirling engine to create power (Solar Energy

[4] This compares to CO_2 emissions of 750 grams per kilowatt hour (g/kWh) from hard coal power plants and 500 g/kWh from natural gas (Solar Millennium AG 2008).

Technologies Program, 2008b). Linear Fresnel reflector technology works much like the parabolic trough system, except that it uses flat mirrors that reflect the sun onto water-filled pipes that generate steam. This is a significant cost advantage because flat mirrors are much less expensive to produce than parabolic mirrors (Ausra, 2008b). Current advances in CSP allow these technologies to produce electricity several hours after sunset and on days with low intensity of solar radiation through heat accumulators and hybrid configurations.

Figure 4-1. Concentrating Solar Technologies

Trough System

Tower System

Dish System

Linear Fresnel System

Sources: Trough, tower, and dish system images reprinted with permission from the National Renewable Energy Laboratory, http://www.nrel.gov/data/pix/; Linear Fresnel system reprinted with permission from Ausra, Inc., http://www.ausra.com/.

Concentrating Solar Power Value Chain

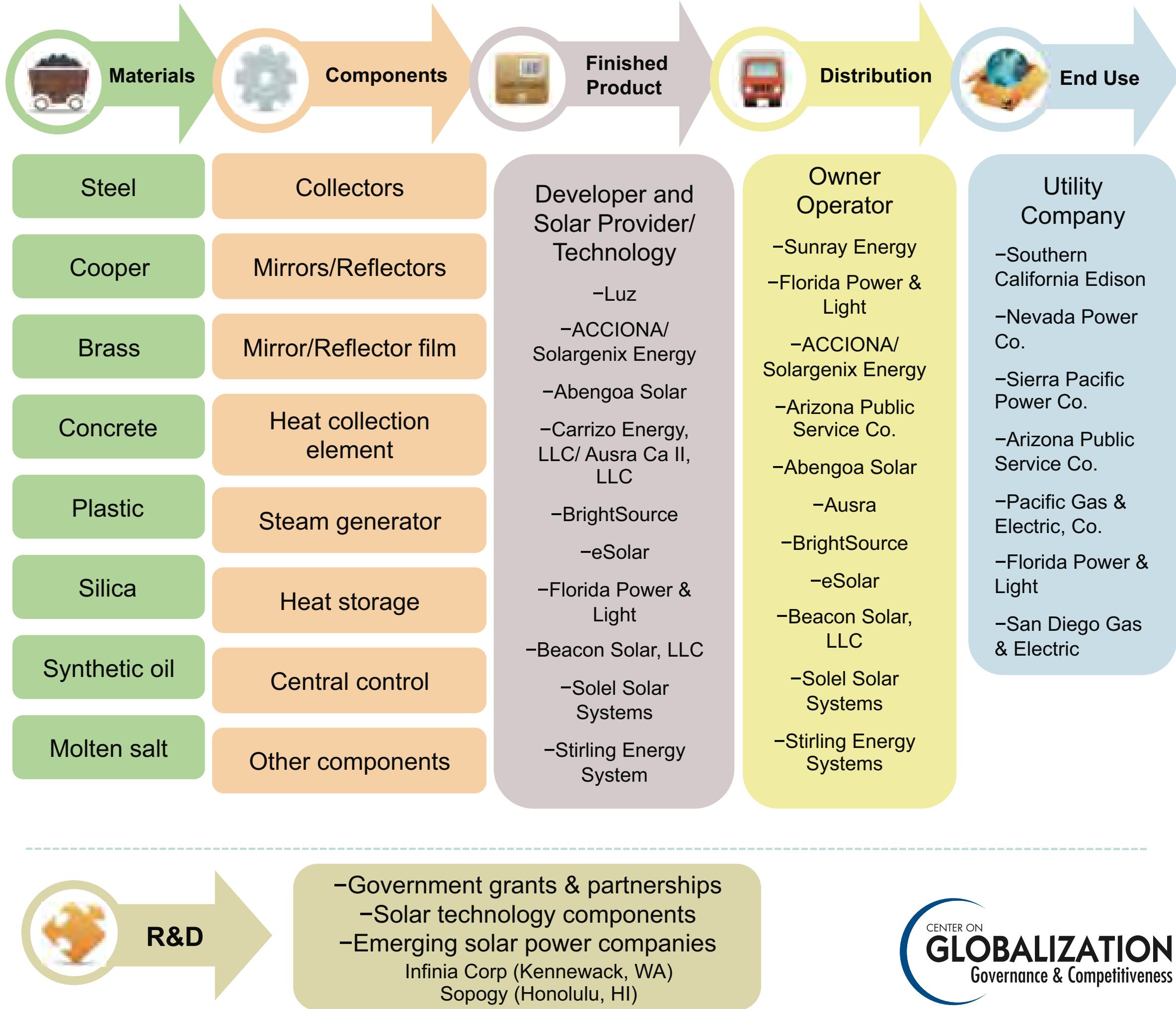
CSP is a new industry, and the roles and actors in the value chain vary significantly by technology and project. In addition, the value chain structure is still evolving. A general value chain illustration can be viewed in Figure 4-2. A more complete value chain with illustrative company information appears at the end of this chapter. At the basic level, there are five stages in the value chain: materials; components; the finished product including solar technology and plant development; distribution via ownership and operation of the CSP plant; and end use of power by utility companies. Research and development (R&D) is an integral part of the component, product, and distribution stages of the value chain. Much of the R&D, plant development, manufacturing, plant design and installation, and operation are conducted by a single company or by closely related companies. Therefore, there is significant vertical integration across the five stages of the value chain.

