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SCALING UP LED LIGHTING TECHNOLOGIES:

Current Status and Recommendations for Future Action in Developing Asia

July 2011

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ACRONYMS

AC	alternating current
ADB	Asian Development Bank
ALC	Asia Lighting Compact
ASEAN	Association of Southeast Asian Nations
AS/NZS	Australian/New Zealand Standard
BIS	Bureau of Indian Standards
BPS	Philippines Bureau of Product Standards
BSMI	Taiwan Bureau of Standards, Metrology and Inspection
CALiPER	commercially available LED product evaluation and reporting
CCT	correlated color temperature
CFL	compact fluorescent lamp
CIE	Commission Internationale de l'Eclairage
CMH	ceramic metal halide
CNIS	China National Institute for Standards
CRI	color rendering index
DGE&EU	Indonesian Directorate General of Electricity & Energy Utilization
DC	direct current
EC	European Commission
ECEEE	European Council for an Energy Efficient Economy
ECO-Asia CDCP	Environmental Cooperation-Asia Clean Development and Climate Program
EECA	New Zealand Energy Efficiency and Conservation Authority
EMC	Energy Management Contract Alliance
EMSD	Hong Kong Electrical and Mechanical Services Department
GDP	gross domestic product
GLS	general lighting service
HB LEDs	high-brightness LEDs
HID	high-intensity discharge
HPS	high-pressure sodium
hr	hour
IEC	International Electrotechnical Commission
IESNA	Illuminating Engineering Society of North America
IT	information technology
JELMA	Japan Electric Lamp Manufacturers Association
JIS	Japan Institute of Standards
kWh	Kilowatt-hour
LCD	liquid crystal display

LED	light-emitting diode
lm	lumen
MH	metal halide
MST	China Ministry of Science and Technology
NLTC	National Lighting Test Center (China)
NPL	National Physical Laboratory (India)
RCL	Regional Centre for Lighting
RDMA	Regional Development Mission for Asia
RGB	red-green-blue
RoHS	Restriction of Hazardous Substances Directive
SDCM	standard deviation of color matching
SNI	Indonesian National Standards Institute
SSL	solid-state lighting
TERI	The Energy and Resource Institute
TISI	Thailand Industrial Standards Institute
UHB LEDs	ultra high-brightness LEDs
UK	United Kingdom
US	United States
USAID	United States Agency for International Development
USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency
UV	ultraviolet
VSQI	Vietnam Standard and Quality Institute
W	watt
WEEE	Waste Electrical and Electronic Equipment

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EXECUTIVE SUMMARY

In the last ten years, light-emitting diode-based (LED-based) lighting products have emerged as a credible, energy-efficient, and long-lasting alternative for some real-world commercial and industrial applications. The development of LED-based lighting products for residential applications has followed quickly, with thousands of products now available in the consumer markets in Asia. A number of projections have estimated that LED lighting will gradually replace at least 20% to 35% of incandescent lighting applications by 2020, if not earlier, due to a combination of increased consumer appetite and regional and national programs.

Despite these projections, the challenges (and the potential) for the adoption of LEDs in Asia are quite significant and require thoughtful actions on the part of policymakers. For example, market trends for LED-based lighting products, especially for consumer lighting in Asia, have the potential to follow the path taken to implement compact fluorescent lighting (CFLs). The problem with CFLs has been the trend towards a "race to the bottom." In turn, product quality has suffered, which has resulted in consumer dissatisfaction and the lack of a regionally agreed-upon quality standard.[1]

In light of the mistakes made in the implementation of CFLs, the intent of this report is to examine the current market, technological issues, and barriers to the adoption of LED-based lighting technologies in order to help policymakers and program managers in Asia[2] identify opportunities, form program policies, and make sound decisions. The report was prepared by the USAID ECO-Asia Clean Development and Climate Program (ECO-Asia CDCP) to support its efforts to promote a cost-effective scale-up of high-quality, efficient lighting solutions in the Asia region. The report provides a guide for those who need to promote, test, and regulate LED-based lighting products.[3]

The Asian Market for LEDs

Globally, the high-brightness LED (HB LED) market grew 11% in 2008, reaching US$ 5.1 billion, and it is projected to continue growing.[4] Lighting and liquid crystal display (LCD) backlighting are the main applications that are driving the market for HB LEDs beyond 2010. Over the next five years, the global market growth forecast for HB LEDs is at least at a compound annual growth rate of 24%. This is expected to reach US$ 14.9 billion in 2013.

[1] USAID (2007).
[2] While this report applies broadly to the Asia region, the information presented herein focus primarily on China, India, and four countries holding membership in the Association of Southeast Asian Nations (ASEAN) – Indonesia, Philippines, Thailand, and Vietnam. Together, these six nations account for 76 percent of the gross domestic product (GDP) of Asia's developing economies, as well as a significant share of the global LED lighting market.
[3] Attachment A contains a brief overview on LEDs for those policymakers who are interested in additional technical details.
[4] Due to intense industry interest in LEDs, the exact market size and production numbers can be difficult to find and to verify. The information presented in this report is a compilation of publicly available information, and is used to illustrate the overall size and growth of the industry in Asia.

In Asia, the market for LEDs is also rapidly expanding. Based on 2008 information, ECO-Asia CDCP estimates that the current market size in Asia for LEDs of all applications is about US$ 7 to US$ 8 billion as of 2010, of which LED lighting constitutes about US$ 500 to US$ 600 million.[5]

Japan, Singapore, Taiwan, and Malaysia have long been major centers of LEDs and LED component manufacturing with respect to HB LED production.[6] The most dramatic increase in LED production in the past decade happened in Taiwan and China. By most estimates, Chinese production of LED-based products currently accounts for a majority of lighting and other products worldwide.

According to experts, most illumination-grade chips being used in Chinese products are currently still imported from outside of China. Most of China's LED industry is in the chip-packaging segment and application development, which are less profitable. However, the Chinese government has been supportive of efforts to expand LED chip manufacturing by offering subsidies designed to bring investment from Taiwan and elsewhere.

Trends in LED Performance and Cost

The advances in compound semiconductors used for LEDs have been following a trend that was predicted by Haitz's Law, which states that LED light output (lumens) and luminous efficacy (lumens per watt of electricity) will roughly double every 18 to 24 months. In accordance with this trend, not only has the performance of LEDs been improving, but the cost has also been decreasing, making the technology more cost-effective for certain applications. One exception is with the efficacy and cost projections of white LEDs; however, improvements in white LED light output and efficacy are slowly being realized.

It is important to note that many comparisons of performance and cost tend to be oversimplified. The comparisons do not include an analysis of the installation costs of lighting systems or maintenance costs of incandescent versus LED systems. There are also oversimplifications that make some LED performance look not so favorable. For instance, the efficacy of an LED is dependent on the whole system, consisting of the LED chip, the packaging (including the design of the LED package and the heat sink), its power supply, and "driver." Each component has its own efficiency value and power requirements. An industry standard to measure each component has not yet been established, so predicting performance based on laboratory data may not be valid.[7]

Measuring and Reporting on LED Performance

LEDs represent a lighting technology fundamentally different than incandescent, fluorescent, or other gas-discharge light sources. For that reason, standards agencies and other relevant bodies face difficulties in measuring and reporting on LED performance and comparing LED output for use in place of traditional lighting sources.

For example, the classification and application of LED-based lighting products is challenging.   Each lighting application has a corresponding set of measurement methods, standards, and tools that may not be entirely applicable towards LED-based lighting, if at all. This includes:

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[5] Lighting is only one application for which LEDs are used. Other applications include television and computer monitor backlighting, equipment monitors and gauges, and decorative displays.

[6] Japan is a relative latecomer in the adoption of LED lighting, as compared to the US, Europe and China. A similar situation for LED lighting exists in South Korea, where local interest in lighting has been low until recently.

[7] While it is reasonable to assume that the semiconductor efficiencies of LEDs will continue to increase rapidly, other components such as heat sinks, optics, solders, may not be able to match LEDs' spectacular gains due to their technological limits.

- measuring directionality;
- measuring color characteristics;
- measuring efficiency;
- measuring reliability and lifetime; and
- comparison methods for light sources.

Near-Term Opportunities for LED-Based Lighting

It is only a matter of time before LED-based lighting will become one of the mainstays in the commercial and industrial lighting markets throughout the world. Specific application of LED-based lighting within these markets will likely occur within one to three years. Application within Asia's residential market, however, will likely not occur as quickly.

Based on current costs and energy savings potentials, areas where LED-based lighting products will likely make a significant impact in the near-term include outdoor and roadway lighting, transportation-related functions, and architectural applications.[8] Examples include traffic signals, exit signs, and signage.

In reaching this conclusion, ECO-Asia CDCP reviewed the available data on actual, documented cases regarding installation of LEDs in comparable applications. The available data was further verified with performance test data. ECO-Asia CDCP's review revealed that:

- LEDs are generally not yet cost-effective in indoor, general/ambient applications, especially in retrofit situations.
- LEDs are most cost-effective in situations where they are displacing a traditional light source in an application with a high duty cycle.
- Available performance and cost data show that LEDs are not yet ready to displace the best fluorescent applications, which include linear fluorescent T8 and T5 lamps.[9]
- Available "best in class" LEDs are now comparable to incandescent and halogen lighting in some applications; however, LEDs have yet to surpass CFLs in cost-effectiveness for general lighting situations, especially in most residential applications.[10]

However, it is important to note that LED products have the potential to be "disruptive," meaning they will find their way into the market through unconventional means and may find other niches that are not in these broadly outlined categories.

Options for Developing LED Standards for Asia

The fact that LEDs are a fundamentally different light source from traditional light sources poses a challenge to those who must set standards and policies for this new technology. ECO-Asia CDCP conducted a survey on technical standards, national regulations, testing and labeling requirements, and other performance and quality requirements that address LEDs available for sale in Asia. The results are summarized below in **Table ES1**. Additional details regarding specific standards and categories are further discussed in Section 7 and summarized in Attachment B.

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[8] Note that architectural applications are likely to be new application areas and not require replacement or refurbishment of existing uses.

[9] USDOE. Solid-State Lighting GATEWAY Demonstrations. (n.d.) Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/lightfair7_mccullough-caliper2.pdf.

[10] The latest round of USDOE CALIPER testing of LEDs replacement for IR reflector halogen applications shows that LEDs do not deliver similar center beam candlepower yet.

Table ES1. Overview of LED Standards Activities in Asia

Country/Region	LED Standards Activities?	Specific Application Category Under Development	Responsible/Lead Organization
Brunei	None	None	Energy Division, Prime Minister's Office
China	Task Team formed	Street, devices, lamps	China National Institute for Standards, others
Hong Kong	Task Team formed	None	Hong Kong Electrical and Mechanical Services Department
India	Task Team formed	Street lighting, off grid	Bureau of Indian Standards
Indonesia	Testing standards being developed	LEDs for solar homes	National Standards Institute
Japan	A number of standards have been published	See Attachment B	Japan Electric Lamp Manufacturers Association, Japan Institute of Standards
Malaysia	Under consideration	Not yet decided	Standards Malaysia
New Zealand	Task Team formed	Street lighting	New Zealand Energy Efficiency and Conservation Authority
Philippines	2010 designated for LED standards	Modules/General Safety	Philippines Bureau of Product Standards
Taipei	A number of standards have been published	See Attachment B	Taiwan Bureau of Standards, Metrology and Inspection
Thailand	Under development	LED modules	Thai Industrial Standards Institute
Vietnam	No	N/A	Vietnam Standard and Quality Institute

Summary and Recommendations

Although LEDs are not to displace many traditional light sources in the near future, LEDs will likely become one of the mainstays of energy-efficient lighting. The versatility of incandescent lighting for many tasks, as well as over a century of investment and development of all things centering on this light source, means that its legacy will not be easily or quickly changed.[11] In addition, developments in the efficiency and cost of existing light sources have not stopped.[12] Thus, the key to ensuring future energy efficiency with lighting will require that each light source be used to its best advantage.

In order for LEDs to achieve their potential for energy efficiency and be used to their best advantage, policymakers must adopt clear policies and standards for LEDs. This is one of the main limitations for implementing LED technologies.

Based on ECO-Asia CDCP's review of the majority of available and verifiable data on actual, documented cases regarding installation of LEDs in comparable applications, policymakers and standards-setting agencies should focus on the following LED application areas:

[11] Consider the pace of the shift from T12 to T8 tube lamps worldwide, or the shift from magnetic to electronic ballast for tube lamps.
[12] For example, the "super CFL" and other coated and halogen IR reflector lamps have made significant progress in efficacy.

- **Area, parking, street, and/or outdoor lighting:** These are high-duty applications and a high-interest area. Policy support may be easily obtained.
- **Traffic lights and transportation-related signals:** Even if they are not as visible as other applications, these are high-duty applications and can yield significant savings both in energy and maintenance costs.
- **Signage and architectural applications:** These are also high-duty cycle applications and have been increasing in numbers.
- **Off-grid lighting applications:** These have the potential to serve a large percentage of Asia not yet connected to the grid.

While consumer-oriented LED products (such as incandescent lamp replacement) are not yet cost effective, policymakers could quickly implement a number of steps to protect early adopters from exaggerated claims about LED performance and to reduce the risk of these poorly performing products "poisoning" the market.

There are a number of considerations that policymakers in Asia should take into account to support the growth of LEDs in the marketplace:

- **A road map for LED-related policies:** Policymakers should design a road map based on LED industry development progress and potential impacts. This would help streamline decision-making because policymakers need to keep pace with the quickly growing LED industry. A region-wide, ongoing effort to design a regional road map for the LED industry would be ideal for optimizing the usage of resources.
- **A regional effort on LED standards and labeling**: A regional effort to harmonize standards and labeling for LEDs would help to speed up adoption of quality LED-based products, reduce confusion, and send the right economic message to suppliers and developers of quality LEDs in Asia.
- **An emphasis on quality of LED products:** A hard-learned lesson from the introduction of CFLs into the Asian markets was that low-quality products undermine energy-efficiency policies and efforts to mitigate greenhouse gas emissions. Given that initial costs for new LED-based products are much higher than CFLs (on a per-unit basis), it is imperative that public and private investments be made wisely.
- **Use available regional institutions:** Currently, many countries focus their standards on energy efficiency and energy performance but do not incorporate quality criteria, such as lifetime performance, into their standards. Therefore, an initial step for the regional harmonization process should be to identify some common quality and performance characteristics for LEDs. This would ensure that minimum quality criteria like energy, light output, and lifetime performance would be uniform throughout the region and thus streamline the process. There are three regional initiatives that can serve as suitable vehicles for such a regional effort: The Asia Lighting Compact, The Regional Center for Lighting, and lites.asia. A coordinated effort from these organizations might foster uniform standards within the region.
- **Develop guidelines for municipalities:** Currently, many municipalities and agencies are in the throes of "LED-fever," which is sometimes the result of being misled by exaggerated and unverified claims of LED performance and quality.
- **Develop guidelines (and labels) for consumers:** Consumers are also being misled by exaggerated and unverified claims. Standard guidelines and labels should be developed to help guide consumers in making sound purchases. This would ensure consumer confidence in LED products in the long run.

