Vertical Specialization and the Role of Consortia in the Solar Photovoltaic Industry

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The solar photovoltaic industry has grown tremendously over the last decade. Worldwide annual solar cell production increased from 370 MW in 2001 to 27,000 MW in 2010. This rapid growth was driven in part by support programs for solar offered by governments across the world, and in part by the reduction in prices of PV systems.

While the industry has grown rapidly, it still accounts for only a very small fraction of total electricity production. In the United States, solar PV currently makes up less than 0.1 percent of total electricity production. During the last decade, governments around the world have undertaken many initiatives to make solar photovoltaics a more significant contributor to electricity generation. For example, the SunShot initiative of the U.S. Department of Energy (DOE) envisages solar reaching 303 GW of total installations by 2030 and 632 GW by 2050, which would make it account for 14 percent of total electricity generation in 2030 and 27 percent by 2050. To achieve this target, many barriers have to be overcome. A crucial element is the reduction in price of solar modules. The current average price of approximately $1/watt of solar modules is more than the $0.50 per watt required to meet the targets under the DOE's SunShot initiative. Reaching the target will require more innovations in solar manufacturing technology.

The declines in price of solar modules from $100 per watt in the 1960s to around $1 per watt today have come about as a result of improvements in technology over a period of 50 years. Further cost reduction to the target of $0.50 per watt is likely to be more difficult and can result only from innovations in each segment of the solar value chain – in materials, capital equipment, manufacturing processes, design improvements in cells and installation techniques. Attaining these difficult innovations is going to require specialized effort from companies and experts focusing on specific problems. The importance of specialization to manufacturing productivity has been known to economists for centuries, and was immortalized by Adam Smith in 1776 in his description of the manufacturing process in a pin factory – "One man draws out the wire, another straights it, a third cuts it, a fourth points it, a fifth grinds it at the top for receiving the head: to make the head requires two or three distinct operations: to put it on is a peculiar business, to whiten the pins is another ... and the important business of making a pin is, in this manner, divided into about eighteen distinct operations, which in some manufactories are all performed by distinct hands, though in others the same man will sometimes perform two or three of them." Smith recognized from his study of the pin factory that manufacturing productivity could be increased through specialization.

In modern economies where products are much more sophisticated than pins, these distinct activities tend to be undertaken by specialized firms rather than specialized workers. However, emerging solar firms making thin film modules do not yet have this specialization and therefore generally prefer to act as materials suppliers, equipment manufacturers, module makers and installers. As the market expands and competitive pressure intensifies, the demand for specialized services will increase in the thin film solar industry.

