Prospects for U.S.-Based Manufacturing in the SSL Industry

Public-sector investments in energy-efficient lighting technology, in particular those made through the U.S. Department of Energy Solid-State Lighting Program, are yielding excellent returns for taxpayers in the form of savings on electricity bills and reductions in carbon emissions. These benefits will compound in coming decades as LED (light-emitting diode) and OLED (organic LED) lighting continues to improve in efficiency and win over consumers.

Meanwhile, a question looms: to what extent will the U.S. economy also benefit from the robust business and job creation that will emerge as a result of the transition to solid-state lighting (SSL)?

Writing the Future

The United States has been at the epicenter of SSL innovation, with private and public R&D initiatives driving solutions that capitalize on the energy savings and unique benefits of LED- and OLED-based lighting. U.S.-based researchers and product developers have been instrumental in toppling cost and performance barriers, and in positioning SSL for rapid market growth. A 2016 DOE study[1] projects that LEDs will account for about 30% of U.S. lighting installations by 2020 and about 86% by 2035. Other studies have reached similar conclusions about the global market.

To date, the United States has attracted SSL investments by major lighting multinationals as well as hundreds of small and medium-sized companies, representing all parts of the SSL value chain. However, early technology leadership does not necessarily translate into sustained U.S.-based manufacturing and employment strength, as the histories of the semiconductor and solar panel industries illustrate.

Some speculate that SSL will ultimately follow the trajectory of these industries, with manufacturing, then engineering and R&D, gravitating to countries such as China, drawn by low labor costs and generous government subsidies for capital investments and infrastructure. But many industry analysts believe this viewpoint is far too simplistic to capture all the dynamics of the SSL industry and the changing nature of global competition.

1 *Energy Savings Forecast of Solid-State Lighting in General Illumination Applications,* U.S. Department of Energy, September 2016

The future of SSL is still unwritten … and technology, manufacturing, and policy decisions being made today will influence the shape of the industry for decades to come. The industry is global, the market potential is enormous and rapidly emerging, and the stakes are high. Clearly, companies will weigh decisions on capital investment and facility location with extreme rigor.

Six Key Factors

What *would* lead a company to invest in U.S.-based manufacturing or engineering facilities? Through roundtable meetings and workshops sponsored by DOE, industry executives have shared valuable insights on this question.

Strategic considerations about sourcing and manufacturing—whether to make or buy, build or acquire—are unique for each company. Decisions also hinge on access to capital, which is often a pressing concern for small businesses, and they vary depending on what part of the SSL value chain is being addressed. Competitive drivers differ substantially for suppliers of substrates, phosphors, chemicals, production and test equipment, LED die, LED packages, LED modules, and lamps and luminaires—as well as for OLED suppliers and manufacturers, where markets to date have remained small and niche-oriented.

Despite all these variables, industry executives have identified six closely interrelated factors that affect location decisions:

- Access to markets
- Access to supply chains
- Access to innovation
- Intellectual property protection
- Labor costs, productivity, and quality
- Government incentives

Following are brief discussions of the six factors and their impacts on various parts of the SSL value chain, along with recent examples illustrating how these factors may play into decisions on where to base manufacturing and engineering operations.

Factor 1: Access to Markets

Market access issues differ for each part of the SSL value chain. For smaller commodity-like products with low shipping costs, manufacturers can successfully serve global markets from virtually any location. LED packaging is now performed almost entirely in Asia to serve customers around the world. In another example, LED replacement lamps, which account for the largest portion of current SSL unit sales, are assembled in highly automated operations in North America, Europe, and Asia, and marketed globally; Asian manufacturers have been gaining an edge because of their low-cost labor and synergies with the strong existing semiconductor packaging infrastructure.