Materials and Components

The major materials in the CSP value chain are silica, iron and steel, concrete, plastic (or polyvinyl chloride), brass, synthetic oil, copper, aluminum, and molten salt. Figure 4-3 highlights the major country sources for these materials and their corresponding components. Table 4-1 highlights some CSP component manufacturing companies.[5] A CSP plant has four major systems: the collector, steam generator, heat storage, and central control. The collector system components vary depending on the type of CSP plant.

[5] The majority of the research on component manufacturing focuses on parabolic trough power plants because these are currently the most widely used CSP technologies. Components and component manufacturers of the Stirling engine and tower CSP plants are also included to the extent possible.

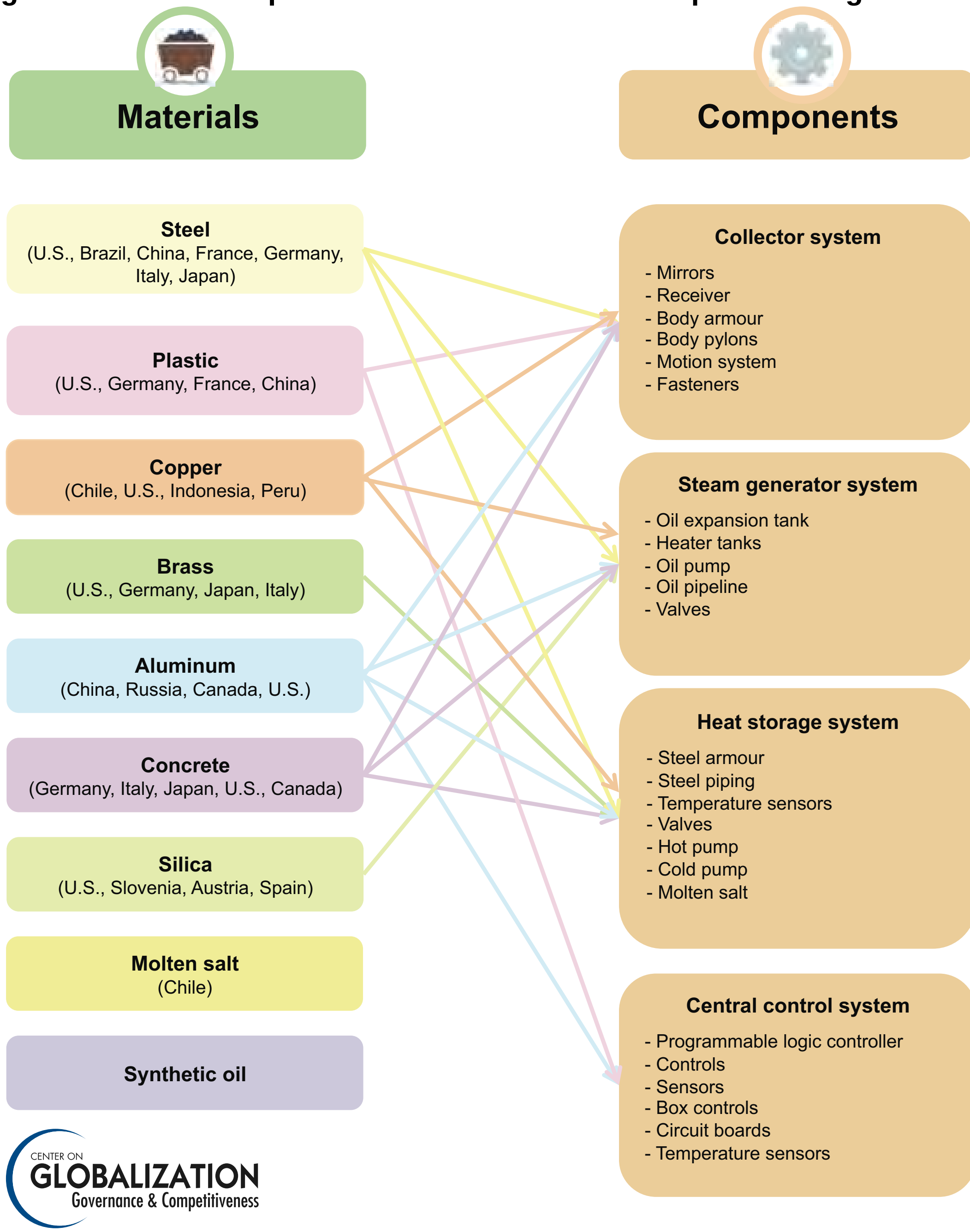
Figure 4-2: Simplified Concentrating Solar Power Value Chain



Source: CGGC, based on company annual reports, individual interviews, and company websites.

In addition to the components listed in Figure 4-3, concentrating solar power plants have many other elements not outlined here because they represent standard technology for generating electricity. These include a natural gas boiler, steam turbine, steam generator, condenser, and cooling tower. These components would certainly be a part of the production process for any CSP plant and would contribute to further manufacturing and construction needs.