In the manufacture of products like solar modules, specialization brings

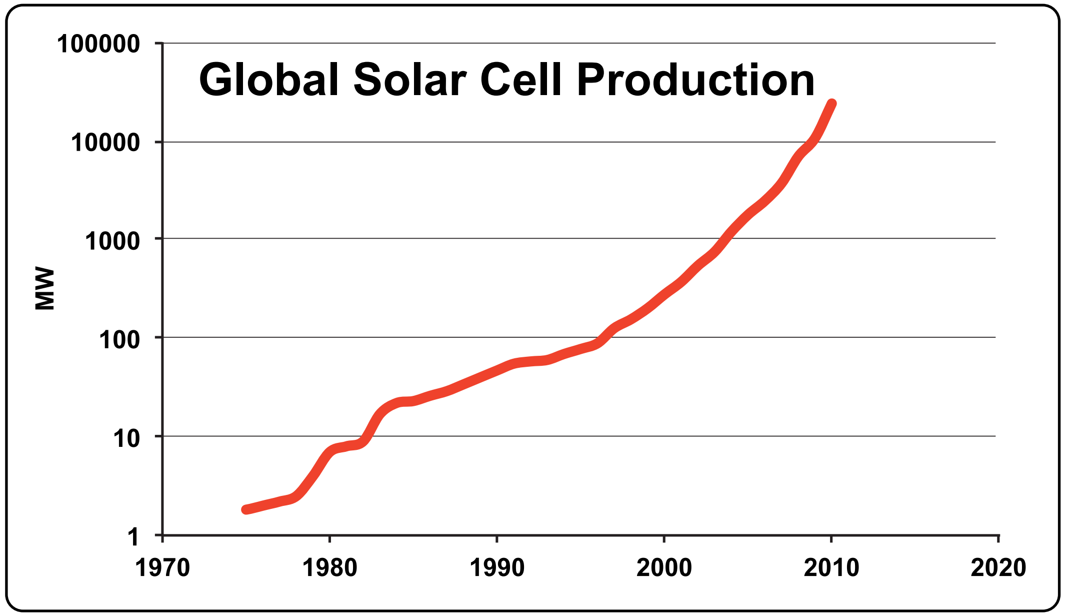

Figure 1 – Rapid Growth of Solar PV Cells Worldwide

along a cost. The activities of the specialists have to be coordinated so that the whole process can run seamlessly, a process which is perhaps more difficult in modern-day manufacturing of solar cells than in 18th-century pin factories. This is especially difficult if rapid innovations are required along the whole value chain. To make a successful improvement in the final solar module, the activities of materials suppliers, equipment makers and module manufacturers have to be coordinated to ensure they are compatible with each other. Such coordination is all the more important when the industry is still experimenting to understand the "right" product, the one that will satisfy consumer demands. Firms will have to be nimble and respond quickly to the feedback they get from consumers, who will buy or reject the new product offerings. This phase of product experimentation and manufacturing process adjustments calls for a forum where firms can share information, collaborate effectively and respond quickly to consumer signals. The U.S. Photovoltaic Manufacturing Consortium (PVMC) – headquartered at the College of Nanoscale Science and Engineering (CNSE) in Albany, New York – was established to provide these coordination facilities to the emerging thin film copper indium gallium selinide (CIGS) technology.

