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 alongside 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 general lighting solutions that capitalize on the energy savings and the unique characteristics 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 2014 DOE study[1] projects that LED lighting sales will represent 48 percent of the general illumination market in the United States by 2020 and 84 percent by 2030. 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, August 2014

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, in the quest for competitive advantages, 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 roundtables and workshops sponsored by DOE, industry executives have offered 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 generally weigh in 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 package manufacturing 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; recently, 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, New Jersey, and uses contract manufacturers in Kingston, New York, and Singapore to serve its global customers, over 70 percent 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 a rapidly growing and potentially enormous market for SSL luminaires, the case for locating manufacturing and engineering here is compelling for many companies. 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, for example, sources its LED lighting components globally and has assembly operations around the world, including three based 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 significant 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. For example, Digital Lumens, which makes intelligent LED lighting for commercial and industrial applications, does all its manufacturing in Asia except for final assembly because its supply chain for custom power supplies, optics, and sensors is there. In contrast, the material supply chain for luminaire manufacturer Finelite is centered in California, which was a factor in the company's recent onshoring of its desk lamp and undercabinet lamp production back to the United States from China.

Next Lighting, headquartered in San Francisco, outsources all manufacturing, often selecting U.S.-based firms to maintain proximity not only to its predominant customer base but also to key suppliers. Injection molding, for instance, is conducted in the Seattle area for its skilled and competitive labor force, and because the plastic resin used in the process is produced in the United States. Next Lighting also sources its fragile optical materials in the United States to minimize shipping damage. On the other hand, mold-making is one of the operations conducted overseas, where Next Lighting has found suppliers to be more agile in turnaround times and cost effectiveness.

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 sensor and control material, and that enhance product life as well as

	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: Philips 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.

performance factors such as color stability over time. LED package producers seek improvements in the application of down-converter materials in order to increase production volume and improve color consistency. Companies at every stage of LED lighting manufacturing 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. Access to innovative partners is paramount to OLEDWorks, which conducts research, engineering, and fabrication at its Rochester, New York headquarters. The only OLED panel maker in the United States, the firm was the brainchild of a cadre of former Kodak employees, who licensed intellectual property from Kodak to start up. The firm now looks to partnerships with suppliers and customers to help fuel future growth. OLEDWorks generally selects U.S.-based partners to facilitate creative collaboration, and is particularly focused on identifying equipment makers that can support development of the small, fast machines that will be vital to keeping capital costs in line.

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, and Japan, augmented by government co-funding of strategically selected precompetitive technologies. However, the Chinese central government is purported to spend approximately $1 billion annually on SSL R&D, with the provinces providing additional incentives.[2]

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. Phosphor manufacturer Intematix, for example, maintains a Chinese presence in order to obtain the Chinese-mined rare-earth materials used in its products, yet does the majority of its manufacturing in Fremont, California, to enhance protection of its proprietary formulas as well as to access specialized materials science skill sets. Likewise, the necessity of protecting MOCVD growth technologies has led companies such as Philips Lumileds and Cree to focus their epitaxial wafer production in the United States.

Intellectual property protection also was a driver in a recent move by Xicato, which bucked the trend toward Asian dominance in LED packaging by onshoring its operations to San Jose, California, for a new line of LED modules. Xicato, which had previously done all its manufacturing in Asia, now estimates that about 80 percent of its new product line, from a value perspective, is manufactured in the United States.

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 off-shore 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.

Factor 5: Labor Costs, Productivity, and Quality

While labor rates in the United States are higher than in many other areas of the world,[3] productivity and quality considerations can provide a competitive counterbalance. Indeed, recent 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,[4] and that U.S. manufacturing, particularly of durables, is increasing productivity and output faster than other areas of the U.S. economy.[5]

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. In addition to Finelite and Xicato, cited above, 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 its manufacturing to the United States in 2012.

Manufacturing quality control is another factor that can favor U.S.-based operations. As a recent 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 … ".[6]

2 Solid State Lighting: Present and Future, Next Generation Lighting Industry Alliance, 2012

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

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

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

6 *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,[7] 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, Soraa, a California-headquartered LED-based lamp manufacturer, announced plans to open a new plant in Buffalo, New York, with support from the State of New York's Buffalo Billion initiative. The new plant is slated to be operational in 2015.

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. 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 "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. ■

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 percent 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, Philips Lighting, and Lighting Science Group 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.

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 Research and Development Multi-Year Program Plan* (May 2014 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.

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