SECTION 1:

THE CURRENT STATUS OF LED TECHNOLOGIES

Introduction

In the last ten years, light-emitting diode-based (LED-based) lighting products have emerged as a credible, energy-efficient, long-lasting, and low-maintenance alternative for some commercial and industrial applications. Globally, LED exit signs and traffic signals have saved millions of kilowatt hours (kWh) of electricity and tens of thousands of maintenance hours since their introduction over a decade ago.[13] The development of LED-based lighting products for residential and commercial-residential applications has also emerged (although at a slower pace than with commercial and industrial applications), with thousands of products now available on the consumer markets in Asia.

As the market for LEDs has progressed over the last ten years, LEDs have generated more stakeholder interest and new manufacturers seem to be entering the market daily. A number of projections have estimated that LED lighting will gradually replace at least 20% to 35% of incandescent lighting applications by 2020, if not earlier, due to a combination of increased consumer appetite for energy efficiency and implementation of regional and national programs to phase out inefficient lamps.[14]

Although the availability of high quality, high-brightness LEDs (HB LEDs) are limited to expert-production manufacturing, this trend seems to be changing, as more fabrication plants for LED "chips" have been coming "on stream."[15] [16]

Along with increased production capacity, the technology for LEDs continues to evolve. For example, a new category of LEDs, ultra high-brightness LEDs (UHB LEDs), along with a new generation of high-powered LED chips (>1W per chip), has been developed for the next generation of LEDs. These new technology developments provide high-quality lighting applications and increase the competitiveness of LEDs versus other traditional lighting applications.

One issue with LEDs, however, is that the "white" or "warm white" light that commercial lighting applications need and that consumers find desirable is difficult to manufacture. To obtain the "white" light, manufacturers need to either mix UHB LEDs of different color spectra or use a phosphor coating with an

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[13] The term, "solid-state lighting" (SSL), is also being used to describe LED-based lighting. The LED is a sub-category of SSL.
[14] Some of the attention on LEDs can also be attributed to "CFL-fatigue" – the fact that policymakers and other decision makers are convinced that the market for CFLs in Asia and elsewhere is "transformed."
[15] E.g., Philips Lumileds Crosses 1 Billion LUXEON LED Benchmark. (2010, August 4). *Business Wire*. Retrieved from http://www.businesswire.com/news/home/20100804005613/en/Philips-Lumileds-Crosses-1-Billion-LUXEON-LED.
[16] Note that all LEDs require semiconductor "chips" to produce light. These chips require high-tech fabrication similar to computer "chips" and other electronic components.

ultra violet (UV) or blue LED. Both of these methods require specialized equipment and knowledge, have the potential to increase costs, and reduce overall energy efficiency.[17]

Nevertheless, the increasing demand for LEDs has resulted in some significant changes in how they are made and sold in Asia. These changes include:

- accelerated LED demand and production;
- increased product availability and variety;
- production for domestic applications;
- concentration of LED manufacturing in regions with low labor and material costs;
- initiation of a number of national efforts to develop policy and standards for LED-based products; and
- emergence of specific regulatory and programmatic requirements for LED-based products.

Despite these increases, policymakers could do more to increase the use of LED applications, which have not fully penetrated the market in accordance to its full potential due to various factors.

Moreover, the market trends for LED-based lighting products, especially for consumer lighting in Asia, have the potential to resemble the path taken by CFLs not so long ago. The trend with CFLs was a tendency towards a "race to the bottom" in terms of product quality. This led to consumer dissatisfaction and lack of a regionally agreed-upon quality standard.[18] LEDs may take this path as many consumers are undergoing "LED-fever" and pay any cost for LED applications without having a clear understanding of LED technologies or what they have to offer. This means consumers are being easily misled by exaggerated or unverified claims about efficiency and product quality, which encourages manufacturers to make inferior products while still selling them at a high price. Implementing a clear set of product standards, including labeling standards, could alleviate this issue.

This report was prepared by the USAID ECO-Asia Clean Development and Climate Program (ECO-Asia CDCP) to support its efforts to promote the scale-up of cost-effective, high-quality, efficient lighting solutions in the Asia region. This report is a guide for those who need to promote, test, and regulate LED-based lighting products. The report provides a technical overview of LED-based lighting technologies in Asia so that policymakers can identify opportunities, initiate better policies, and make better-informed decisions about adopting LED technologies throughout the region.

This report will first examine the current market, technological issues, and barriers to the adoption of this technology. This report will then provide background information on what standards have been, or will be, put in place. Finally, this report will provide some recommendations of what policymakers should do to address identified barriers and issues for adopting LED technologies and applications. These recommendations are supported by technical information on LED technologies and applications, contained throughout the report. Attachment A contains a primer on LEDs for policymakers who are interested in additional technological details.

While this report broadly applies to the Asia region, the information presented herein focuses primarily on policy activities in other regions that would best serve the needs of China, India, and four countries holding membership in the Association of Southeast Asian Nations (ASEAN) – Indonesia, Philippines, Thailand, and Vietnam. Based on data compiled by ECO-Asia CDCP, the combination of these six nations account for 76 percent of the gross domestic product (GDP) of Asia's developing economies, as well as a significant share of the global LED lighting market.

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[17] A primer on LED technology is provided in Attachment A of this report.
[18] USAID (2007).

The Asia Market for High-Brightness LEDs

Overall, the market for High-Brightness LEDs (HB LEDs) is rapidly expanding both worldwide and within Asia.

The global LED-based lighting market is projected to grow over the next several years. In 2008, the HB LED market grew 11%, reaching US$ 5.1 billion.[19] In the following year, the market saw a small decline due to worsening economic conditions, resulting in an estimated market size of US$ 4.9 billion.[20] However, this decline only affected the more mature LED markets such as automotive lighting, mobile phones, and outdoor video screens – other HB LED emerging segments, such as backlights for notebook computer LCD displays and televisions, showed continued strong growth. LED lighting and LCD backlighting applications will be driving the market for HB LED beyond 2010. Over the next five years, the market growth forecast for HB LEDs is at least at a compound annual growth rate of 24%. Global HB LED sales are expected to reach US$ 14.9 billion by 2013.

In Asia, the market for LEDs, of which HB LEDs is a subset, is also rapidly expanding. The exact number is hard to determine as it changes on a weekly basis. However, the current market size for LEDs can be estimated by examining past data and making estimations based on those market trends. Some data suggests that the total domestic LED applications revenue in China in 2008 was US$ 6.5 billion, which is an increase of 50% over 2007.[21] In India, the lighting market was worth US$ 1.5 billion in 2008, of which LED constitutes 3%, or about US$ 45 million.[22] Because the other countries in the region are not very developed, they can be assumed to be following India's LED lighting market in terms of growth, which currently constitutes about 2% to 3% of the overall lighting market size. Based on this 2008 information, the current market size in Asia for LEDs can be assumed to be about US$ 7 to US$ 8 billion in 2010, of which lighting constitutes about $US 500 to US$ 600 million and growing.

With respect to HB LED production, Japan, along with Singapore, Taiwan, and Malaysia, have long been epicenters of LEDs and LED component manufacturing in Asia. Japan accounted for about 44% of world supply in 2008 despite being a relative latecomer in the adoption of LED lighting, as compared to the US, Europe, and China. Only recently did companies like Toshiba Lighting and Sharp enter into the market with quality illumination products, and these companies are now supplying a wide variety of LED luminaire products and replacement lamps.[23] A similar situation for LED lighting exists in South Korea, where local interest in lighting has been low until recently. In February of 2010, in an effort to cut carbon emissions and save electricity, the Korean government announced that it would be spending $47 million to promote LED-based lighting products.[24]

In the global market, some of the most dramatic increases in LED production in the past decade have happened in China. The Chinese government, through the Ministry of Science and Technology and other agencies,[25] have encouraged the growth of the LED market.[26] As a result, Chinese manufacturing of products

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[19] Due to intense industry interest in LEDs, the exact size and production numbers can be difficult to come by or to verify. The information presented in this section is a compilation of publically available information, and is used to illustrate the overall size and growth of the industry in Asia.
[20] Strategies Unlimited (2010).
[21] See Attachment C; the largest applications were in architectural illumination and display.
[22] Kutty, B. LEDs will light up your future! (2008, May 1) *Dare*. Retrieved from www.dare.co.in.
[23] Steele, Robert. (October 2009). Strategically Speaking: Insights Into LEDs & Lighting, from Strategies Unlimited: Recent conferenes in Asia highlight LED Industry progress. *LEDs Magazine*. Retrieved from http://www.ledsmagazine.com/features/6/10/13.
[24] Korea Makes New Push for LED Lighting. (2010, March 24). *Power Integrations*. Retrieved from http://www.powerint.com/blog/mrgreen/korea-makes-new-push-led-lighting.
[25] In 2009, Shenzhen Municipal Government also issued a series of documents, including the Shenzhen LED industry plan, with the intention to spend more than RMB 200 million RMB in the next three years to boost its LED industry.

using imported LED components,[27] currently accounts for a majority of products worldwide, both in lighting and other product categories. There are also several hundred LED-packaging firms in China with the highest volume in Shenzhen and the Shanghai area. Shenzhen itself has roughly 1,000 enterprises engaging in LED lighting technology research and development, production, and application.[28] There are also several thousand LED application companies in China. The exact number is hard to determine, as it is growing an exponential basis.[29] (For an in-depth discussion of China's LED industry, refer to Attachment C).

It is important to note that much of the profit in the LED industry is in chip production, with much lower margins in the packaging and application stages. Generally, LED chip production accounts for 70% of profits while and LED chip packaging accounts for the remaining 30%. Most of China's LED industry is in the chip-packaging segment and application development, which are less profitable. However, the Chinese government has been supportive of the industry and offers subsidies designed to bring outside investment. For example, the Chinese government offers US$ 1.2 to $US 1.5 million for each chip fabrication machine installation, which has successfully attracted many LED chip makers from Taiwan to set up facilities in China.[30]

Other than China, Japan, Singapore, Malaysia, and Taiwan, few other Asian countries have exhibited much significant growth in LED production capabilities. However, India is currently working on leveraging its expertise in IT industries to foster LED production. Additionally, India has shown increased interest in conducting its own research and development of LED production processes. In the past, production of HB LEDs was limited to a handful of companies in the US, Japan, Korea, and Europe, which held most of the intellectual property on LED production processes. However, this trend is now changing, as countries like India and China have shown increased interest in developing its own production processes.

Trends in LED Performance and Cost

The advances in compound semiconductors used for LEDs have been following a trend that was predicted by *Haitz's Law*, which states that LED light output (lumens) and luminous efficacy (lumens per watt of electricity) will roughly double every 18 to 24 months, so that the future LED performance will likely follow a trend similar to that of the past 30 years. In accordance with this trend, not only has the performance of LEDs been improving, but the cost has also been decreasing, making the technology more cost-effective for certain applications.

One exception to this trend is with the efficacy and cost projections of white LEDs. Although improvements in white LED light output and efficacy are slowly being realized, development of white LEDs is fundamentally different and involves more technologies than single-colored LEDs, which makes white LED development more costly and performance advances less forthcoming. [31]

Despite these obstacles in white LED development, white LEDs still have much utility. For example, in terms of utilizing white LEDs for illumination, a technology roadmap maintained by the U.S. Department of Energy

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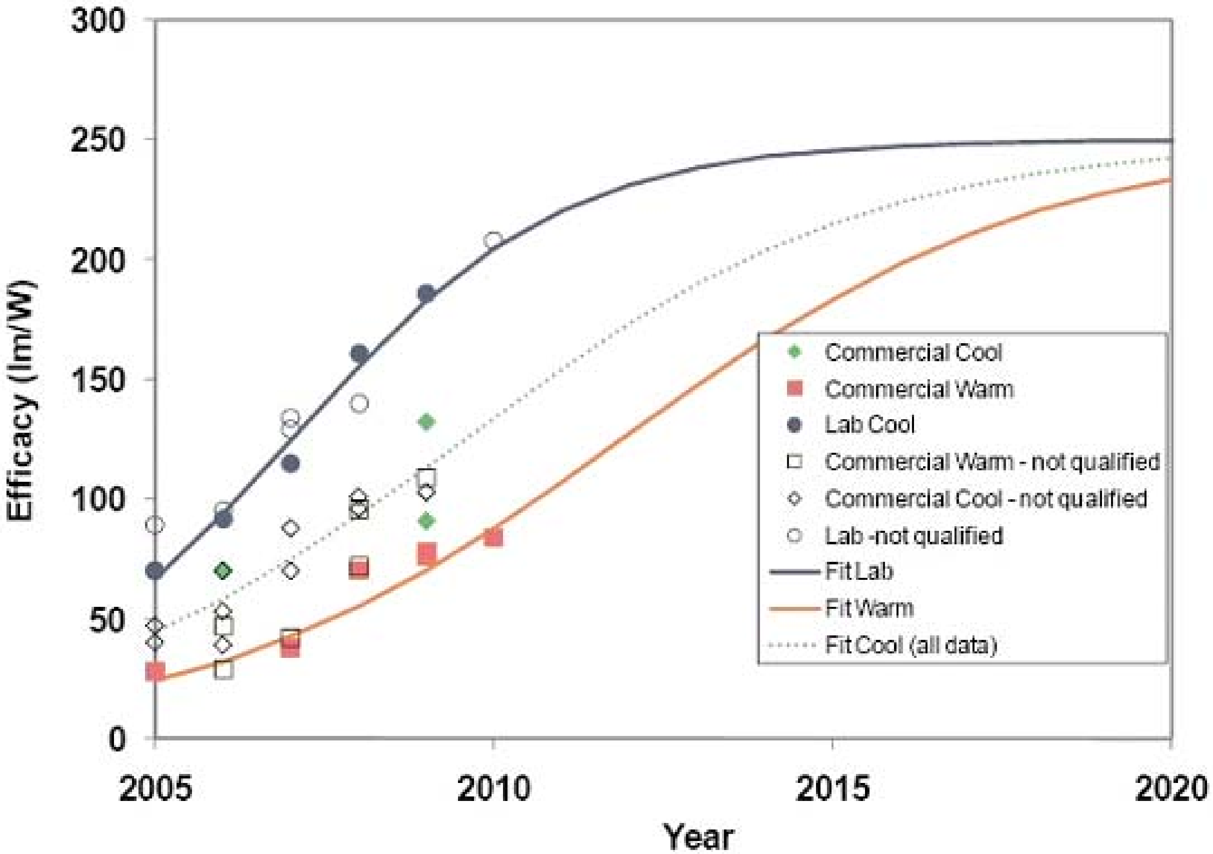
[26] Stevenson, R. China's LED production on a growth trajectory. *OLE* July/August 2009. Retrieved from www.optics.org.
[27] For instance, most illumination-grade chips being used in Chinese products are imported from Tier II manufacturers in Korea (e.g., Samsung) and Japan (e.g., Stanley), and from Tier I manufacturers (e.g., Philips, Toyoda Gosei, and Seoul Semiconductor).
[28] In 2009, Shenzhen Municipal Government also issued a series of documents, including the Shenzhen LED industry plan, with the intention to spend more than RMB 200 million RMB in the next three years to boost its LED industry.
[29] Beyond the packaging companies, it has been estimated by some experts that number of companies assembling LED applications in China may reach 10,000 or more.
[30] Officials from Taiwan based LED companies have pointed out that LED chip production requires high level of technology application and significant experience, and that a massive capacity ramp would not necessarily translate to quality chips that will meet industry standards. In addition, the capacity ramp up will affect pricing, and erode the margins of many small to mid tier LED manufacturers.
[31] *See,* Attachment A, which contains a primer on LEDs and white light LEDs.