Steps in Value Chain		
LED DIE MANUFACTURING	LED PACKAGING	LAMP AND LUMINAIRE PRODUCTION
Growth of LED wafer by metal organic chemical vapor deposition (MOCVD) Wafer processing (by mostly conventional semiconductor processes); separation into LED chips	Packaging of LED chips, including deposition of phosphor material to convert blue LED emission to white light	Integration of LED packages into luminaire or lamp Integration of driver, heat sink, optical components, and mechanical structure for luminaire

For other products, manufacturing in close proximity to markets and customers is a competitive advantage. Manufacturers assess where their growth and profit potentials are most attractive and establish engineering and production nearby, often locating in multiple parts of the world to serve multiple markets. A case in point is Veeco Instruments, which conducts engineering and R&D for its MOCVD equipment in Somerset, N.J., and uses contract manufacturers in Kingston, N.Y., and Singapore to serve its global customers, many of whom are in Asia.

Luminaire manufacturers have strong incentives to localize manufacturing and engineering as they strive to deliver high-value lighting solutions to commercial and industrial customers while minimizing turnaround time, inventories, and shipping costs. The need to localize will likely intensify with the integration of increasingly customized systems for monitoring and control, color tuning, and smart communications into SSL luminaires. Because the United States is an enormous market for SSL luminaires, the case for locating manufacturing and engineering here is compelling for many companies. The three largest lighting manufacturers in the U.S.—Acuity Brands, Eaton-Cooper, and Hubell—have historically manufactured here to serve domestic customers. They plan to continue manufacturing domestically and are transitioning their factories from conventional to SSL products. The same logic, of course, also drives companies to manufacture luminaires outside the United States for proximity to fast-growing markets in Asia, Europe, and other parts of the world.

Factor 2: Access to Supply Chains

Most SSL manufacturers, of all sizes, source from suppliers around the globe based on competitive pricing, quality, and service. Munich-headquartered industry giant OSRAM Sylvania, for example, sources its LED lighting components globally and has assembly operations around the world, including in the United States. Considerable engineering expertise in SSL companies goes into supply chain management and control.

Locating in proximity to suppliers can speed adaptation to constantly evolving product designs and customer demands. Cree is a case in point. While portions of its manufacturing processes are handled in Asia, Cree has found many of the building blocks for its vertical integration model in the United States, and often selects domestic suppliers when close collaboration is needed to ensure high quality and tight operational integration.

Sometimes supplier considerations weigh against a U.S. location—when, for example, key parts of the supply chain are based overseas, thus making it easier to do certain portions of the manufacturing overseas. Almost all LED package manufacturing nowadays is done in Asia, which tends to draw related links in the supply chain there as well. In contrast, the material supply chain for luminaire manufacturer Finelite is centered in California, which the company says has helped it to rapidly respond to market requirements.

Factor 3: Access to Innovation

Constant innovation is a competitive necessity in SSL manufacturing. Luminaire and light-engine producers seek solutions that are increasingly optimized for flexibility, materials efficiency, weight reduction, ease of assembly, and integration of sensors and controls, and that enhance product life as well as performance factors such as color stability over time. LED manufacturers seek improvements in efficiency within the LED epitaxy-phosphor-package system, which translate to lower production costs. They also look for improved manufacturing and integration techniques, such as improved application of down-converter materials in order to increase production volume and improve color consistency. Companies at every stage of LED lighting manufacturing

Status of Manufacturing	
LED DIE	Despite enormous growth in epitaxy in Asia (mostly devoted to LED displays), MOCVD remains strong in North America. Most top-level manufacturers perform MOCVD near their headquarters: Lumileds and Cree in North America, Osram Semiconductors in Europe, and Nichia in Japan. Wafer processing, often handled locally, is increasingly moving to Asia.  North America is strong in producing tools and equipment for LED manufacturing, including tools for MOCVD (dominated by Aixtron in Europe and Veeco in North America), specialty wafer processing, packaging, and testing and inspection. U.S.-based Plasma-Therm, Ultratech, and KLA-Tencor sell to manufacturers worldwide.

want high-speed, non-destructive test equipment. And technology breakthroughs are essential in bringing down the costs of producing OLED panels.