Figure 4-3: CSP Components and Materials with Top Producing Countries



Source: CGGC, based on company annual reports, individual interviews, and company websites.

Table 4-1. Illustrative Companies Making Concentrating Solar Power Components

Component	Illustrative Companies	Location
Collectors	European Partners	Europe
	Industrial Solar Technology	Golden, CO
	Luz/Solel	Israel
	Solargenix Energy	Sanford, NC
	Solar Millennium AG	Germany
	Sopogy	Honolulu, HI
Mirrors/Reflectors	Alanod	Germany
	Ausra Manufacturing	Las Vegas, NV
	Boeing (formerly McDonald Douglas)	Chicago, IL
	Cristaleria Espanola SA	Spain
	Flabeg	Germany
	Glaverbel	Belgium
	3M Company	St. Paul, MN
	Naugatuck Glass	Naugatuck, CT
	Paneltec Corporation	Lafayette, CO
	Pilkington	United Kingdom
	SCHOTT North America	Elmsford, NY
Mirror/Reflector Film	Alanod	Germany
	3M Company	St. Paul, MN
	ReflecTech	Arvada, CO
Heat Collection Element	Luz/Solel	Israel
	SCHOTT North America	Elmsford, NY
Steam Generator System	Siemens	New York, NY
Heat Storage System	Radco Industries	LaFox, IL
Central Control System	Abengoa Solar USA	Lakewood, CO
Linear Receiver	Luz/Solel Solar Systems	Israel
	SCHOTT North America	Elmsford, NY
Concentrator Structure	European Partners (Euro Trough)	Europe
	Solargenix	Sanford, NC
Other Components	Other components used in power plant production but not unique to concentrating solar include a natural gas boiler, steam turbine, steam generator, condenser, and cooling tower	

Source: CGGC, based on company annual reports, individual interviews, and company websites.