(USDOE) in cooperation with LED manufacturers shows that some white LEDs are bright enough for general illumination applications.[32]

Figure 1. LEDs for General Illumination Performance Trends



Source: USDOE

The luminous efficacy of white LEDs is currently better than incandescent and halogen technologies (around 25 lumens/watt), and has caught up to some fluorescent and gas discharge applications such as directional lighting for commercial applications (e.g., garage and street lighting, around 60 to 80 lumens/watt).[33] Projections from **Figure 1** indicate that white LEDs should be able to surpass fluorescent for general lighting during the coming decade (over 100 lumens/watt).

Despite white LED's utility in terms of luminous efficacy and performance, these devices are still significantly more expensive than commercial incandescent light bulbs, where price differentials can be in several orders of magnitude greater. Below, **Table 2** illustrates these projections.

[32] Navigant (2009).

[33] Note that in applications like area lighting, a direct comparison of LEDs with conventional sources using metrics such as total lumens or lumens/Watt, may not be valid. Rather, the luminaires must be compared based on parametric test results or actual measured performance, taking distribution, uniformity, and other performance characteristics into account.

Table 2. LED Price and Performance Projections

Metric	Unit	2009	2010	2012	2015
LED Efficacy (2580-3710K, 80-90 CRI)	lm/W	70	88	128	184
LED Price (2580-3710K; 35 A/cm2)	$/klm	36	25	11	3
LED Efficacy (4746-7040K, 70-80 CRI)	lm/W	113	134	173	215
LED Price (4746-7040K; 35 A/cm2)	$/klm	25	13	6	2
OEM Lamp Price	$/klm	130	101	61	28

Source: USDOE

The breakeven time associated with replacement of a current light source by an LED-based source is a function of how long the lamp operates each day, the upfront cost of the replacement light source, and the cost of the replaced lamp and/or the cost of the lamp-fixture combination for that particular application. From these perspectives, the LED technology for white light has surpassed the efficacy of the incandescent lamp, but still has a much higher upfront cost. The chart below illustrates the relative costs of LEDs currently in the US market.

Table 3. Relative Costs of Directional Lighting

SURVEY OF LED DIRECTIONAL LAMPS: Retail and Online, May 2010, USA (manufacturer data)								
Light Source	**Range of Values**	**Input Power (W)**	**Total Light Output (lumens)**	**Calculated Efficiency (lm/W)**	**Average Rated Life (hours)**	**Warranty (years)**	**Price (USD)**	**Calculated USD per Kilolumen**
All types	low	1	35	7	1500	1	$2.73	$4
	high	300	2480	54	50000	20	$80.81	$425
I	low	25	180	7	1500	1	$2.73	$4
	high	300	2480	19	3000	2	$16.27	$19
HI	low	200	490	10	1500	1	$3.32	$6
	high	100	1310	16	12000	4	$15.59	$16
CF	low	5	420	36	2000	1	$30.14	$6
	high	26	1250	54	25000	9	$4.27	$42
LED	low	1	35	25	12000	3	$14.88	$76
	high	16	850	54	50000	20	$80.81	$425

Source: LED Consulting, 2010, Reported in ECEEE.

Comparing performance of white LEDs to other traditional light sources can be a useful reference point; however, it is important to note that many comparisons can oversimplify data and need to be read in context. For instance, while the above data shows that white LEDs have higher upfront costs, the analysis does not include installation costs of lighting systems, nor are maintenance costs of the incandescent and LEDs systems taken into account. To put this in context, maintenance for an LED system can be virtually non-existent when compared to maintenance for an incandescent system, so that LED lifecycle savings may be larger.

It is also important to be familiar with LED technologies, applications, and how performance is measured because oversimplification of data can be tailored to make LED efficacy and performance look unfavorable compared to other light sources. One nuance to know about measuring LED performance is that the efficacy of an LED is dependent on the whole system. This system consists of the LED chip, the packaging that includes the design of the LED package and the heat sink, the power supply, and "driver." Each component has its own efficiency values and power requirements that are not yet standard in the industry. Therefore, depending on how LED component efficiencies are measured, predictions can vary widely and may be entirely unreliable.[34]

As noted previously, the trend for LEDs to have higher upfront costs is a barrier to having increased market penetration. Despite this barrier, however, commercial and industrial markets have started to prefer LEDs for some applications to other traditional light sources because of LEDs' utility as being more energy efficient and as requiring less maintenance. For instance, with regard to LED-based lighting and fixtures, energy savings and low maintenance characteristics are much more important than other factors like initial cost or usability because energy expenditures, and frequent maintenance would cost more in the long-run. This is especially true in the case of street/outdoor lighting with LED fixtures. Since the introduction of LEDs, many initiatives have been initiated to replace conventional high intensity discharge (HID) sources with LEDs.

In regards to the residential market, initial cost and usability are more important factors than energy efficiency or maintenance. Other factors such as ease of installation, simplicity, and design may play a large part in transforming the market for LEDs in the future. However, based upon past trends from the development of fluorescents, it appears that the higher cost of LEDs is a significant enough barrier for individual consumers such that most of the growth in the LED market will be predominantly confined to the commercial and industrial sectors.

[34] While it is reasonable to assume that the semiconductor efficiencies of LEDs will continue to increase rapidly, other components such as heat sinks, optics, solders, may not be able to match LEDs' spectacular gains due to their technological limits.

SECTION 2:

MEASURING AND REPORTING LED PERFORMANCE

There are two basic ways lighting is used: 1) for *luminance* applications, where we look directly at the light source (e.g., traffic signal); and 2) *illuminance* applications, where light sources are used for illuminating other objects (e.g., an overhead lamp). These two applications each have a corresponding set of measurement methods, tools, and vocabulary that existed before LED-based lighting was a reality.

Applying traditional measurement tools towards LED lighting technology is problematic because it is unlike other forms of lighting. For instance, an incandescent light bulb produces light when electricity is passed through a metal filament until it becomes hot enough to glow. In a CFL, an electric current is driven through a tube containing gases, producing ultraviolet light that is transformed into visible light by the fluorescent coating (phosphor) on the inside of the tube. LEDs, in contrast, are made of very thin layers of semiconductor material. One layer will have an excess of electrons, while the next will have a deficit of electrons. This difference causes electrons to move from one layer to another, which generates light. The more electrons that pass between the layers, the brighter the light.

Despite these differences in technologies, measuring tools have not yet evolved to incorporate LED technology's unique features. This presents a significant challenge, especially when measuring LED performance against the performance of traditional light sources. These many challenges are summarized in this section, which will also include a more in-depth discussion of LED life and color measurement challenges.

Directionality

Many traditional light sources, like incandescent light bulbs, emit light spherically (in all directions). In contrast, LED light sources emit light hemispherically (in a specific direction). A functional, LED-based package contains a UHB LED chip encased in epoxy with a heat sink, metallic leads, and a light reflector. These packages tend to be flat and are typically mounted on a heat sink or substrate, which is why light is emitted hemispherically. Utilizing LEDs for directional applications like task lighting is more advantageous because LED light can be "aimed," which reduces wasted light. However, for other applications, manufacturers have faced challenges in producing LED devices that could compare with incandescent lamps in terms of light distribution and consistency.

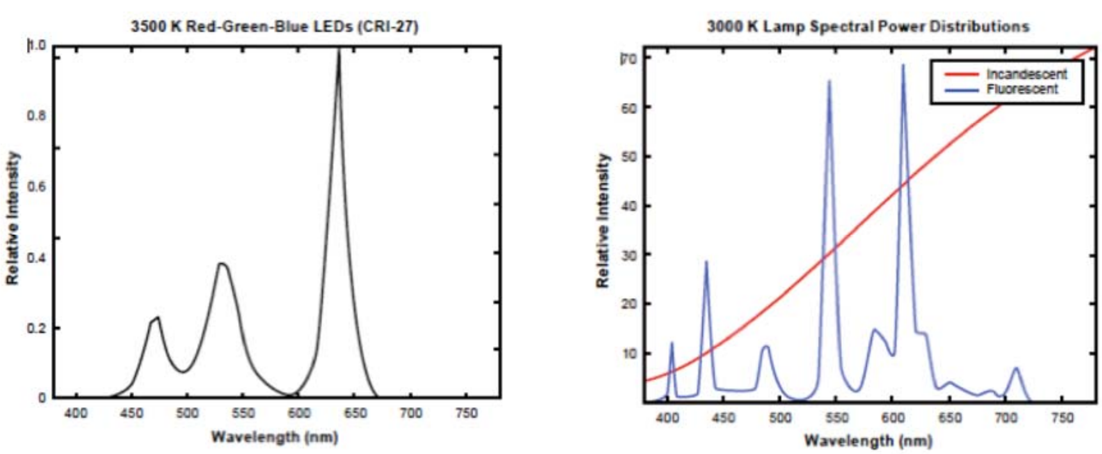
Figure 2. Philips' LED-Based A Lamp Incandescent Replacement ("L-Prize" Entry)

Source: ECO-Asia CDCP

Light Source Comparison

An individual LED chip emits light in a specific wavelength (color), which makes them efficient for colored-light applications. However, to create white light in LEDs, a variety of color mixing techniques are needed – UV, blue-colored LED with a phosphor, or multiple complementary colored LEDs could be included in the packaging. Depending on the technique used, the resulting light will appear white, but it will have a very different spectrum than traditional sources, especially in comparison to incandescent light. This makes it difficult to directly compare the characteristics of light from an LED source to a traditional source, and sometimes even to another LED source. The spectral distribution of a Red-Green-Blue LED (RGB LED) is illustrated below, along with the spectral distribution of typical incandescent and fluorescent lamps for comparison.

Figure 3. Examples of RGB LED, Incandescent, and Fluorescent Spectral Distributions



Source: US DOE CALiPER Program.

Color Characteristics (Light Quality)

In evaluating white light, there are generally two descriptors of light quality that most people are familiar with: *correlated color temperature* and *color rendering*. These metrics are not entirely useful for measuring the light quality of white LEDs.

What appears to our eyes as "white" is actually a mix of different wavelengths in the visible portion of the electromagnetic spectrum.

Incandescent, fluorescent, and high-intensity discharge (HID) lamps radiate across the visible spectrum, but with varying intensity in the different wavelengths. The spectral power distribution (SPD) for a given light source shows the relative radiant power emitted by the light source at each wavelength. Incandescent sources have a continuous SPD, but relative power is low in the blue and green regions. (*See* Figure 3, above). The typically "warm" color appearance of incandescent lamps is due to the relatively high emissions in the orange and red regions of the spectrum.

In contrast, LEDs are monochromatic, meaning an individual LED chip emits light in a specific wavelength. This is the main reason why LEDs are so efficient for colored-light applications. For example, in traffic lights, a red filter on an incandescent lamp can block 90% of the visible light from the lamp, but red LEDs provide the same amount of light for about one-tenth of the power. However, because LED light is monochromatic, various phosphors and other components are needed to produce a broader wavelength spectrum of light to produce white light.

These differences translate to problems with using the Color Rendering Index (CRI), a common measuring tool for light quality devised by the International Commission on Illumination, to measure the light quality of LEDs. The CRI indicates how well light sources render the colors of objects, materials, and skin tones by providing a quantitative "score" of the ability of a light source to reproduce the colors of various objects faithfully in comparison with an ideal or natural light source. The CRI measuring procedure involves comparing the appearance of at least eight color samples as seen under the light source being tested and a reference light source. The differences between the tested light source and the reference light source are averaged and then subtracted from 100 to get the CRI. Small average differences will result in a higher score, while larger differences give a lower score.[35] Sunlight and some incandescent lamps have a perfect CRI of 100. By this method, light sources that mimic incandescent light or daylight for the eight color samples are, by definition, the ones that will score highest on the CRI.

The CRI is not especially relevant for measuring LEDs because their bandwidth emissions are highly dissimilar to the reference light source, and there may be some white light LED applications that are useful beyond what CRI measures, which is only how well a light renders eight different colors under sunlight. For instance, white light generated by commercial RGB LED clusters can be visually appealing, yet the clusters themselves have relatively low CRI values.[36] Because of this, the International Commission on Illumination (CIE) recently recommended that CRI should not be used with white light LEDs.

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[35] If the lamp to be tested has a correlated color temperature (CCT) of less than 5000 Kelvin (K), the reference source is a black body radiator (approximately like an incandescent lamp). For higher CCT sources, the reference is a specifically defined spectrum of daylight.

[36] Similarly, neodymium incandescent lamps, sold under brand names including GE Reveal®, Philips Natural Light, and Sylvania DaylightTM, have low CRIs. However, objects illuminated with them appear brighter and livelier when compared with unfiltered incandescent lamps.

A new metric to accommodate LEDs and other light sources, tentatively called Color Quality Scale (CQS), is currently under development. In the meantime, the USDOE and other organizations involved in LED measurements and standards recommend that CRI only be considered a reference for evaluating white LED products and systems and that CRI not be used to make product selections in the absence of in-person and on-site evaluations. Furthermore, the USDOE recommends that CRI be compared only for light sources of equal correlated color temperature (CCT).[37]

Despite these steps towards changing how we use the CRI system, it has been around for over 40 years and is a standard that most light designers and other evaluators are familiar with. Until new standards, like the CQS, are established, policymakers should make aware of the fact the CRI should not be used to measure the quality of white light LEDs.

Correlated Color Temperature (CCT) is another metric that is commonly used for measuring light quality, but like CRI, is not entirely relevant for measuring the quality of LED light sources. CCT measures, in Kelvins (K) the relative warmth or coolness of a light source in comparison to an incandescing object, such as the sun or a heated filament. Since LED "white" light can be a combination of several LED light sources, or a monochromatic light source and phosphor combination, it is difficult to accurately ascribe a CCT.

Currently, the most efficient white LEDs emit light of 4500K to 6500K CCT. Color temperatures over 5,000K are blue-white, while lower color temperatures (2,700K to 3,000 K) are yellow-white to red. Thus, this is why white LED light is white to blue-white in appearance. Some LED light fixtures (luminaires) and lamps are manufactured to mix LEDs of various color temperatures to reach a target CCT by balancing the highest efficacy sources with warmer LEDs, which are less efficient. This process varies according to the make, model, and CCT of the LEDs, but generally is better than high pressure sodium (usually around 22 CRI) and standard metal halide (around 65 CRI), but somewhat lower than ceramic metal halide (80 to 90 CRI). The nominal CRI for neutral (4000K to 4500K) and cool white (5000K or higher) LEDs is typically 70 to 75. In most street and area lighting applications, CRIs of 50 or higher are adequate for gross identification of color.

There are many debates and theories regarding vision and color. Until the advent of a universal, simple way to describe light and color appearance, comparing LEDs to other existing light sources remains a very difficult challenge.

Efficiency

Traditionally, lighting energy efficiency is characterized in terms of lamp ratings and fixture efficiency.

The lamp rating indicates how much light the lamp will produce when it is operated at standard operating conditions. Measurements are taken in lumens and standard operating conditions are typically at room temperature, or 25 degrees Celsius. The luminous efficacy of a light source is expressed as lumens per watt (lm/w).

Light fixture (luminaire) efficiency is a function of both the light source (the light "bulb" or lamp) and the fixture, including necessary controls, power supplies and other electronics/ballast, and optical elements. Luminaire efficiency is measured in terms of the percentage of lumens actually emitted by the fixture.