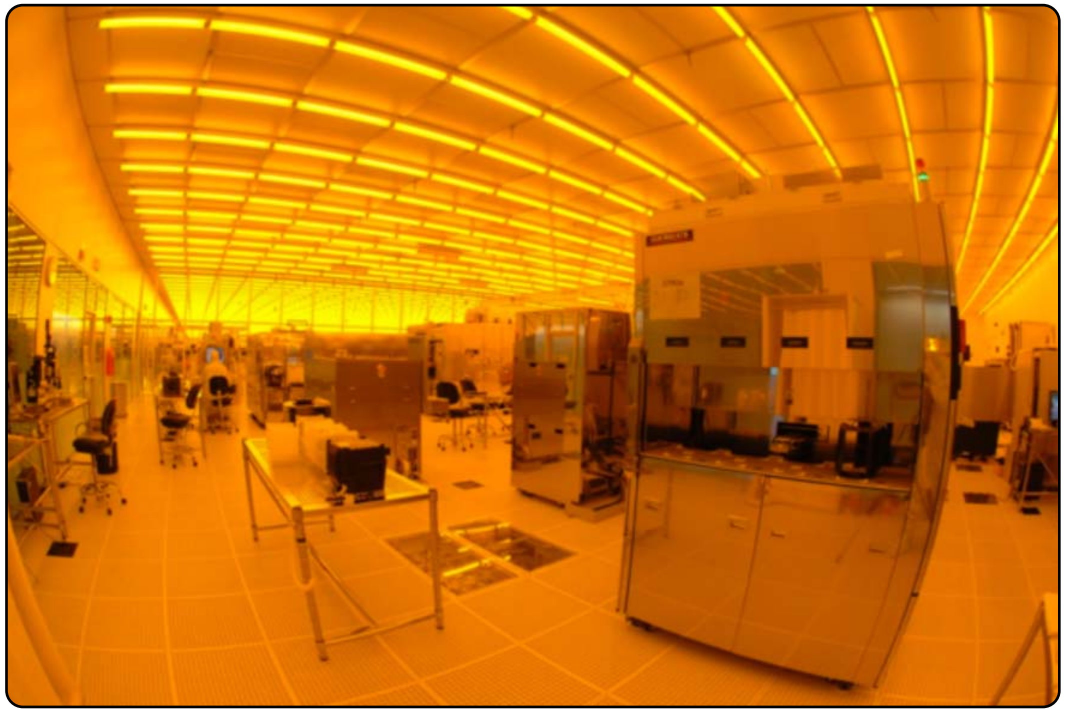

Figure 2 – A 300 mm Fab at the College of Nanoscale Science and Engineering

A classic example of the benefits of specialization and improved value chain coordination can be seen in the semiconductor industry. The early semiconductor manufacturers acted as a single-shop manufacturing facility, doing everything from materials improvement, equipment manufacturing, design and manufacturing of chips. As the industry grew, specialized firms emerged along the value chain to meet the demands of the increasingly complex manufacturing process. These specialized firms were often spun off from the divisions of the big firms. The equipment firms in the semiconductor industry like ASML, Applied Materials and KLA-Tencor have become a crucial part of the semiconductor supply chain. The innovations by these companies have become critical for advancing semiconductor technology, as important as the innovations made by chip manufacturing companies like Intel or IBM. This specialization in roles was an important contributor to the advancement of semiconductor technology, which in turn drove the expansion of the semiconductor product market.

But this specialization has come with costs of its own. Within two decades, the specialization had led to the emergence of a sophisticated, but unwieldy, supply chain. With numerous firms along the supply chain focusing intensely on their individual components and materials, ensuring compatibility of individual innovations became a difficult task. The first attempt at tackling this problem was taken by the Japanese government when the Ministry of Trade and Industry (MITI) set up the Very Large Scale Integration (VLSI) consortia to help diverse Japanese semiconductor manufacturers coordinate their research. In the 1980s, the Japanese semiconductor industry catapulted onto the global semiconductor market, and the coordination activities undertaken by MITI were thought to have played an important role. The relative decline of the semiconductor industry in the U.S., in turn, spurred the formation of SEMATECH, a consortium that was started by U.S. semiconductor companies, with the help of a subsidy from the U.S. government, to coordinate their research and manufacturing initiatives. A crucial contribution of SEMATECH was the effort to build a consensus roadmap for the industry outlining the critical roadblocks to advancing semiconductor technology. The consensus-building effort for technological advancement was institutionalized in the creation of the International Technology Roadmap for Semiconductors (ITRS), a biennial document released by SEMATECH to this day. In the last decade, as advances in semiconductor technologies brought the industry into the realm of nanotechnology, CNSE has taken the leadership role in coordinating the research and manufacturing activities of the semiconductor firms – so much so that SEMATECH has relocated its entire operation from Austin, Texas to CNSE's world-class Albany NanoTech Complex.

The lessons from the semiconductor industry have important implications for the development of CIGS thin film solar technology. CIGS technology is expected to expand rapidly in the coming years, with the market research firm Lux predicting a market for CIGS of 2.3 GW by 2015. As CIGS production expands, the need for specialization along the manufacturing supply chain and the subsequent need for coordination among the segments of the supply chain will increase. The pressure for reducing costs and improving efficiency will give an incentive for firms specializing in materials and production of manufacturing tools to emerge. Some companies like Manz Automation and Singulus are already producing specialized deposition tools for CIGS manufacturing. Efficient coordination across the supply chain will become important as consumers and firms both learn from deployment of CIGS modules, and as new markets for CIGS emerge.

The ability of CIGS modules to be deployed on flexible substrates holds enormous potential for use of CIGS in BIPV and other similar segments. As costs come down and efficiency improves, CIGS would expand into new market segments involving "plug-and-play" deployment of solar. As CIGS technology expands to these markets, CIGS module manufacturers will need to make new innovations to respond to the demands of consumers in these segments. This might require changes in materials and manufacturing tools. A well-coordinated supply chain is almost a necessity for the CIGS industry to be able to respond quickly to consumer signals, and penetrate these new market segments effectively. PVMC, headquartered at the College of Nanoscale Science and Engineering and spearheaded by CNSE in partnership with SEMATECH, is well placed to play this role of coordinating the different specialized firms along the CIGS supply chain.