Manufacturing & Development

CSP is appealing to developers because it is a renewable and reliable resource with predictable costs. CSP developers currently planning major power plant projects in the United States are large multinational or national companies already involved in the renewable energy field. In many cases, the developers are international firms that have established U.S. subsidiaries. These include Abengoa Solar USA, ACCIONA Solar Power, Inc., and Solel, Inc. (see Table 4-2). Therefore, although there is a significant international corporate presence in the CSP value chain, foreign-owned subsidiaries and offices are being developed in the United States along with U.S.-owned plants. Other developers include current or former utility and energy companies expanding into renewable energy, such as FPL Energy and Solargenix Energy (formerly Duke Solar Energy).

Table 4-2. Concentrating Solar Power Developer Companies

Illustrative Companies	Location
U.S.-based	
Abengoa Solar USA/Solucar Power (*Subsidiary of Abengoa*)	Victorville, CA
ACCIONA Solar Power Inc. (*Subsidiary of ACCIONA Energia*)	Henderson, NV
Ausra	Palo Alto, CA
Bright Source Energy, Inc.	Oakland, CA
E-solar (Idealab)	Pasadena, CA
FPL Energy	Mojave, CA
Industrial Solar Technology Corp	Golden, CO
Inland Energy	Upland, CA
Sky Fuel	Albuquerque, NM
Solel, Inc. (*Subsidiary of Solel Solar Systems Ltd*)	Henderson, NV
Solargenix Energy	Sanford, NC
Stirling Energy Systems	Phoenix, AZ
International	
ACCIONA Energia	Spain
Abengoa - Abengoa Solar	Spain
Albiasa Solar	Spain
Ener-T Global	Israel
Epuron	Germany
Eskom	South Africa
Grupo Enhol	Spain
Luz II *(BrightSource subsidiary)*	Israel
Novatec BioSol AG	Germany
Samca	Spain
Sener Group	Spain
Solar Millennium AG	Germany
Solar Power Group	Germany
Solel Solar Systems Ltd	Israel

Source: CGGC, based on company annual reports, individual interviews, and company websites.

The solar thermal industry appears to be significantly integrated across the value chain. Many developers conduct their own R&D to create unique, patented concentrating solar technologies. Concurrently, CSP developers often manufacture the patented components, build the power plant, and operate it. The planned Ivanpah Solar Power Complex is a good example. BrightSource Energy owns Luz II, one of the early CSP technology design and manufacturing companies, and Luz II will manufacture the CSP technology while BrightSource oversees the development, operation, and management of the plant. BrightSource will then sell the power produced to Pacific Gas & Electric. The U.S. Department of Energy also partners with a number of power plant owners and operators to help improve plant operation and management and develop better plant technology (Blair, 2008).

CSP plant construction requires commodity type materials (steel and concrete), and many companies contract out the manufacturing of non-patented components. Even when the developer of a U.S.-based CSP plant is an international company, the United States can expect significant job growth from plant construction and ongoing operations. There are two assembly sites: the first, which can be anywhere in the world, produces easily transportable components. The second, where larger components are assembled, must be near the plant to minimize transportation costs. This implies U.S. job growth potential in both component manufacturing and plant assembly.