[37] This recommendation applies to all light sources, not only to LEDs, as differences in CRI values of less than five points are not significant. For example, light sources with 80 and 84 CRI are essentially the same.

While this is an appropriate measure for luminaires that have interchangeable lamps, this has limited usefulness for measuring LED luminaires. The manner in which the LEDs are integrated into the luminaire have a material impact on the performance of the LEDs inside the luminaire. Thus, depending on what is under consideration, the resulting efficacies can vary. In addition, most LED lighting systems are composed of many discrete components. The losses in these components also need to be measured accurately in order to calculate overall efficacy, not just of the LED chips. The specific points of potential energy waste in an LED system can include:

- **Materials Losses:** Defects in the crystal structure of the LED chip can lower the light output.
- **Internal Losses:** Some photons cannot escape from the LED chip; they convert back to heat energy.
- **Thermal Losses:** As the temperature at the p-n junction internal to the LED chip rises, its light output declines.
- **Encapsulant and Optical Element Losses:** The materials in sealants, optical layers and lenses must be carefully matched to the spectrum of the chip to allow as much light as possible to pass through these layers. If phosphors are added, they must also be "tuned" to maximize the light emission.
- **Solder or Other Contact Losses:** Poorly soldered or bonded components resist the flow of electricity, and convert it to heat energy, compounding any thermal issues in the device.
- **Controllers, Drivers, Transformers, and Other Power Supply Component Losses:** Each of these devices can have its own power demand and contribute to the system efficiency.
- **Luminaires:** The LEDs are usually integrated with one or more conventional luminaire components, such as reflectors, housing, or lenses, each of which has loss potentials.

Reliability

LED chips have a significant advantage over other sources in terms of reliability. Traditional light sources with filaments and electrodes will burn out sooner if switched on and off frequently. For example, in incandescent lamps, the tungsten filament degrades with each hour of operation. When the filament breaks, the lamp "burns out." This break occurs as the lamp is switched on and the electric current rushes through to break a weakened filament. In fluorescent and high-intensity discharge (HID) lamps, the high starting voltage erodes the emitter material coating the electrodes to the point of failure. In contrast, LED life and lumen maintenance is unaffected by rapid cycling so long as the "drivers" are designed to take advantage of this characteristic.

Reliability of LED chips should therefore be considered part of LED performance and quality metrics.

Life

One of the most remarkable qualities of LED technology is that it has a long rated life – up to 50,000 hours or more – compared to about 40,000 hours for even the best linear fluorescent lamps.[38] LED chips do not burn out in the same way that conventional sources do. Rather, their lumen output decreases over time.

[38] In general, the life of a conventional lamp is defined and published by the ANSI/IES and IEC/CIE to be the time at which 50% of the test lamp population burned out. The use pattern that lamps are subjected to depends on the typed of lamp being tested. For example, incandescent lamps are required to operate continuously at their specified voltage until they burn out, whereas fluorescent lamps are operated under controlled conditions cycling 3 hours on and then 10 minutes off until they burn out.

Although conventional lamps also have some light output depreciation over the course of their life, these percentages are not taken into account when lamps are rated for longevity. However, depending on the application, a lamp may require retirement before the end of its life because of decreased light output.

Table 4, below, is a matrix showing light output depreciation over time of various light sources.

Table 4. Rated Life and Lumen Output for Various Light Sources[39]

Light Source	Rated Life (hours)	Lumen Maintenance @50% rated life	Lumen Maintenance @ 100% rated life
Incandescent	1,000	90%	78%
Tungsten-halogen	2,000	97%	93%
Metal Halide	15,000	80%	65%
Fluorescent (med load)	20,000	85%	75%
High Pressure Sodium	24,000	90%	72%
Mercury Vapor	24,000	75%	65%

The rate of degradation of the LEDs happens based on a number of factors. These factors include: the quality of the LED chip, the design of the LED package, and the design of the LED system. The most important factors here are heat dissipation within the LED, and the long-term performance of the associated electronics, or "drivers." A quality chip without appropriate heat removal, for example, is going to degrade much faster than a properly driven, properly cooled LED chip. Similarly, a quality chip associated with a short-lived or low-quality driver will also not perform well over the long run. Further, life testing for LEDs is impractical due to the long expected lifetimes and the current rapid pace of development. Even with 24/7 operation, testing an LED product for 50,000 hours would take 5.7 years. Furthermore, products under testing would be obsolete by the time they finished life testing due to the fact that technology continues to develop and evolve.

A life testing procedure for LEDs has been proposed by the Illuminating Engineering Society of North America (IESNA) based on the idea of "useful life," or the point in time at which the device's light output has declined to a level that no longer meets the needs of the application. For example, for general ambient lighting, the level might be set at 70% of initial lumen output. Useful life would be stated as the average number of hours that the LEDs would operate before depreciating to 70% of initial lumens. The leading HB LED manufacturers have begun using the L70 language, stating that their white LEDs "are projected" to have lumen maintenance of greater than 70% on average after 50,000 hours when used in accordance with published guidelines.

[39] Data adapted from Narendran (2001).

Controls for LEDs

Unlike incandescent lamps, which are universally dimmable with inexpensive controls, fluorescent and HID sources present a number of challenges in this regard. With general lighting applications, only CFLs with a dimming ballast may be operated on a dimming circuit; HID sources require specialized electronic ballasts for any degree of dimming. Dimming ballasts for commercial-grade (at specifications) fluorescent systems are readily available and effective, although at a substantial price premium. Further, all of these sources usually do not perform well over a wide (1% to 100% light output) dimming range like incandescent lamps do.

LEDs have an advantage over fluorescent and HID sources in that LEDs can be dimmed over a wide range. However, the challenge with dimming LED-based devices are in the electronics, or "drivers." Like with fluorescent and HID commercial applications, LED-based dimming systems could be available and effective, but at a cost. In the case of general lighting, LEDs face a similar challenge to dimmable CFLs – they need to be compatible with a wide range of dimmers currently in use. LED manufacturers would need to adequately test the compatibility of their products with the variety and technologies used in dimming incandescent lamps (including halogen).

Eye Safety

The vast majority of LEDs are completely safe and do not present any hazard to the human eye. However, as the radiant output power of individual LED chips and multi-chip LED arrays continues to increase, there is also growing concern over the increased potential risk of eye damage. High-powered LEDs can cause a thermal heating effect in proportion to the power density of the radiation, which can result in tissue damage to the retina, similar to exposure to laser sources. Shorter wavelength radiation emitted by some LEDs can cause a photochemical effect in the retina, changing the chemistry of the cells, and UVs at shorter wavelengths can cause damage to the cornea and/or the lens.

One ongoing issue with LED safety is the problem of whether to classify an LED as a laser or a lamp – both have merits and both present problems, depending on how the LEDs are arranged and used. Lasers and LEDs can cause a thermal heating effect in proportion to the power density of the radiation. At shorter wavelengths below 400 nm, UV light is largely absorbed by, and can cause damage to, the cornea and/or the lens.

SECTION 3:

NEAR-TERM OPPORTUNITIES FOR LED LIGHTING

It is only a matter of time before LED-based lighting will become one of the mainstays in residential, commercial, and industrial markets throughout the world. In one to three years, LED-based lighting products with commercial and industrial specific lighting applications will find their way into more mainstream and residential lighting applications. Even with the recent pace of product development, Asia's residential lighting market will not see large adoption of LED products within this one-to-three year timeframe (other than for the novelty factor) due to the combination of high initial costs and lack of availability of quality products. The exception may be in the off-grid (DC) lighting market, where investments are being made to replace kerosene and other inefficient, polluting light sources in rural Asia.[40]

Non-Residential/Non-General Lighting Opportunities

Based on ECO-Asia CDCP's review of available data on actual, documented, and verifiable cases, areas where LED-based lighting products will likely make a potential for significant impact in one to three years are in outdoor and roadway lighting, transportation-related functions, and architectural applications. ECO-Asia CDCP made these predictions based on current costs and energy savings potentials through installing LEDs in comparable applications. These predictions were verified with performance test data.[41]

Based on the compiled data, ECO-Asia CDCP made the following findings:

- LEDs are generally not cost effective in indoor applications, especially in retrofit situations.
- LEDs are most cost-effective in situations where they are displacing a traditional light source in an application with a high duty cycle in a new-build situation. New-build situations include new area, parking, street, or outdoor lighting installations, as well as decorative and signage lighting.
- Available performance and cost data show that LEDs are not yet ready to displace the best fluorescent applications for general lighting, like linear fluorescent T8 or T5 lamps.[42]
- Available "best in class" LEDs are now comparable to incandescent and halogen lamps in some applications, but LEDs have yet to surpass CFLs in cost-effectiveness for general lighting situations, especially in most residential applications.[43]

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[40] *See, e.g.,* Asian Development Bank (ADB) and The Energy Resource Institute (TERI). (2010, October 29). "Lighting for All" Scheme to Bring Clean Energy to 50 Million Asians. Retrieved from http://www.adb.org/media/Articles/2010/13378-asian-affordable-electricities/; *see also* Lighting Africa – Catalyzing Markets for Modern Lighting. Retrieved from www.lightingafrica.org.
[41] Architectural applications are likely to be new application areas and not replacement or refurbishment of existing uses.
[42] McCullough (2009).
[43] The latest round of USDOE CALIPER testing of LEDs replacement for IR reflector halogen applications shows that LEDs do not deliver similar center beam candlepower (CBCP) yet.

- LEDs will continue to make additional impacts in areas such as traffic signals and signage. These areas are briefly elaborated further below. However, it is important to note that LED products have the potential to be "disruptive" and may find other market niches that are not in these broadly outlined categories. This is because these products are entering the market at different entry points, and may or may not be limited to their traditional distribution channel for their product categories and applications.

Traffic Signals

LED traffic signals offer a huge potential for energy savings and maintenance efforts over incandescent lamps. As mentioned previously, colored LED lights have significant advantages over traditional incandescent lights because LEDs are monochromatic while incandescent lights require a colored filter to produce colored light. As a result, the luminous efficacy of the LED system far exceeds that of incandescent lamps, and LED traffic signals use 80% to 90% less electricity. Additionally, in times of power outages, battery backup systems for important intersections can power LED signals for much longer periods of time than with incandescent signals.[44]

LED traffic signals also hold a significant maintenance advantage over existing incandescent systems. LED traffic signals last 5 to 10 times longer than conventional signals and therefore require much less maintenance. This translates to reduced safety risk for the work crews as well as reduced maintenance costs.

In Asia, many traffic signals in large cities have been converted to having LEDs. For example, Singapore has converted all of its incandescent traffic lights to LED traffic lights in an initiative that began in the 1990s. However, the overall proportion of traffic signals replaced is believed to be small throughout the region, as many second and third-tier cities have not yet started converting their traffic lights over.[45]

The most likely reason why the majority of traffic lights have not been converted over is the initial cost of LEDs, which is considerable. An incandescent traffic signal lamp costs on average US$ 2 to US$ 2.50, excluding the reflector and cover. By comparison, LED traffic signal module costs vary, but generally cost about many times more than the incandescent unit. For example, a red LED signal can range from US $50 to US $100, and a green LED module may cost twice as much.

Exit Signs

Similar to LED-based traffic lights, LED-based "Exit" signs are better in terms of energy efficiency, lifetime, and luminous efficacy. Like traffic lights, new and retrofit exit signs also take advantage of the colored nature of the LED light, replacing the need for colored filters. This translates to an energy savings of 90% when compared to incandescent exit signs and an energy savings of 50% when compared to CFL signs.

Because of their energy-savings potential, LED exit signs were the focus of a number of utility programs in the US, and are now well established in the US lighting market. The introduction of the US EPA/USDOE ENERGY STAR® Exit Sign program in 1996 further enhanced US market acceptance of LED exit signs, and established a set of performance specification for these products that can be adapted for Asia. In the US, the Energy Policy Act of 2007 requires that all new exit signs meet ENERGY STAR® requirements.

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[44] To illustrate, a 68-light intersection (4 lanes) with incandescent signal lamps consumes about 6.8 kilowatts, while the same intersection, configured with LED signals, consumes a tenth of that amount, or 680 watts. This has the potential to lengthen battery run time by a factor of ten, moving a system from being able to run 15 minutes to a system that would be able to run for over 2 hours. Other advantages of such low power consumption include the ability to reduce system and back-up battery size, thereby decreasing purchase and/or maintenance or battery replacement costs as well.

[45] The Clinton Climate Initiative is working to reduce climate impacts in the world's top 40 cities, and includes LEDs promotion.

Transportation

At airports, shipping facilities, highways, and other transportation areas, LED guidance signals and other traditional installations offer several advantages. Due to the location of many of these lighting applications, maintenance can be a major burden. Thus, the fact that LEDs have long lifespans alleviates a lot of the maintenance burdens.

Moreover, many lighting applications in transportation rely on colored lights. Utilizing LED colored lights would reduce a lot of the energy costs.

In Asia, there are hundreds of airports, shipping ports, and other facilities that are under development or that are being upgraded. These facilities require markers, numbers, signs, and other high duty cycle lighting tasks related to transportation indicators.[46] The wholesale replacement of incandescent transportation-related lighting with more energy-efficient and longer-lasting LED units can result in significant energy and maintenance savings for shipping and aviation facilities, most of which are struggling to meet the rapidly growing transportation demands of this region. **Table 5** presents possible energy savings in using LED applications.

Table 5. Typical Intersection and Airport Lighting Use

	Traffic Signal Per Intersection			Aviation Per Airport – One Runway			
Lamp Location	**Ball**	**Turn**	**Pedestrian**	**Approach**	**Touchdown**	**Centerline**	**Edge**
# Lamps Required	24	2	8	96	180	120	70
Incan. Watts/Lamp	150	125	125	375	60	120	120
Subtotal (Watts)	3,600	250	1,000	36,000	10,800	14,400	8,400
LED Watts/Lamp	15	10	15	56	9	18	18
Subtotal (Watts)	360	20	120	5,400	1,620	2,160	1,260
Savings (Watts)	**3,240**	**230**	**880**	**30,600**	**9,180**	**12,240**	**7,140**
Total Savings (Watts)	**4,350**			**59,160**			

Source: Ecos Consulting, Research Report to the Northwest Energy Efficiency Alliance, US (2005).

[46] Frost & Sullivan (2010).

Commercial Signage and Architectural Building Decoration

Many signs are switched on 24 hours per day, and typically, architectural decorative lighting tends to be on starting at dusk and remain lit past midnight. Many cities in Asia have architectural decorative lighting, like in the Bund in Shanghai, China. A variety of LED products are now available for new or retrofit commercial signage and architectural lighting that could further reduce the electrical load. LEDs can even replace traditional neon and fluorescent signs. Some of these LED products include:

- *Color wash floodlighting* for variable color on interior and exterior walls in entertainment venues and other high-profile building facades.
- *Channel lettering replacement products*, which are available from a variety of manufacturers.
- *Replacement neon polycarbonate tubing*, which places LEDs into a package that looks like a neon tube, typically used for architectural neon accents on buildings and in entertainment venues.

Retail Food and Beverage Refrigerated Display Case Lighting

Because LEDs are cool to the touch, are not adversely affected by cold temperatures, are more efficient at directional illumination, and do not require much space, LED lighting options for refrigerated display cases in groceries are better than the traditional fluorescent options currently being used. The fact LEDs are cool to the touch, for instance, reduces the amount of heat introduced into the refrigeration space when compared to fluorescents, thus yielding secondary energy savings at the compressor level.