CIGS has been demonstrated to be the highest-energy-producing and most likely successful "thin film" solar technology. It offers the greatest potential for lowest cost of ownership (COO) with highest-efficiency, optimal form factor on both rigid and flexible substrates, and it is environmentally safe. As a result of these attributes, it is the fastest-growing solar technology (96 percent CAGR supply market forecast), with potential use for building integrated devices, solar farms, commercial and residential rooftops, portable devices and, potentially, terawatt-scale deployment. CIGS offers the highest probability of U.S. solar industry leadership, with U.S. suppliers representing more than 40 percent of global CIGS manufacturers. U.S. strength in CIGS manufacturing is due largely to U.S. industry's historical leadership in semiconductor technical know-how, capabilities and experience.

While CIGS has inherent advantages of flexible form factor (see examples of tools in Figures 3 and 4) and lower-cost substrates, its market penetration is limited by volume-manufactured module efficiencies around 12 percent (despite laboratory efficiencies demonstrated at 20 percent). The target for CIGS programs is an increase in module efficiency by 50 percent over the next five years, and overall reductions in manufacturing cost structure. Process technology for thin-

Figure 3 – Large-scale Sputtering Tool Capable of Processing 1 m Wide Web to be Installed at USPVMC Manufacturing Development Facility

Figure 4 – Large-scale CIGS Deposition Tool Capable of Processing 1 m Wide Web to be Installed at USPVMC Manufacturing Development Facility

film CIGS solar cells has reached maturity for mass production. Several companies have begun large-scale production, but further improvement in cell and module performance is needed to reduce costs and improve competitiveness in the PV market. CIGS flexible solar cells have the potential for reduced production costs. However, significant challenges remain that will be addressed through the PVMC to accelerate deployment of CIGS products that have achieved the following cost and performance targets.

To achieve these CIGS solar cell cost and performance objectives, among other challenges, USPVMC will focus on the following high-priority technical opportunities:

(1) *CIGS Cell and Module Structures Process and Equipment Optimization* – optimize manufacturing processes and equipment to close the efficiency gap between lab production and commercial production of high-efficiency CIGS cells.
(2) *Develop CIGS Manufacturing Processes and Metrology for Next-Generation High-Efficiency, High-Volume Production Lines* – develop materials integration, process and equipment to raise efficiencies and commercialize technologies needed for next-generation CIGS manufacturing.
(3) *Develop Methodology for CIGS Reliability Enhancement* – Characterize CIGS materials and process integration interactions to develop specific models around failure mechanisms, performance and yield to provide direction for process, equipment, metrology and innovations.
(4) *Balance of System* – develop BOS technologies that reduce cost and improve the performance, reliability and functionality of CIGS PV systems.
(5) *CIGS PV Manufacturing Productivity* – implement productivity approaches and develop factory systems in a manufacturing development facility to develop solar fabs of the future.

The value proposition offered by PVMC is multifaceted. PVMC – in partnership with industry, universities and government – will harness the interdisciplinary capabilities required to rapidly develop and deploy breakthrough solar technologies, as opposed to making incremental progress. PVMC will offer the capacity for developing "integrated solutions" by bridging new cell, module and materials development. This will lead to improved efficiencies and accelerated availability of new products which, in turn, will enhance productivity and competitiveness for PVMC's PV industry participants. PVMC will serve as the hub around which an innovation ecosystem for PV technologies will attract, coalesce and grow: research and pre-competitive technology development, commercialization and manufacturing; venture capital and private equity funding; private, public and international investment; the relocation of emerging technology companies and top talent; and increased employment in the participating regions. By integrating the industrial research consortium and manufacturing development facilities models, PVMC offers lab-to-fab capabilities that will support rapid commercialization of new technologies and incubation of new start-up firms. PVMC offers the federal government an unparalleled opportunity to promote the competitiveness of the U.S. photovoltaic industry, recapture lost market share, and retain and create millions of jobs in the U.S. ■

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