The National Renewable Energy Laboratory (NREL) estimates that approximately 455 construction jobs are created for every 100 megawatts (MW) of installed CSP (Stoddard et al., 2006). The 280 MW Solana Generating Station scheduled for construction this year is expected to have an even greater impact, generating 1,500 to 2,000 construction jobs during the two-year construction period (Abengoa Solar, 2008). According to an analysis by *Black & Veatch*, a 100 MW CSP plant would produce 4,000 direct and indirect job-years in construction compared to approximately 500 and 330 job-years for combined cycle and simple cycle fossil fuel plants of the same production capacity, respectively (Stoddard et al., 2006).

During the operation phase of the power plant, permanent jobs are created in areas such as administration, operation, maintenance, service contracting, water maintenance, spare parts and equipment, and solar field parts replenishment. CSP plants generate an estimated 94 operation and management jobs per 100 MW, whereas conventional coal and natural gas plants of the same size generate between 10 and 60 permanent jobs. Despite the greater job creation, the total operation and maintenance cost for a CSP plant is approximately 30% lower than for a natural gas plant, even before the cost of natural gas is included (Stoddard et al., 2006).

The NREL estimates that an investment of $13 billion dollars in the installation of 4,000 MW of CSP, as expected based on the current and planned CSP plant development across the United States, will create 145,000 jobs in construction and 3,000 direct permanent jobs (Stoddard et al., 2006). Although the majority of the construction and operation and management jobs would be located in the Southwest, there will also be significant gains in manufacturing jobs, which would likely be more widely distributed across the country.

Government support also plays a vital role in the development of new solar technologies. The National Renewable Energy Laboratory in Golden, Colorado, receives federal funding to partner with private companies to improve the quality and cost-competitiveness of many renewable energy products, including CSP, and to perform high-risk research on new fluids, mirrors, and systems for CSP plants (Blair, 2008).

Concentrating Solar Market

Current penetration rates of CSP in the United States are near zero because existing large scale plants account for just 419 MW of power compared to a total U.S. installed electricity generating capacity of 1,758,346 GWh in 2007 (National Renewable Energy Laboratory, 2008 and Edison Electric Institute, 2008). Just 9% of the electricity generated in the United States came from renewable energy sources (6.4% hydroelectric and 2.5% other) and 91% was produced by other sources (50.5% coal, 18.3% natural gas, 3.3% oil, and 19% nuclear) (World Bank, 2008). Therefore just 2.5% of U.S. electricity was produced by a combination of geothermal, wind, photovoltaic, and CSP technologies. In fact, in 2006, only 1% of the nation's energy supply was generated from solar power (Energy Information Administration, 2008a).

Technological developments, the evolution of the regulatory environment on carbon emissions, and the volatility and accelerated increase in fossil fuel prices have created the perfect environment for commercial delivery of CSP. Between 2002 and 2007 the price of natural gas for electric power use more than doubled (Energy Information Administration, 2008b). Therefore, although current CSP costs are approximately 18 cents per kWh (Pernick & Wilder, 2008) compared to 6 cents per kWh for coal and 9 cents per kWh for natural gas (Rosenbloom, 2008), the volatility of and long-term increases in fossil fuel costs will make CSP costs more competitive (Pernick & Wilder, 2008). Furthermore, research suggests that increasing the CSP electricity production to 4 GW and incorporating new technological improvements could bring the cost of CSP down to 10 cents per kWh, which would be more competitive with natural gas and coal (Western Governors' Association, 2006). Other research from Clean Edge, Inc. and Co-op America estimates that by 2025, the cost of CSP will decline to 5 cents per kWh (Pernick & Wilder, 2008).

In 2006, total solar collector shipments for all types of solar collectors in the United States increased 29% from the previous year (Energy Information Administration, 2007). The largest market share gain was seen in shipments for high temperature collectors like those used in utility-scale CSP plants, which accounted for 18.5% of all solar collector shipments in 2006, compared to less than 1% in 2005. The Nevada Solar One solar thermal power plant that began generating power in 2007 is credited for this increase. Shipments of high temperature collectors are expected to further increase as additional U.S. CSP plants are developed.