There is a lot of interest in Asia for LED-based refrigerated display case lighting applications. A number of well-known manufacturers, as well as newly established LED manufacturers, have introduced refrigerated case products in the past year. Both test and full-scale installations have taken place in the US and elsewhere, including China.[47] Fluorescent manufacturers are aggressively moving to keep their dominance in this market, and several manufacturers have introduced cold-cathode fluorescents. While these new fluorescent systems may promise incremental energy savings, LEDs can still offer important advantages over many of them, including lower maintenance and lower possibility of in-case lamp breakage.

Area Lighting

LED-based lighting has gained the most attention and traction in the shortest length of time in area lighting for both indoor and outdoor public spaces, parking lots, and street lighting.

With respect to indoor lighting, the distinction needs to be made between a retrofit device versus a lighting fixture designed specifically for LEDs. An example of a retrofit device is an LED-based lamp made to fit into an existing incandescent socket or an LED tube made to replace a T8 linear fluorescent tube. These tend to be not well-executed. In contrast, lighting fixtures designed for LEDs take advantage of its unique features such as directionality and controllable or "tunable" light characteristics.[48] Lighting fixtures designed for LEDs are what is gaining the most attention and traction in the area lighting market.

With new LED light fixture designs, manufacturers have successfully introduced a number of innovative systems to effectively and efficiently light areas with LEDs. Examples of these systems include the Cree LR24, and the MaxLite Flat LED panel, shown in **Figure 4**, below. Products like these are slowly gaining momentum in the US and Europe, as more new buildings are being designed with these systems in mind.

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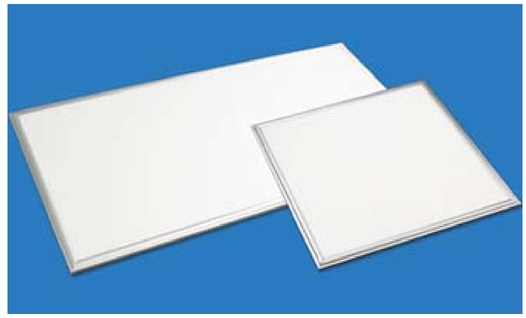
[47] *See*, *e.g.*, General Electric. Wal-Mart Uses GE LED Refrigerated Display Lighting to Save Green. (n.d.). Retrieved from http://pressroom.geconsumerproducts.com/pr/ge/Walmart_LED_display.aspx.
[48] An example of this would be an LED-based reflector lamp versus a lighting system such CREE's LR6 downlighting fixture.

Figure 4. LEDs for Area Lighting

Cree LR24

Source: Cree, www.creeledrevolution.com



MaxLite LED Panel

Source: MaxLite, www.maxlite.com

With respect to outdoor lighting, LED-based products have made significant progress in establishing itself as a credible alternatives to HID, induction, fluorescent, and other traditional street and outdoor light sources in terms of performance and design. Municipalities around the world from Europe to Asia are racing to test and install LED street and public lighting.

LED-based street and area lights have many advantages over conventional sources. The most important advantage is that LEDs are not a point-source like high-pressure sodium (HPS) or metal halide (MH). Therefore, the available luminous flux, or total amount of light, can be more evenly distributed and controlled. This characteristic allows designers to aim individual LEDs in the light fixture for optimal distribution and precise cut-off, allowing them to achieve the performance of HPS or MH with a smaller lumen package, thereby reducing energy consumption in the process.[49] Because of its high functionality, LED-based street and area lighting is the most innovative and widely-adopted application out of the other LED applications.

Installation of these applications has yielded many valuable lessons and cautionary tales that policymakers should be aware of. For that reason, the USDOE has compiled performance and cost data from a number of high-profile test installations on a range of products.[50] USDOE's test installation reports – called GATEWAY Demonstrations – is publicly available and can be found at their website. Full, parametric laboratory test results of products used in these demonstrations are also available on USDOE's website.[51]

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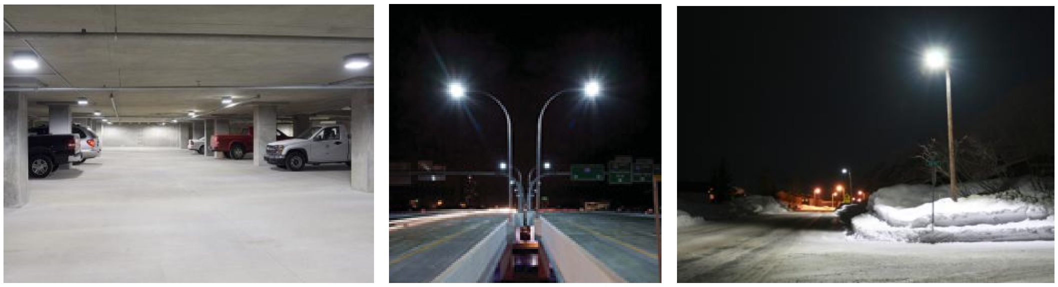
[49] Note that in applications like area lighting, a direct comparison of LEDs with conventional sources using metrics such as total lumens or lumens/Watt, may not be valid. Rather, the luminaires must be compared based on parametric test results or actual measured performance, taking distribution, uniformity, and other performance characteristics into account.
[50] E.g., Harger, Jim (2008, August 1), "LED lights fail to illuminate Grand Rapids streets." *The Grand Rapids Press*. Retrieved from http://blog.mlive.com/grpress/2008/08/led_lights_fail_to_illuminate.html; Punch on the Web (2010, November 25). "Failed Solar powered street lights – any lessons?" Retrieved from http://www.punchng.com/Articl.aspx?theartic=Art201011250185978.
[51] U.S. Department of Energy. "Solid-State Lighting GATEWAY Demonstrations." (n.d.). Retrieved from http://www1.eere.energy.gov/buildings/ssl/gatewaydemos.html.

Figure 5. Installations of Indoor and Outdoor LEDs Lighting Demonstrations in the US



Source: USDOE and Cree

Figures 6 and 7, below, illustrate how one manufacturer has taken advantage of LEDs' unique characteristics in their design process and applied them towards street and area lighting. **Figure 6** shows the actual LED module with a reflector and lens system, which can precisely direct the light output of individual LEDs. **Figure 7** shows the array of these LED modules installed in a "bar" where a number of light bars can be combined to reach the total lumens needed, as well as the distribution pattern desired for a particular luminaire or application.

Figure 6. LED lens & reflector system

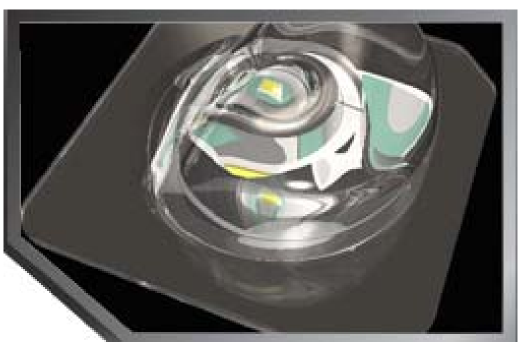


Figure 7. A modular LED "bar"

Source: BetaLED, Inc., www.betaled.com

SECTION 4:

OPTIONS FOR DEVELOPING LED STANDARDS IN ASIA

The fact that LED technologies are relatively new and fundamentally different from traditional light sources poses many challenges for standards setting. These challenges are compounded by the fact that standard-setting processes tend to be slow and therefore do not keep up with ongoing advances made in the LED industry. Thus, by the time a particular standard can be developed for LEDs, the technological advances may have rendered some performance parameters inadequate.

Nevertheless, setting LED standards is important for a number of reasons that will be elaborated in this section below. Although the standards-setting process for LEDs will be a challenging effort, regional coordination between policymakers at the onset of the process would alleviate some of these challenges, while also ensuring that standards are not overly complex or incompatible. ECO-Asia CDCP thus recommends that, at the very least, the region design LED-specific standards so that the lighting market can accommodate more product diversity and innovation, as well as account for uncertainties in the pace of development.

In reaching this conclusion, the ECO-Asia CDCP team conducted a survey on technical standards, national regulations, testing and labeling requirements, and other performance and quality criteria that address LEDs available for sale in Asia.[52] The results are summarized in **Table 6** below. Additional details regarding specific standards and categories are further discussed in this section and summarized in **Attachment B**.

[52] While this report broadly applies to the Asia region, the data presented focus primarily on China, India, and four countries holding membership in the Association of Southeast Asian Nations (ASEAN) - Indonesia, Philippines, Thailand, and Vietnam. Together, these six nations account for 96 percent of the gross domestic product (GDP) of Asia's developing economies as well as a significant share of the regional LEDs market.

Table 6. Overview of Standards Activities in Asia

Country/Region	LED Standard Activities?	Specific Application Category Under Development	Responsible/Lead Organization
Brunei	None	None	Energy Division of the Prime Minister's Office
China	Task Team formed	Street, devices, lamps	China National Institute for Standards and others
Hong Kong	Task Team formed	None	Hong Kong Electrical and Mechanical Services Department
India	Task Team formed	Street lighting, off grid	Bureau of Indian Standards
Indonesia	Testing standards under development	LEDs for solar homes	Indonesian Directorate General of Electricity & Energy Utilization, Indonesian National Standards Institute
Japan	A number of standards have been published	See Attachment B	Japan Electric Lam Manufacturers Association, Japan Institute of Standards
Malaysia	Under consideration	Not yet decided	Standards Malaysia
New Zealand	Task Team formed	Street lighting	New Zealand Energy Efficiency and Conservation Authority
Philippines	2010 Designated for LED standards	Modules/General Safety	Philippines Bureau of Product Standards
Taipei	A number of standards have been published	See Attachment B	Taiwan Bureau of Standards, Metrology and Inspection
Thailand	Under development	LED modules	Thai Industrial Standards Institute
Vietnam	No	NA	Vietnam Standard and Quality Institute

With respect to global LED standards development, there are a number of efforts underway to help define LEDs, which could serve as reference points for Asia's future LED standards development efforts. Most notable are the Europe's efforts through the Ecodesign Initiative, the USDOE's Solid-State Lighting Commercialization Support, and the USDOE's five-year plan to accelerate adoption of energy-efficient lighting. Based upon the ECO-Asia CDCP's survey of the Asia region's standards-development activities, ECO-Asia CDCP recommends that the region look to standards developments in Europe and the US as a base from which the region should build its standards-setting activities upon. The following standards have already assisted in the development or coordination of a number of LED-related standards, including some standards currently under development throughout Asia:

- ANSI C78.377-2008, Specifications for the Chromaticity of Solid-State Lighting Products: Specifies recommended chromaticity (color) ranges for white LEDs with various correlated color temperatures (CCTs).

- IES LM-79-2008, Approved Method for the Electrical and Photometric Testing of Solid-State Lighting Devices: Specifies a standard test method for measuring the photometric properties of SSL devices, allowing calculation of luminaire efficacy.

- IES LM-80-2008, Approved Method for Measuring Lumen Depreciation of LED Light Sources: Specifies a standard method for measuring the lumen depreciation of LEDs, allowing calculation of LED lifetime.

- IES RP-16 Addenda a and b, Nomenclature and Definitions for Illuminating Engineering: Provides industry-standard definitions for terminology related to solid-state lighting.

- IES G-2, Guideline for the Application of General Illumination ("White") Light-Emitting Diode (LED) Technologies: Provides lighting and design professionals with a general understanding of LED technology as it pertains to interior and exterior illumination, as well as useful design and application guidance for effective use of LEDs.

- NEMA LSD 45-2009, Recommendations for Solid-State Lighting Sub-Assembly Interfaces for Luminaires: Provides guidance on the design and construction of interconnects (sockets) for solid-state lighting applications.

- NEMA LSD 49-2010, Solid-State Lighting for Incandescent Replacement – Best Practices for Dimming: Provides recommendations for the dimming and design of screw-based incandescent replacement solid-state lighting products.

- NEMA SSL 3-2010, High-Power White LED Binning for General Illumination: Provides a consistent format for categorizing (binning) color varieties of LEDs during their production and integration into lighting products.

- UL 8750, Safety Standard for Light Emitting Diode (LED) Equipment for Use in Lighting Products: Specifies the minimum safety requirements for SSL components, including LEDs and LED arrays, power supplies, and control circuitry.

In addition to the European and US standards covered above, there are a number of safety standards that are applicable to LEDs. These include:

- IEC 60825-1, Safety of laser products - Part 1: Equipment classification and requirements. This standard was developed by the International Electrotechnical Commission and has been adopted in Europe as EN 60825-1. This standard is commonly known as the Laser Safety Standard but also covers LEDs, and treats them as lasers. Note that LED products sold in the EU must be tested according to IEC 60825-1.

- EU General Product Safety Directive. This directive requires that all consumer products for sale in the EU should be safe. The Directive does not reference IEC 60825-1, but manufacturers have used use this standard to help define "safe." It is important to note that different EU member countries have various guidelines (rather than directives) covering laser and LEDs: no laser or LED pointer can be above Class 2, and all LEDs in children's toys must be Class 1.

Within the Asia region, Japan and Taiwan are ahead in terms of standards development. ECO-Asia CDCP recommends that, in addition to examining developments in Europe and the US, the region look to the standards adopted in Japan and Taiwan as a reference point for future standards development.

Japan has developed a number of LED-related standards, including:

- TS C0038 – (Pub.2004-11-20)(Expire 2011-05-19) – Photobiological safety of lamps and lamp systems.
- JIS C8121-2-2 (Pub. 2009-03-20) – Miscellaneous lampholders Part 2-2: Particular requirements – Connectors for printed circuit board based LED- modules.
- JIS C8152 – (Pub. 2007-07-20) – Measuring methods of white light emitting diode for general lighting.
- JEL 311 – (Pub. 2006-03-22) – General Rules for Photometric Method of White LED Lighting.
- JIS C 8153 – (Pub. 2009-03-20) – DC or AC supplied electronic control gear for LED modules – Performance requirements.
- JIS C8147-2-13 – (Pub. 2008-10-20) – Lamp controlgear – Part 2-13: Particular requirements for d.c. or a.c. supplied electronic controlgear for LED modules.
- JIS C8154 – (Pub. 2009-03-20) – LED modules for general lighting – Safety specifications.
- JIS C8155 – (Plan 2010) – LED module for general lighting service – Performance requirements.
- TS C 8153 – (Pub. 2007-07-20; Expire 2010-07-19) - White light emitting diode devices for general lighting – Performance specifications.
- JIS C 8156 – (Plan 2010) – Self-ballasted LED – lamps for general lighting services by voltage >50V – Safety specifications.
- JIS C 8157 – (Plan 2011) – Self-ballasted LED lamps for general lighting services – Performance requirements.

Taiwan (Chinese Taipei) has published several LED device/product standards. These are listed below:

- CNS15233: Fixtures of roadway lighting with light emitting diode lamps – outdoor,
- CNS15247: Test methods on light emitting diode components and modules (for general lighting service) for normal life – other.
- CNS15248: Methods of measurement on light emitting diode components for thermal resistance – other.
- CNS15249: Methods of measurement on light emitting diode components for optical and electrical characteristics – other.
- CNS15250: Methods of measurement on light emitting diode modules for optical and electrical characteristics – other.