For many companies, staying on the cutting edge in addressing such issues means collaborating with the right partners. Lumileds, for example, draws a lot of its employees from the materials science departments of top U.S. universities, such as the University of California Santa Barbara, the University of Illinois, the Massachusetts Institute of Technology, Georgia Tech, and Purdue University. The company also benefits a great deal from collaborating with those universities, as well as with national laboratories such as Sandia and Brookhaven. And access to innovative partners is paramount to OLEDWorks, which conducts research, engineering, and fabrication at its Rochester, N.Y., headquarters. The only OLED panel maker in the United States, the firm was the brainchild of a cadre of former Kodak employees. OLEDWorks recently expanded its production and technology expertise by acquiring the Philips OLED assets in Aachen, Germany. With expertise in device manufacturing, the firm partners with material suppliers and customers to help fuel future growth. OLEDWorks generally selects U.S.-based partners to facilitate creative collaboration, ranging from equipment makers that can support development of the small, fast machines that will be vital to keeping capital costs in line, to end product designers that integrate the OLED lighting panels.

Since proximity to a critical mass of expertise—embodied in the regional supply chain, related industries, universities, consulting firms, and the labor force—can be a powerful competitive advantage, companies continually monitor "where the action is" on innovation. Regional levels of R&D investment are one significant indicator. SSL R&D, under way throughout the developed world, is funded predominantly by industry in the United States, Europe, Taiwan, South Korea, Japan, and China, augmented by government co-funding of strategically selected precompetitive technologies. Such investments not only advance the technology and associated energy savings, but also encourage manufacturers to locate in those regions.

Factor 4: Intellectual Property Protection

Many executives cite intellectual property protection as an essential factor that favors U.S.-based manufacturing, one that is especially relevant for companies utilizing proprietary techniques. A prime example of this involves U.S. LED manufacturers such as Lumileds and Cree, who keep MOCVD production close to headquarters to protect not only patents, but also trade secrets and the industrial knowhow surrounding the MOCVD process. This enables those companies to continue to produce the best LED material in the world.

Factor 5: Labor Costs, Productivity, and Quality

While labor rates in the United States are higher than in many other areas of the world,[2] productivity and quality considerations can provide a competitive counterbalance. Indeed, data indicate that U.S. manufacturing productivity and output have been trending positive, keeping pace with or exceeding those of some key Asian and European competitors,[3] and that U.S. manufacturing, particularly of durables, is increasing productivity and output faster than other areas of the U.S. economy.[4]

LED PACKAGING

Status of Manufacturing

Almost all LED die packaging is performed in Asia. Packaging is labor-intensive due to the need for process flexibility and for handling a wide range of product types on the same production line, favoring regions with relatively low labor costs. Shipping costs for small and light LED packages are low, also contributing to the decision to manufacture such products at offshore facilities. More automated wafer-level packaging approaches could change the equation for packaging location.

U.S.-based suppliers such as Intematix serve global markets for phosphors and other materials.

The competitiveness of the U.S. labor force, particularly in highly skilled and automated operations, is borne out by several instances of companies deciding to onshore SSL manufacturing. Examples include Carclo, which moved its optic molding operations from the United Kingdom to the United States in 2008 and has since added considerable capacity to its U.S. operations; and TOGGLED, which initially manufactured commercial-grade LED replacements for fluorescent tubes in China, but automated and relocated a substantial portion of its manufacturing to the United States.

Manufacturing quality control is another factor that can favor U.S.-based operations. As a *New York Times* article noted, many Chinese producers "have a poor and worsening reputation for quality, which may hurt them in the long term. Instead of lasting a decade like well-made LEDs, the low-priced LEDs occasionally burn out after less than a year … ".[5]

As luminaire manufacturing transitions to solid-state lighting, domestic luminaire manufacturers estimate that they'll be manufacturing SSL luminaires exclusively within five years. Because SSL manufacturing requires new skills and expertise, these manufacturers are retraining their employees to deal with such things as electronic component pick-and-place, thin-film deposition, power supply characterization, and LED characterization, as they capitalize on existing workforces, supply chains, and market understanding to make their transition to manufacturing the new technology.