The Sun Belt region has 5,203 million acres suitable to the implementation of CSP plants (Leitner, 2002) and almost all of the existing and planned CSP plants in the United States will be located in that region. Currently, four parabolic trough plants are operating with a combined capacity of 419 MW, two in California and one each in Arizona and Nevada. Another three parabolic troughs, two linear Fresnel reflectors, and two tower plants are expected to be in operation by 2011, and two dish engine plants also are planned (see Table 4-3). Once in operation, these will account for more than 3,000 MW combined. Figure 4-4 illustrates the distribution of existing CSP developers and component manufacturers across the United States. As manufacturing for the nine planned CSP plants gets underway, it is expected that the number of U.S. component manufacturers will increase, as indicated by Abengoa, which expects to open a mirror manufacturing plant at a later stage of development for the Solana Generating Station (Barron, 2008).

Table 4-3. Existing and Planned U.S. Concentrating Solar Power Plants

Project Name	Location	Capacity (MW)	Operation Year
Antelope Valley plant	Southern CA	245	2011
APS Saguaro	Saguaro, AZ	1	Operating
Beacon Solar Energy Project	Kern County, CA	250	2011
Corrizo Energy Solar Farm	San Louis Obispo, CA	177	2010
FPL plant	Florida	300	2011
Ivanpah Solar Power Complex	Ivanpah, CA & Broadwell, CA	400	2011
Mojave Solar Park 1	Mojave Desert	553	2011
Nevada Solar One	Boulder City, NV	64	Operating
SEGS I & II	Daggett, CA	44	Operating
SEGS III-IX	Kramer Junction, CA	310	Operating
Solana Generating Station	Gila Bend, AZ	280	2011
Solar One	Victorville, CA	500	TBA
Solar Two	Imperial County, CA	300	TBA

Source: CGGC, based on company annual reports, individual interviews, and company websites.

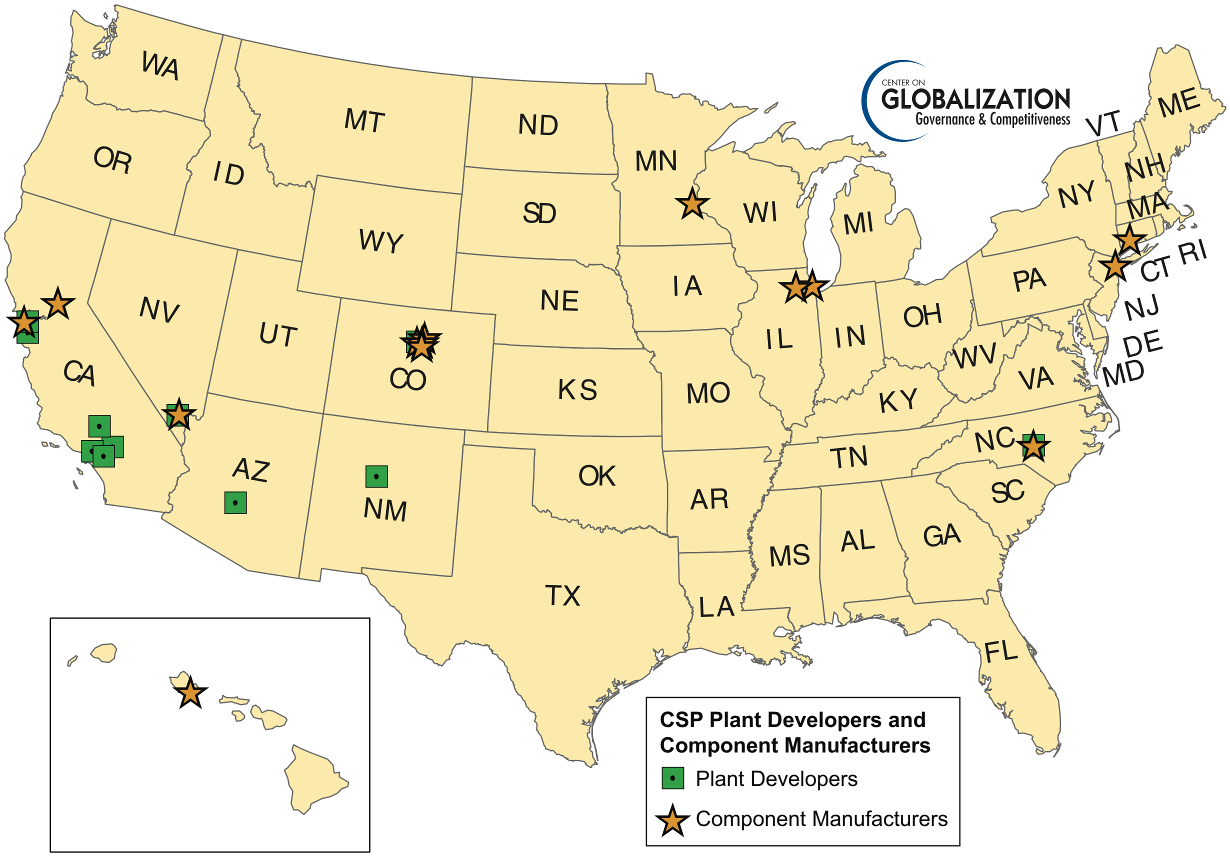
Case Study: Solar Manufacturing Can Replace Lost Auto Jobs