SECTION 5:

RECOMMENDATIONS FOR FUTURE ACTION IN ASIA

Although LEDs are not likely to completely displace traditional light sources, LEDs will likely become one of the mainstays of energy-efficient lighting. The versatility of incandescent lighting for many tasks, as well as over a century of investment and development centering on incandescent lighting, means that its legacy will not be easily or quickly changed.[53] Additionally, developments in the efficiency and cost of existing light sources have not yet stopped.[54] Thus, the key to ensure future energy efficiency in lighting products will require that each light source be used to its best advantage.

In order for LEDs to achieve their best potential for energy efficiency and widespread adoption, clearer policies and standards need to be developed. It is apparent that current metrics cannot adequately describe the characteristics of LEDs. This poses a challenge to those who must set standards for LEDs. Continuing to utilize old measurement systems not only misleads both policymakers and consumers, it has the potential to limit LED technology's ability to effectively command the lighting market.

In order for the Asia region to take advantage of this energy efficient, low maintenance, and innovative technology, new standards must be implemented to take into account LEDs' unique features. ECO-Asia CDCP recommends that agencies across the region update their national lighting standards library to accommodate LEDs, which should take place in the near future. Although the standards-setting process can be slow and resource-intensive, many governments are keen to develop their domestic LED industry, improve their energy efficiency, or both. Therefore, governments across the region could save time and resources by directing efforts towards conferring on formulating region-wide standards. There are also other initiatives underway, including compliance with the Restriction of Hazardous Substances Directive (RoHS), which also should be taken into account.

Policymakers, regulators, standards-setting bodies, and agencies across the region should conduct an immediate standards and policy "triage" for LEDs. Based on ECO-Asia CDCP's review of the majority of available data on actual, documented cases regarding installation of LEDs in comparable applications that can be verified, the triage should initially focus on the following application areas for LEDs:

- **Area, parking, street and/or outdoor lighting:** This is a high-interest area, and policy support for standards may be easily obtained. However, standards for these application areas can be very involved, and related standards such as pole height, distribution, illumination levels, etc. may also need to be revisited, adding to the time investment.

[53] Consider, e.g., the pace of T12 to T8 tube lamp replacement worldwide or magnetic to electronic ballasts for tube lamps.
[54] E.g., the "super CFL" and other coated and halogen IR reflector lamps have made significant progress in efficacy.

- **Traffic lights and transportation-related signals:** These are high-duty applications that can yield significant savings both in energy and maintenance costs, even if they are not as visible as other applications. Changing transportation and traffic-related lighting may also require code or regulation changes in addition to changes in standards.

- **Signage and architectural applications:** Similar to traffic and transportation-related applications, these are high-duty cycle, and they are also increasing in numbers as more commercial buildings are being built and retrofitted around the region.

- **Off-grid lighting applications:** These applications have gained significant interest in recent years, as a new generation of low-wattage LEDs has started to meet some basic rural lighting needs. Additionally, off-grid lighting applications have the potential to serve a large percentage of Asia that is not yet connected to the grid. Like with street lighting, complementary standards for these applications will be needed, such as in charging and battery capacity.

As noted earlier, LED products have the potential to be "disruptive" and may find other market niches that do not fit neatly into these above broadly-outlined categories, or for other traditional distribution channels. In addition, the lessons learned from the introduction of CFLs indicate that while consumer-oriented LED products (such as incandescent lamp replacement) are not yet cost effective, a number of steps, including quality standards for consumer products, should be put in place in the near future in order to protect early adopters from exaggerated claims and from products with dubious performance. Adopting minimum quality standards would reduce the risk of inferior products "poisoning" the market.

Finally, there are a number of variables that policymakers in Asia may wish to consider when analyzing the growth of LEDs:

- **Road map for LED-related policies:** Policymakers will require a road map for LED categories that covers standard-setting, regulation, and promotion that is based on industry development progress and potential impacts to guide their decisions. Policymakers may also want to consider a regional, ongoing effort to coordinate on a regional road map for LED categories based on the potential impacts in terms of energy savings and costs. This will allow a continued "triage" for standards and regulation development that can allow policymakers and standard setting agencies to keep pace with the industry.

- **A regional effort on LED standards and labeling:** A regional effort towards harmonization of standards and labeling for LEDs can help to speed up the adoption of quality LED-based products and reduce the overall efforts needed around the region. Currently, there is no recognized set of common quality criteria for LED-based products in place across Asian consumer or commercial markets. This presents an opportunity for harmonization of quality standards that can help reduce confusion, speed up adoption, and send the right economic message to suppliers and developers of quality LEDs in Asia.

- **Quality is essential:** A hard-lesson from the introduction of CFLs into Asian markets was that low-quality products could undermine energy-efficiency policies and efforts to mitigate greenhouse gas emissions. High-level policymakers need to recognize that the prevalence of low-quality LED products in the market will again constitute a significant barrier to the full realization of energy-efficiency policy goals. Given that first costs for new LED-based products are much higher than CFLs (on a per-unit basis), it is imperative that public and private investments should be made as wisely as possible.

- **Use available regional institutions:** Currently, many countries focus their standards on energy efficiency and energy performance and do not explicitly incorporate other quality criteria into their standards. Therefore, an initial step for the regional harmonization process for LEDs can begin by identifying some common performance characteristics for LEDs that can ensure energy, light output, and lifetime performance provide a minimum level of product quality in the market. There are three regional initiatives that can serve as suitable vehicles for such a regional effort:

  1) **The Asia Lighting Compact (ALC)**– Based in Singapore, the ALC is a regional, independent, public–private partnership whose mission is to promote standards harmonization, product quality, and adoption of energy efficient lighting. It has worked with regional stakeholders to develop a set of quality standards for CFLs in Asia. (*See* www.asialighting.org)

  2) **The Regional Center for Lighting (RCL)** – Based in Sri Lanka, the RCL is a technology hub for lighting in Asia. RCL's mission is to advance sustainable lighting and make it affordable to improve the well-being of the citizens and the countries within the region. It is developing a technology and knowledge portfolio and laboratory capacity. (*See* www.rclsa.net)

  3) **Lighting Information and Technical Exchange for Standards (lites.asia)** – The objective of lites.asia is to facilitate a greater involvement by Asian/APEC countries in the development of the International Electrotechical Commission's (IEC) standards. This should result in standards which are more appropriate for regional needs, thus enabling Asian/APEC countries to adopt IEC specifications with minimum local variations. (*See* www.litesasia.org)

A combined, coordinated effort by these organizations could help advance both the technology road map and standards harmonization for the region. These organizations should also work together to recommend performance and quality categories, as well as recommend product categories, test methodologies, data sharing plans, etc. both suitable and acceptable for agencies and stakeholders in Asia. These organizations could help develop guidelines in these two important areas:

- **Guidelines for municipalities:** Currently, many municipalities and agencies are in the throes of "LED-fever." They are determined to make investments in LEDs at all costs and are confused by misleading performance and lifetime claims when carrying out cost-benefit analyses. One possible approach to address this issue is to develop a one-page guide for evaluating LEDs and product claims. Officials and agencies would then use this guide to screen out dubious products. A follow-up step would be to seek support for a regional organization, whose purpose would be to disseminate information regarding best practices in public and municipal lighting for agencies throughout the region.

- **Guidelines (and labels) for consumers:** Similar to the many municipalities and agencies, consumers are also blinded by exaggerated and unverified claims of performance and quality. As a result, low-cost consumer products are appearing in many markets without any oversight or recourse for consumers. This remains a preventable disaster. Energy or consumer agencies can work with a recognized regional organization on product quality, such as the ALC, to develop a consumer guide and/or a standard label to help consumers choose quality products. This guide can use common descriptors of performance and quality for consumers around Asia and would help prepare the market for quality products.

ATTACHMENT A:

A PRIMER ON LEDS

Note: the materials used in this section were taken from a number of sources, including USDOE, Wikipedia, Philips/Lumileds, Navigant Consulting, Inc., and Carnegie Mellon University.

Coverage

LEDs were invented in 1969 and represent the first fundamentally new lighting technology since gas-discharge lamps. LEDs bring many advantages to electric lighting, with the most notable advantages being energy efficiency and an extremely long service life. Other characteristics of LED systems can include:

- A smaller profile than that of other lighting systems.
- Like with fluorescent lamp systems, declining performance when heat builds up.
- Like with any other system, a lifespan that is determined by the duration of the shortest-lived component.
- Typically fast "on-times" in the order of 60 nanoseconds (versus 10 milliseconds for incandescent lamps).
- If various colors are mixed within an LED system, and if it lacks the circuitry needed to balance the light output as temperature varies, the overall color appearance of the light output may shift.

The LEDs covered in this report are limited to LED-based lighting products. To date, this includes LEDs that emit visible and ultraviolet (UV) energy.[55] This report focuses only on the so-called high brightness LEDs (HB LEDs) and ultra-high-brightness LEDs (UHB LEDs), although there is no standard industry definition of the HB LEDs or of UHB LEDs. This report does not cover the wide range of solid-state lighting (SSL), which includes lasers and organic light emitting diodes (OLEDs).

Background

Materials in electric and electronic applications are classified into three groups according to their *conductivity*, which is a property that describes how easily current flows in the material. These materials include:

- *Conductors* – these are conducting materials such as copper and gold, where electric current flows with virtually no resistance.
- *Insulators* – these materials that are opposite of conductors, like plastic and rubber, where virtually no electric current is able to pass.
- *Semiconductors* – these materials in between the two conducting extremes, and are solid, crystalline materials that are more conductive than an insulator but less conductive than pure conductors.

[55] Sometimes UV emitting semiconducting chips are coated with a phosphorescent layer that emits light in the visible spectrum when it is exposed to UV light. Ultimately, the user sees visible light. This technique is sometimes used to produce white light.

Creating LEDs from Semiconductors

By layering semiconductor materials that have different levels of conductivity, a *diode* can be produced. A diode is a valve-like device through which electrical current flows in one direction and is blocked from flowing back in the other direction. More specifically, by applying a voltage difference across two distinct layers of the diode, current flows through the material. Light emitting diodes, or LEDs, are special types of diodes that convert electrical energy into light through a phenomenon called electroluminescence.

The physical explanation for LEDs is as follows: the flowing current in an LED excites electrons in one semi-conducting layer to a high-energy state. These excited electrons then combine with "holes," or places in the material where there are a lack of electrons. This combination of electron and hole allows the electron to settle into a lower energy state and emit a photon, or "light packet." The photons that are emitted from this recombination make up what we perceive as light from the diode.

Photons that are produced from this recombination process typically have nearly identical energies. Consequently, each LED emits light that falls within a narrow bandwidth. This bandwidth is determined and limited by the materials the LEDs were made with. This bandwidth can be produced in the visible range of the electromagnetic spectrum, but also in the infrared and ultraviolet range through the use of different semiconductors. It is the narrow bandwidth in the visible light range that causes the light from LEDs to appear monochromatic.

Manufacturing the LED Wafer

Like other semiconductors, each LED consists of extremely thin, "sandwiched" layers of materials that typically are compounds formed of two to four elements. These thin layers are brittle and must be either created on, or transferred to, a more durable and rare earth metal, such as sapphire, gallium, or indium. These materials function as a *substrate*, i.e., their crystalline structure is selected to be compatible with the compound semiconductor materials.

Precise amounts of impurities, or *dopants*, are purposely introduced to the semi-conducting layers of an LED and determine the electrical properties of the compound materials. By doping layers differently, different colors and efficiencies of LEDs can be achieved. Some doping processes are well known and established (such as the process that produces red LEDs), while others are in earlier stages of development.

The creation of the thin layers that make up an LED involves many carefully-designed and controlled steps and additional materials, including some toxic gases. The processes for creating LEDs require clean rooms and sophisticated controlled-system equipment, similar to the processes used for creating other semiconductors. The most common processes for creating the newest generation of LEDs are molecular beam epitaxy (MBE) and metalorganic chemical vapor deposition (MOCVD).

Unlike the semiconductors used in computer processing and memory chips, however, LEDs are far more difficult to fabricate. They cannot be produced on large "wafers," which are sliced nodules or boules of ultra pure semiconductor materials grown under controlled laboratory conditions. Most LED wafer substrates are four or six inches in diameter or smaller, due to the brittleness of the materials and the challenges of growing defect-free boules.

LED wafers that pass quality control criteria are further processed to create individual LEDs. Layers of conductive metals and photoreactive films are applied and then etched in geometric patterns to create the basis for microscopic circuits. Optical materials can also be applied and shaped at the wafer level of production. The result is a gridded matrix of individual LEDs with the required shapes and layers. Wafer size and composition are important economic and process factors because they limit the number of individual LEDs that can be produced from one wafer.

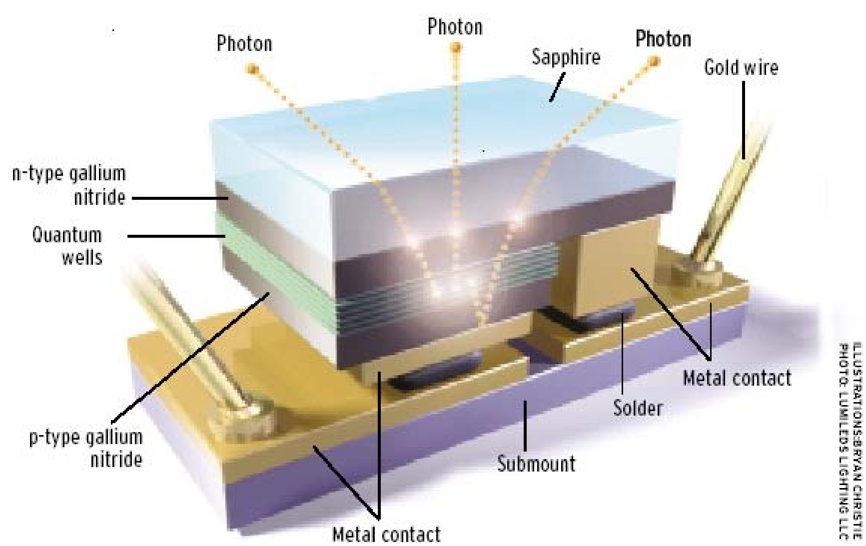
Creating the LED Package

Once the microscopic circuits are in place, the individual LEDs are then separated into what are known as *die*. The LED wafer itself is not a functional light source, however. Once the die pieces are separated, there are several more steps to create the functional circuit and efficient emitter, known as a *package*. The LED die can be placed inside reflective cups, or coated on some planes with highly reflective material. Metal leads are attached to one or more surfaces of the LED. These are usually made of gold. Sometimes the die pieces are encased in a highly transmissive material, usually an epoxy. The encasing material can be molded into an optically desirable shape, laser-shaped, or deposited in a fine film.

The final steps in manufacturing LED packages are as critical to performance as all of the preceding steps. The brightest LEDs to date are carefully shaped in three dimensions to allow as much light as possible to exit the device. In addition, most of the high-brightness LEDs making the news today incorporate either a thermal heat sink, or a means of direct attachment to a thermal heat sink. Thermal heat sinks help maintain the temperature of the LED, which is critical because higher temperatures adversely affect the quality and quantity of light emitted from the package. The heat sink can be a metal such as aluminum, copper, or a conductive ceramic material. High temperatures can permanently affect the performance characteristics of an LED, shortening its useable life span, lowering its light output, and shifting the color of light that is emitted.