2 U.S. Bureau of Labor Statistics, International Labor Comparisons, August 2013

3 U.S. Bureau of Labor Statistics, Percent changes in manufacturing output per hour, 2009–2010, 2010–2011

4 U.S. Bureau of Labor Statistics, Percent change in productivity, output, and hours from first quarter 2012 to first quarter 2013, preliminary

5 *New York Times*, "As LED Industry Evolves, China Elbows Ahead," Keith Bradsher, June 17, 2014

Factor 6: Government Incentives

Many Asian countries offer substantial incentives to attract manufacturing investments, including monetary support for capital equipment purchases, as well as recruiting and relocation support, subsidies for land and building development, subsidies for energy and water, workforce training, export incentives, corporate tax breaks, refunds of the value-added tax, tariff protections from foreign competition, and streamlined permitting. In contrast, U.S. federal, state, and local taxes are relatively high, monetary support for manufacturing has been comparatively modest, and support for SSL has come primarily in the form of market-side rebates and other incentives that indirectly benefit manufacturers by spurring demand. Nevertheless, state and local tax incentives have been a factor in attracting such companies as Cree and OLED developer Universal Display Corporation to make significant investments in U.S.-based infrastructure and R&D.

Interestingly, some role reversal has been happening lately. China has been deemphasizing incentives such as low-interest loans to manufacturers in favor of measures to stimulate demand,[6] in an attempt to accelerate growth in Chinese residential and commercial markets for SSL; and, like their American and European counterparts, Chinese regulators are phasing out incandescent bulbs in favor of energy-efficient lighting. At the same time, some states and localities in the United States are instituting more high-profile tax incentive policies to attract manufacturing and R&D in targeted sectors such as SSL. For example, Cecil County, Maryland, has provided some assistance to local LED luminaire manufacturer I-Lighting, including underwriting the extensive training of the company's staff in how to operate the complex equipment that populates the circuit boards, and I-Lighting has gotten additional financial aid from the state of Maryland.

Challenges to Competitiveness

Despite the positive indicators for U.S.-based manufacturing, SSL industry leaders cite a host of challenges that may dampen future business and job creation in this country. Some report a thinning out of the U.S. supply chain and knowledge base in such core manufacturing operations as extrusions and mold-making, as well as in LED fabrication. Others perceive an erosion of the U.S. innovation edge, with R&D and technical support from university and government laboratories diminishing, especially relative to other regions.

Many industry leaders advocate active roles for federal, state, and local governments in increasing the competitiveness of the United States as an SSL manufacturing location.

6 *New York Times*, "As LED Industry Evolves, China Elbows Ahead," Keith Bradsher, June 17, 2014

LAMP AND LUMINAIRE PRODUCTION

Status of Manufacturing

Lamp manufacturing can be highly automated and is distributed worldwide. Very low prices have allowed Chinese companies to capture about 30% of global share for replacement lamps, with Japan, South Korea, Germany, Taiwan, and the United States sharing the rest of the market in fairly even proportions.

Cree and Philips Lighting have LED lamp manufacturing facilities in the United States.

Local manufacturers typically dominate markets for luminaires, which are designed for local building types and can entail high shipping costs.

Recommendations include maintaining ongoing government support of SSL applied research to help maintain an edge in innovation, growing government co-funding of R&D for automated and flexible manufacturing, increasing incentives to defray capital costs, facilitating development of a highly educated workforce, and further bolstering U.S. demand for SSL through consumer education and accurate product labeling, as well as through effective "Buy American" procurement policies.

Regardless of the challenges, it is clear that the United States is well positioned to attract SSL engineering and manufacturing investments—some of the time, in some circumstances. The relative weighting of the six factors cited in this discussion not only varies widely by industry sector, but also changes over time. Generally, as a sector matures, the advantages of a U.S. manufacturing location diminish. Some companies may strategically divest some manufacturing, while others will continue to manufacture while seeking to move up the value-added food chain. Lumileds, for example, is going beyond supplying LED packages to offering customized solutions at the module level.

In this dynamic and fast-growing SSL industry, one thing remains certain: innovation, flexibility, and efficiency will be essential in keeping the United States competitive as a manufacturing location. ■

Unless otherwise noted, data for this paper come from four DOE sources: the *Solid-State Lighting Research and Development Manufacturing Roadmap* (September 2014), the *Solid-State Lighting R&D Plan* (June 2016 update), the online *SSL Postings* series "SSL in America" (www.ssl.energy.gov/sslamericapostings.html), and annual DOE workshops that attract leaders in the SSL industry. Subscribe to the *SSL Postings* mailing list by contacting postings@akoyaonline.com.