Infinia Corporation recognizes the market potential for CSP and the need for U.S. job growth in manufacturing. With these ideas in mind, the company developed a concentrating solar dish system, called the Infinia Solar System, which is the only CSP technology specifically designed to be mass manufactured by Tier 1 and Tier 2 auto manufacturers in the United States. Infinia included U.S. auto suppliers from the very beginning in product development, design, and manufacturing layout decisions. CEO J.D. Sitton explains that Infinia developed a solar technology product that can be "stamped out like a Chevy and installed like a Maytag." The product can be manufactured on existing auto production lines and shipped as a kit that can be installed by the most basic construction crew (Sitton, 2008).

There appears to be great potential for this approach. U.S. auto production has the capacity to produce over 19 million vehicles, but only about 15 million of the current capacity is being used. Infinia estimates each unit of auto production capacity can be retooled to produce 10 units of the Infinia Solar Power System. Therefore, the idle auto production capacity could produce 40 million units of this new technology per year. This would equate to 120,000 MW of solar capacity and as many as 500,000 manufacturing jobs in Washington, Michigan, and the upper Midwest (Sitton, 2008).

Production of the Infinia Solar System will be launched in January 2009. Infinia initially planned for nearly 100% of manufacturing to be in the United States. However, factors such as Congressional delay in extending the renewable energy investment tax credits and the U.S. government's lack of an effective renewable energy policy have created uncertainty regarding the near-term viability of the U.S. market. Thus, Infinia is investing some of its manufacturing abroad, where the markets are more economically attractive. The initial manufacturing distribution will be 60% U.S. and 40% international (Sitton, 2008).

Figure 4-4: Geographic Distribution of U.S.-Based Concentrating Solar Power Plant Developers and Component Manufacturing Companies