Although less energy is wasted as heat with the more advanced LED technologies, as compared with incandescent lamps, they still generate significant thermal output despite the fact that they tend to be very low-power devices. An HB LED without an appropriate heat sink would become very hot to touch. The heat buildup internally within the diode causes mechanical failures, as the disparate materials inside the device expand at different rates, causing physical stress. For instance, the gold lead wires can snap, or the epoxy encapsulant can expand, tearing apart the nearby components.

Figure 8. Diagram of an LED package



”White Light” from LEDs

Unlike conventional light sources, most of which emit some version of white light and must be filtered to produce colored light, LED sources are inherently colored light sources (due to their narrow photon bandwidth). The compound semiconductor materials determine the spectral power distribution (or color) of the light that is emitted from an LED.

Currently, there are a number of major material systems that are used for HB LEDs, with a number of experimental prototypes using other material systems under development and testing.

- **AlGaAs (aluminum gallium arsenide):** the red end of the visible spectrum (longer wavelengths, low energy)

- **AlGaInP (aluminum gallium indium phosphide):** red-orange-amber-yellow portion of the visible spectrum (mid-wavelength, middle energy)

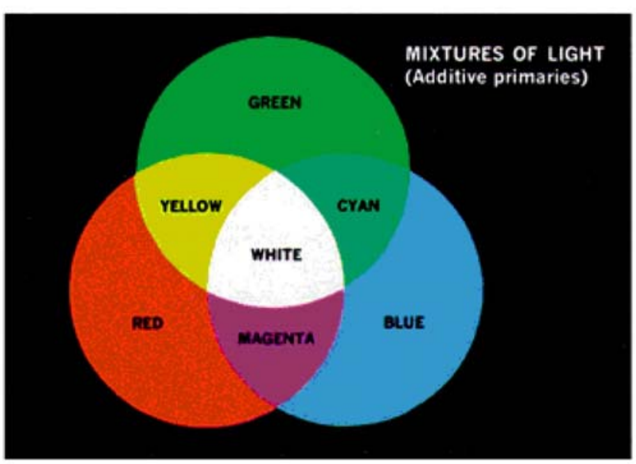
- **AlInGaN (aluminum indium gallium nitride):** theoretically spans the visible spectrum, with the exception of some gaps in green; however, it is primarily used for the green-blue end of the visible spectrum, and ultraviolet (short wavelengths, high energy)

As discussed earlier, LEDs chips also vary in *color purity*, that is, how pure the color of light is versus how close to white the light might be. LED die from a single wafer can also vary in dominant color characteristics. Manufacturers sort LED chips into bins by both of these characteristics. This expensive process is reflected in the price of the die: bins with the least variation are the most costly.

Using LEDs to Make “White Light”

When white light passes through a prism, it is split into component colors, making some version of a “rainbow.” Mixing two colors that are opposite each other in a color space, such as blue and yellow, creates binary white light. Red, green, and blue can also be mixed together to make white light. Regardless of the technique used, the relative amount of energy of each color must be balanced to create the perception of a neutral white. Otherwise the result appears “cool,” which is closer to the blue end of the spectrum, or “warm,” which is closer to the red end of the spectrum **(Figure 9)**.

Figure 9. Color Mixing Chart



Source: Navigant (2011)

A variety of color mixing techniques are used to create "white light" LEDs. The more colors of light that are represented in a white light, the more satisfying the result may be because human vision has evolved under the very broad spectrum of daylight. The most common ways of creating white light with LEDs are:

- Placing discrete red, green, and blue LED die close enough to each other to create the impression of white when viewed directly. Some large video display walls are composed of millions of units, like pixels, of colored LEDs.

- Placing discrete red, green, and blue LEDs inside a device with a diffuser so that viewers only see the "blended" light.

- Encapsulating a blue or ultraviolet LED in a layer of phosphors. The phosphors are excited by the short wavelength radiation, and then emit light in longer wavelengths, such as yellow and red. The blue LED/phosphor solutions are less efficacious than the discrete red-green-blue systems.

LED manufacturers are struggling to create LED light sources that mimic more conventional sources, such as incandescent and fluorescent lamps.

Phosphor Technology

The production of phosphor-based white light LEDs are limited not only by the progress of the LED technology, but also of the progress of the phosphor technology.[56] Phosphors must be "tuned" in two ways. First, they must be tuned to accept a certain wavelength of excitation light, which is the light that "pumps" the electrons in the phosphor to higher energy levels. Second, the phosphor must be tuned to release a certain emission light, which is light that is produced as a result of the electron falling from the pumped-up state to a lower energy state. The tuning of these two parameters is achieved by changing the chemical structure of the phosphor specific to white light applications.

Two other factors important to consider with phosphor technology include: 1) the degradation rate of the phosphor compared to the other phosphors; and 2) the LED and the emission efficiency. Phosphors degrading at different rates can lead to a change in color temperature and color rendering over the lifetime of the LED. A phosphor with too short of a lifetime would likewise limit the lifetime of the LED. The emission efficiency of the phosphor is important in that the ratio of output of the different colors needs to be appropriately balanced.

Producing LED Lighting Systems

LEDs must be incorporated into an integrated system in order to be used in most lighting applications. At a minimum, the system contains: *LEDs*, a *circuit* (either on a board, or formed of wires), a *thermal heat sink*, and a *driver/power supply* that connects the circuit to the source of electricity and modifies it to meet the particular LEDs' operation requirements. The entire system must be taken into account when comparing input power demands because other components in the system, such as the driver, have their own added requirements.

LEDs are direct current (DC) devices, so the use of an alternating current (AC) requires additional components. The driver is analogous to the ballast in conventional fluorescent systems. The newest, highest

[56] Although there are currently white LEDs on the market that are a blue LED with a yellow phosphor, these do not have the necessary color rendering characteristics to be used for most lighting applications.

power LEDs require sophisticated electronic drivers. Usually an LED system includes some type of housing or support, and often it includes reflectors or lenses to direct or diffuse the light. Beyond these basics, there are a myriad of LED systems marketed or assembled from components, and very few standards available. There are however, two basic types of systems:

1) **Chip on board (COB) and surface-mount type (SMT) LEDs:** These are mounted on the surface of a circuit board. The board can either be rigid or flexible. The system can be very small, with many die packed densely into a small area to function as a point source. In the alternative, the system can cover larger areas or long lengths, with the LEDs spaced to achieve particular light distribution patterns.

2) **LED modules, clusters, or "lamps":** These systems have discrete LED packages soldered into place in more conventional circuits, such as with LED holiday lights and LED neon sign replacement kits. Some LED-based lighting devices are designed for use in conventional screw-base or pin-base sockets, meaning they have all the system components integrated into a single product.

LED Production and the Environment

Highly toxic and controlled substances are used to manufacture LEDs and other electronics in the semiconductor industry. For example, ammonia, arsine, nitrogen, and phosphine gases are used in the fabrication process, which are stored in bulk at LED chip fabrication facilities. Dust from the sawing or scribing of chips can also contain toxins.

However, LEDs are manufactured in clean rooms similar to how other semiconductors are manufactured, and manufacturing standards (governed by local environmental laws) are in place to limit human toxins exposure. The wafer and chip fabrication processes are highly energy-intensive, as are the mining and refining of the precursor metals (gallium and indium) and rare earth phosphors (for white LEDs). Unlike most gas discharge lamps, no mercury is contained in LEDs.

Assembly of LED lighting systems is also similar to that of other electronics devices. Much of it is automated, and involves soldering of components onto etched circuit boards. Lead solders are commonly used, but lead-free solders are an alternative. Depending on environmental regulations in place at the manufacturing plant's location, highly volatile solvents may be used to clean finished circuit boards. Much like the computer industry and, increasingly, the lighting industry, LEDs, components, and LED lighting systems are manufactured in Asia, particularly in Malaysia, Taiwan, China, and India.

LEDs last longer than the light sources they may replace. However, the lifespan of the LED system, including the housing, may be more or less than conventional sources, depending on the types of components used. Due to the smaller size and lighter weight of LED lighting systems, they have a lower volume and weight than conventional systems (except for the heat sink components, which can be made of aluminum and tend to be large and heavy).

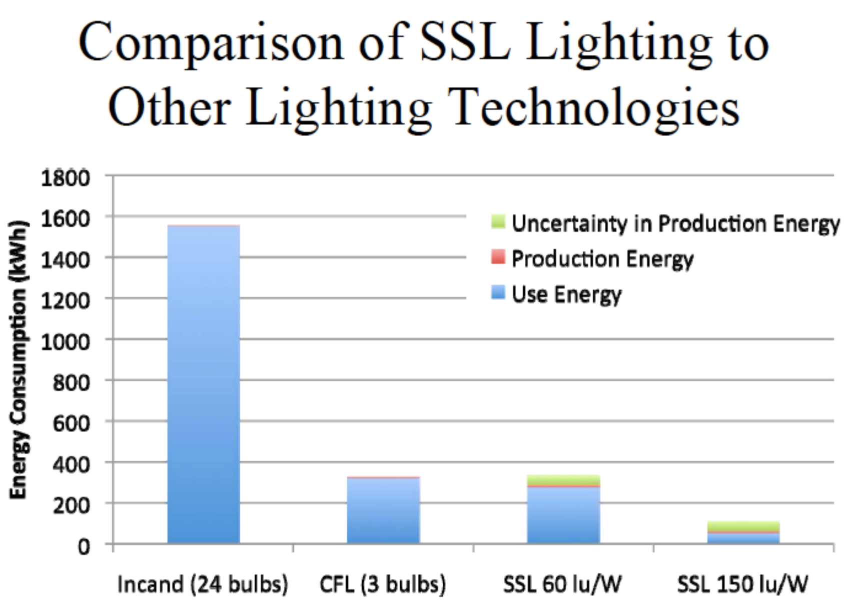
If the system has integral components, the entire device would have to be disposed of at the end of its useful life. The use of thermo-bonded plastics and metals may make it difficult to separate components for reuse or recycling. Older red LEDs are likely to contain small amounts of arsenic, a potent toxin. Many new LEDs contain no arsenic, but they do contain gallium and indium, about which little is known of possible health and environmental effects.

A recently released study conducted by Carnegie Mellon University's Green Design Institute provided the following summary:[57]

- LED processing currently appears to be a small contributor to overall life cycle energy consumption of SSL lamps.
- Materials for the lamp, especially heat sink, are a significant contributor to the overall environmental impact of LEDs lighting systems.
- Designs are expected to reduce material needs as heat sink designs are optimized to reduce cost;
- Opportunities to reduce overall life cycle energy consumption in these materials can be recovered (i.e., takeback or recycling systems implemented);
- Current estimates of energy for manufacturing is small compared to current use energy, life cycle energy is comparable to other competing technologies.
- Product dependent – results could be different for different SSL applications.

Figure **10**, below, contains a comparison of energy use and production energy for incandescent, CFL, and LED technologies.

Figure 10. Energy Use and Production Energy for Selected Light Sources



Source: Carnegie Mellon University

[57] Matthews, Deanna H. and others. Solid-State Lighting Life-Cycle Assessment. (2009). Carnegie Mellon University.

ATTACHMENT B:

ECO-ASIA CDCP LED STANDARDS SURVEY RESULTS

ECO-Asia CDCP LED Standards & Programs Survey Results Matrix		
No.	**Questions**	**Brunei**
1	What standards development activity on LED does your organization do or has happened/is happening in your country? Please provide us a copy of the standard if you have.	None at the moment.
2	If there is, in what category (e.g. indoor lighting, outdoor lighting, others – please specify specific application area: street lighting, automotive, etc.) is it and in what stage is it in the standards development?	None at the moment.
3	Which organization in your country is taking the lead and who are the other organizations involved in the standards development?	The Energy Division at the Prime Minister's Office fully supported by the Department of Electrical Services at the Prime Minister's Office, Construction Planning and Research Unit at the Ministry of Development and the Department of Mechanical and Electrical Works, Public Works Department in promoting and the adoption of Standards specifically for Electrical and Electronics Equipment/Appliances/Products.
4	Are there other existing and/or planned programs/initiatives that pertain to the promotion of LEDs (i.e., replacement) in your country?	None at the moment.
5	Can you provide more information/web links or contacts familiar with these activities/programs/initiatives?	None specified.

No.	Questions	Hong Kong
1	What standards development activity on LED does your organization do or has happened/is happening in your country? Please provide us a copy of the standard if you have.	N/A (According to the development background of HK lighting industry, the HK lighting industry still follows EN and BS EN standards. Currently, there is no new released local and regional LED related standard. Because the demand from the market and the industry, Hong Kong government is starting to form the task team for solving these standard related issues.)
2	If there is, in what category (e.g. indoor lighting, outdoor lighting, others – please specify specific application area: street lighting, automotive, etc.) is it and in what stage is it in the standards development?	N/A The explanation was described as above. Now the stage for standard development is at the beginning stage.
3	Which organization in your country is taking the lead and who are the other organizations involved in the standards development?	In Hong Kong, Hong Kong government's departments in charge the standards development. Each department will focus on its own professional field. Now following departments and organizations are involving in this task: 1) EMSD; 2) HyD; 3) OFTA; 4) ITC; 5) ASTRI (ITC funded); 6) HKPC (ITC funded).
4	Are there other existing and/or planned programs/initiatives that pertain to the promotion of LEDs (i.e., replacement) in your country?	In Hong Kong, the Hong Kong government funded projects to evaluate the feasibility for deploying LED streetlamp technologies/products in Hong Kong. Now, HyD, ITC, and ASTRI are involving in this project. Besides, ASTRI also started the 'Green Hong Initiative' since 2009.
5	Can you provide more information/web links or contacts familiar with these activities/programs/initiatives?	http://www.astri.org

No.	Questions	Indonesia
1	What standards development activity on LED does your organization do or has happened/is happening in your country? Please provide us a copy of the standard if you have.	Major Laboratory for Energy Technology (B2TE-BPPT) conducts performance test of LED for Solar Home System application. The test is done based on standard testing for general lamps
2	If there is, in what category (e.g. indoor lighting, outdoor lighting, others – please specify specific application area: street lighting, automotive, etc.) is it and in what stage is it in the standards development?	Application of LED for SHS (mainly indoor lighting) and Street lighting application using PV as power source.
3	Which organization in your country is taking the lead and who are the other organizations involved in the standards development?	National Standard Body; Technology Application and Assessment Agency; Directorate General of Electricity and Energy Utilization; Electricity Certification Service (LMK)
4	Are there other existing and/or planned programs/initiatives that pertain to the promotion of LEDs (i.e., replacement) in your country?	LED is already introduced in the market. The Government has no specific program on LED yet.
5	Can you provide more information/web links or contacts familiar with these activities/programs/initiatives?	None specified.