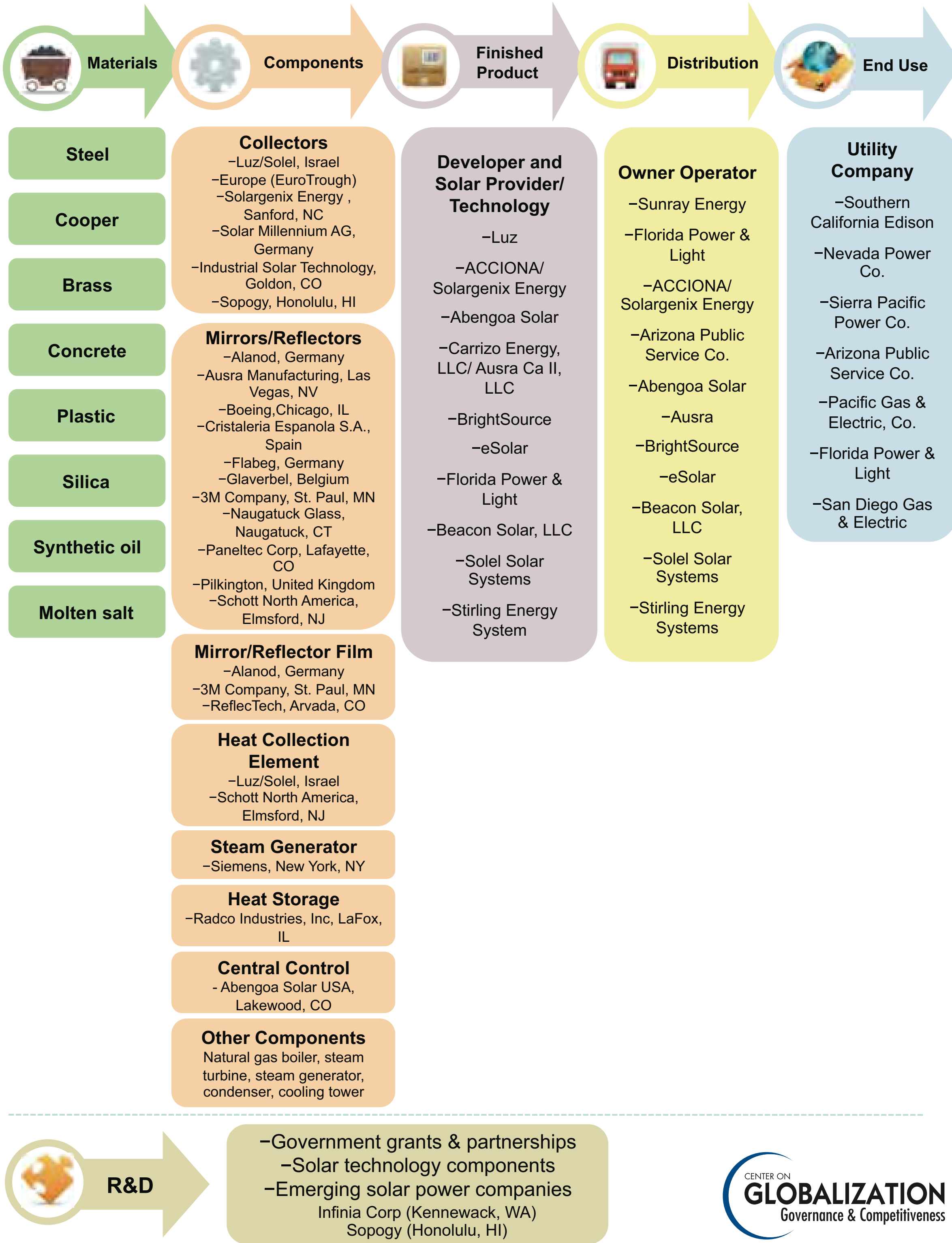
Source: CGGC, based on company annual reports, individual interviews, and company websites.

In addition to its potential to provide new production capacity for ailing auto manufacturing plants, Infinia believes its solar system is twice as efficient as photovoltaic products and has broader potential than other CSP technologies because it does not need flat ground or cooling water. This means it can be deployed in and around towns, making new transmission lines unnecessary. New business agreements to install this technology will be announced in the fall of this year (Sitton, 2008).

Conclusion

The example of Infinia Corporation illustrates the extensive manufacturing and technology innovation opportunities for CSP development in the United States. Furthermore, technological developments and the volatility and increase in fossil fuel prices are reducing the disparities in cost between renewable and non-renewable energy sources. Worldwide concern about carbon emissions also is strengthening the market. CSP has the potential to reduce carbon emissions while positively impacting job growth, if it is able to benefit from government tax incentives and more extensive technology deployment.

Figure 4-5. Concentrating Solar Power Value Chain, with Illustrative Companies



Source: CGGC, based on company annual reports, individual interviews, and company websites.

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