No.	Questions	Japan
1	What standards development activity on LED does your organization do or has happened/is happening in your country? Please provide us a copy of the standard if you have.	TS C0038 – (Pub.2004-11-20)(Expire 2011-05-19) – Photobiological safety of lamps and lamp systems; JIS C8121-2-2 (Pub. 2009-03-20) – Miscellaneous lampholders Part 2-2: Particular requirements – Connectors for printed circuit board based LED-modules; JIS C8152 – (Pub. 2007-07-20) – Measuring methods of white light emitting diode for general lighting; JEL 311 – (Pub. 2006-03-22) – General Rules for Photometric Method of White LED Lighting; JIS C 8153 – (Pub. 2009-03-20) – DC or AC supplied electronic control gear for LED modules – Performance requirements; JIS C8147-2-13 – (Pub. 2008-10-20) – Lamp controlgear – Part 2-13: Particular requirements for d.c. or a.c. supplied electronic controlgear for LED modules; JIS C8154 – (Pub. 2009-03-20) – LED modules for general lighting – Safety specifications; JIS C8155 – (Plan 2010) – LED module for general lighting service – Performance requirements; TS C 8153 – (Pub. 2007-07-20; Expire 2010-07-19) - White light emitting diode devices for general lighting – Performance specifications; JIS C 8156 – (Plan 2010) – Self-ballasted LED – lamps for general lighting services by voltage >50V – Safety specifications; JIS C 8157 – (Plan 2011) – Self-ballasted LED lamps for general lighting services – Performance requirements.
2	If there is, in what category (e.g. indoor lighting, outdoor lighting, others – please specify specific application area: street lighting, automotive, etc.) is it and in what stage is it in the standards development?	We are in charge of general lighting field only, not automotive etc. And we, JELMA etc, focus into the standards of measurement, light source safety and performance.
3	Which organization in your country is taking the lead and who are the other organizations involved in the standards development?	Japan Electric Lamp Manufacturers Association (JELMA), Japan Luminaires Association (JLA), Illuminating Engineering Institute of Japan (IEIJ), 3 drafting organizations, are in charge of Japan Industrial Standard (JIS). We basically intend to harmonize with IEC standard etc as international standards.
4	Are there other existing and/or planned programs/initiatives that pertain to the promotion of LEDs (i.e. replacement) in your country?	Yes. There is a collaborating group with above 3 JIS drafting organizations and National Institute of Advanced Industrial Science and Technology (AIST), Japan Commission Internationale de l'Éclairage (JCIE) , Japan LED Association(JLEDS).
5	Can you provide more information/web links or contacts familiar with these activities/programs/initiatives?	Yes, I can do some. Also I would ask you to provide more information about you and your research results as soon as possible.

No.	Questions	Malaysia
1	What standards development activity on LED does your organization do or has happened/is happening in your country? Please provide us a copy of the standard if you have.	Early discussion by the Technical Committee on Lighting, Lamps and accessories to consider developing national standards related to LED.
2	If there is, in what category (e.g. indoor lighting, outdoor lighting, others – please specify specific application area: street lighting, automotive, etc.) is it and in what stage is it in the standards development?	Not decided yet.
3	Which organization in your country is taking the lead and who are the other organizations involved in the standards development?	STANDARDS MALAYSIA as the National Standards Body and SIRIM Bhd which is responsible for managing the Technical Committee on Lighting, Lamps and accessories.
4	Are there other existing and/or planned programs/initiatives that pertain to the promotion of LEDs (i.e. replacement) in your country?	No information.
5	Can you provide more information/web links or contacts familiar with these activities/programs/initiatives?	No information.

No.	Questions	New Zealand
1	What standards development activity on LED does your organization do or has happened/is happening in your country? Please provide us a copy of the standard if you have.	EECA carries out the Government program to develop minimum energy performance standards (MEPS) and labeling requirements for products. For LED's - Review of current/draft LED standards in other APEC economies to develop harmonized methods of Testing. EECA is aware that there is potential for improved standards in the area of LED lighting. They are an internationally traded product, mostly imported into New Zealand making harmonization of standards important to ensure good consumer choice and low costs of compliance.
2	If there is, in what category (e.g. indoor lighting, outdoor lighting, others – please specify specific application area: street lighting, automotive, etc.) is it and in what stage is it in the standards development?	Domestic Street Lighting
3	Which organization in your country is taking the lead and who are the other organizations involved in the standards development?	EECA is the Government Authority & Regulator tasked with managing products regulated under the Energy Efficiency (Energy using Products) Regulations. Performance standards cited in these regulations are usually developed (or adapted from international standards) in conjunction with DCCEE (formerly DEWHA, Australia) as well as industry stakeholder groups.
4	Are there other existing and/or planned programs/initiatives that pertain to the promotion of LEDs (i.e., replacement) in your country?	EECA is a signatory to the international ENERGY STAR programme. It is possible that an ENERGY STAR LED standard would be suitable for use in the New Zealand market to endorse high performing products.
5	Can you provide more information/web links or contacts familiar with these activities/programs/initiatives?	http://www.eeca.govt.nz/ http://www.eeca.govt.nz/standards-and-ratings/energy-star

No.	Questions	Philippines
1	What standards development activity on LED does your organization do or has happened/is happening in your country? Please provide us a copy of the standard if you have.	The Philippines has programmed for 2010 the development of a national standard for safety specifications for LED modules for general lighting and a national standard for performance requirements for self-ballasted LED lamps for general lighting services. The Philippines will review IEC 62031 (LED modules for general lighting -Safety specifications) & IEC/PAS 62612 IEC:2009 (E) (Self-ballasted LED-Lamps for general lighting services-Performance requirements for possible adoption as national standard. The Bureau of Product Standards (BPS) has recently convened its technical Committee on Lamps and Related Equipment to start the standard development process for LED products. This was triggered with requests from various sectors. The scope of related existing Philippine National standards do not include LED.
2	If there is, in what category (e.g. indoor lighting, outdoor lighting, others – please specify specific application area: street lighting, automotive, etc.) is it and in what stage is it in the standards development?	Currently in the process of deliberating the possible adoption of IEC 62031:2008- LED Modules for General Lighting- Safety specifications and its normative references. (The next meeting has been scheduled on 14 April 2010. The scope will be decided during the deliberation process.) The proposed national standards shall cover LEDs for general lighting applications as well as Christmas lights using LEDs. We are in the initial stage of standards development. Time line is to finish the development of the LED standards within 2010.
3	Which organization in your country is taking the lead and who are the other organizations involved in the standards development?	The Bureau of Product Standards (BPS under the Department of Trade and Industry in partnership with other government agencies.(Other agencies include the Department of Health with respect to food, drugs, cosmetics, devices and substances; the Department of Agriculture with respect to products related to agriculture.) Standards development is led by the Bureau of Product Standards (BPS) under the Department of Trade and Industry (OTI). In the case of energy standards and labeling, the development process is handled jointly by DTI-BPS and DOE-ERTLS. This is done through the Technical Committee approach. In particular, BPS TC 4 on Lamps and Related Equipment which will develop the standards for LED is composed of representatives from BPS, DOE, stakeholders, and PELMATP. PELMATP is the acronym for Philippine Efficient Lighting Market Transformation Project, a project of DOE. BPS TC Chair comes from the private sector.
4	Are there other existing and/or planned programs/initiatives that pertain to the promotion of LEDs (i.e., replacement) in your country?	The Philippines does not have any program yet for the promotion of LEOs. however. we have some initiatives on LED application under the Philippine Energy Efficiency Project, in particular the retrofit of Baguios Burnham Park lamp posts at the lagoon area traffic lights in three major cities. and lighting for some households in off grid areas. The Philippines will closely monitor and evaluate the aforementioned LED applications under the PEEP.
5	Can you provide more information/web links or contacts familiar with these activities/programs/initiatives?	Department of Energy (DOE) at: www.doe.gov.ph DOE is the lead agency in the implementation of the Philippine Efficient Lighting Market Transformation Project (PELMATP).

<table>
<tr><th>No.</th><th>Questions</th><th>Chinese Taipei</th></tr>
<tr><td>1</td><td>What standards development activity on LED does your organization do or has happened/is happening in your country? Please provide us a copy of the standard if you have.</td><td rowspan="2">Taiwan already published several LED device/product standards. Below listed the progress of the LED standards.
Published standards:
CNS15233: Fixtures of roadway lighting with light emitting diode lamps -- outdoor
CNS15247: Test methods on light emitting diode components and modules (for general lighting service) for normal life -- other
CNS15248: Methods of measurement on light emitting diode components for thermal resistance -- other
CNS15249: Methods of measurement on light emitting diode components for optical and electrical characteristics -- other
CNS15250: Methods of measurement on light emitting diode modules for optical and electrical characteristics -- other
Under Review
Optics measurement method for LED lighting system -- Indoor & outdoor
Environment and reliability testing method for LED devices -- other
Fixtures of flood lighting with light emitting diode lamps -- Indoor & outdoor
Optical and electrical characteristics measurement method for LED chip -- other
Drafting
Fixtures of T-Bar (Ceil mounted) with light emitting diode lamps -- indoor
Quality testing method for LED chip
Accelerated life testing method for LED chip --other
Thermal resistance measurement method for LED chip -- other
ESD testing method for LED device
Power supply measurement method for LED lighting system --other
Environment sustainability testing method for LED lighting system – indoor & outdoor
Accelerated life testing for LED device and module --other</td></tr>
<tr><td>2</td><td>If there is, in what category (e.g. indoor lighting, outdoor lighting, others – please specify specific application area: street lighting, automotive, etc.) is it and in what stage is it in the standards development?</td></tr>
<tr><td>3</td><td>Which organization in your country is taking the lead and who are the other organizations involved in the standards development?</td><td>BSMI/MOEA is the lead. BOE/MOEA and DOIT/MOEA are involved.</td></tr>
<tr><td>4</td><td>Are there other existing and/or planned programs/initiatives that pertain to the promotion of LEDs (i.e., replacement) in your country?</td><td>BOE lunched a 3- year program (2009~2011)to replace all incandescent traffic sign by LED traffic sign. BOE lunched a LED street lamp demonstration project to set 47 LED lamp demonstrate site.</td></tr>
<tr><td>5</td><td>Can you provide more information/web links or contacts familiar with these activities/programs/initiatives?</td><td>BOE/MOEA: http://www.moeaboe.gov.tw/
DOIT/MOEA: http://doit.moea.gov.tw/doiteng/
BSMI/MOEA: http://www.bsmi.gov.tw/wSite/mp?mp=2</td></tr>
</table>

No.	Questions	Thailand
1	What standards development activity on LED does your organization do or has happened/is happening in your country? Please provide us a copy of the standard if you have.	We are developing standard for LED modules for general lighting-Safety specifications by adopting IEC 62031. No copy of the standard is available because it is in Thai language only.
2	If there is, in what category (e.g. indoor lighting, outdoor lighting, others – please specify specific application area: street lighting, automotive, etc.) is it and in what stage is it in the standards development?	For general lighting. Committee Draft (CD) stage.
3	Which organization in your country is taking the lead and who are the other organizations involved in the standards development?	Thai Industrial Standards Institute (TISI) and Department of Alternative Energy Development and Efficiency (DEDE). TISI is responsible for safety and performance standards, but DEDE is responsible for energy efficiency standard.
4	Are there other existing and/or planned programs/initiatives that pertain to the promotion of LEDs (i.e., replacement) in your country?	There are no activities, programs and initiatives in the present
5	Can you provide more information/web links or contacts familiar with these activities/programs/initiatives?	None noted.

No.	Questions	Vietnam
1	What standards development activity on LED does your organization do or has happened/is happening in your country? Please provide us a copy of the standard if you have.	None yet.
2	If there is, in what category (e.g. indoor lighting, outdoor lighting, others – please specify specific application area: street lighting, automotive, etc.) is it and in what stage is it in the standards development?	None noted.
3	Which organization in your country is taking the lead and who are the other organizations involved in the standards development?	- Vietnam Standards and Quality Institute - Technical committee related to lighting equipment
4	Are there other existing and/or planned programs/initiatives that pertain to the promotion of LEDs (i.e., replacement) in your country?	No, but Vietnam is considering program for promotion of LEDs. There is a national objective program on saving and conservation energy.
5	Can you provide more information/web links or contacts familiar with these activities/programs/initiatives?	www.vsqi.gov.vn

ATTACHMENT C:

AN OVERVIEW OF THE LED INDUSTRY IN CHINA

OCTOBER 2010

Background

The LED industry in China started from the end of 20th century and continues to grow along with the international development of LED industry and technology. The technology level of high-light epitaxial wafers and chips increases every year, and the production capacity of LED lighting has likewise been growing very rapidly. The categories and applications of LEDs have been expanding, and with the rapid development of the LED industry, the industrial structure has been optimizing as well.

There are about a half million people, more than 20 research institutions, and 4000 enterprises and companies working in the LED industry in China. More than 100 enterprises have over 10 million Yuan in sales, and there are about 3000 enterprises working in the downstream application field. New LED lighting production and application markets have continually expanded. Now LEDs are widely used as road lighting and indoor lighting, and the size of the LED industry has been scaling up rapidly. In regards to product categories and production scales, China is advanced at the international level – China is the biggest export and production country of solar LED and landscape lights.

Currently, Asia, North America, and Europe are the three main LED industry bases in the world. Toyodo Gosei, Japan Nichia, U.S. Cree, Lumileds, and Europe Osram are the leading enterprises in the LED industry. They own the core technology patents and hold the competition advantage. These enterprises use cross-authority to avoid patent issues. Other enterprises without cross-authority are required to obtain unilateral authority from these enterprises to avoid patent disputes. Leading enterprises all focus on the high-end market, while the other enterprises in Taiwan, Korean, and China compete in the middle and lower-middle end markets.

LED Industry Development in China

The LED industry includes epitaxial wafers growth, chips processing, packaging, and other raw material manufacturing. A relatively completed industrial chain has already formed in China.

Epitaxial Wafers Growth and Chips Manufacturing Industry

In the LED industrial chain, epitaxial wafers growth and chips manufacturing belong to a technology and capital-intensive industry. The processing technology has been very difficult and will require big investment. Currently, the industry of epitaxial wafers growth and chips manufacturing in China lacks core technology and professional engineers. Meanwhile, foreign have patents restrained manufacturing.

In the past 2 years, the epitaxial wafer and chip industry in China has developed rapidly due to the swift increase of LED chips demand. According to ECO-Asia CDCP's data, there are more than 40 enterprises working in the LED chip manufacturing area. The number of stock metalorganic vapour phase epitaxy (MOCVD) is 150, the number of gallium nitride MOCVD (GaN MOCVD) installed for manufacturing is over 135, and the number of quaternary MOCVD installed for manufacturing is 18. The number of equipment in research institutions in China has also been increasing. Chinese enterprises continue to enlarge their investment on epitaxial wafers manufacturing, and according to the initial statistics, over 100 MOCVD will be purchased, which is greatly beyond the forecast of early 2009.

In 2009, the annual growth rate of the output value of chips in China increased by 25% and reached 2.3 billion Yuan, while in 2008, the annual growth rate was 26%. The production capacity of national GaN chips in 2009 increased dramatically, reaching 2.24 billion pieces per month and 18.2 billion pieces for the entire year. This represents an increase of 40%. The localization production rate also increased by 46%. The output and localization production rate in 2009 is shown in **table AC1** as below. (Source: CSA)

Table AC1. Output and national localization production rate in 2009

Category	Output (Billion Pieces)	National Localization Production Rate (%)
GaN LED	18.2	46
Quaternary LED	20.0	51
Normal LED	17.0	65
Total	55.2	52

The performance of nationally made chips in the area of monitors, signal lamps, outdoor lighting, and small-middle size backlights is improving very fast. Meanwhile the performance and output of high-power chips has also increased substantially, but increases are still in the middle-low level. High-power chips mainly depend on imports. Almost all high-efficacy and highly reliable LEDs produced in China are depending on imported top grade epitaxial wafers. The low-power chips made in China can reach efficacy of 120lm/W and 80~100lm/W for power chips, which is very close to the international level. The efficacy of the Si-based chips with domestic independent patents can reach 70lm/W, and China has already achieved large-scale manufacturing of this kind of chip.

Chip factories continue to expand their LED chip production capacities in order to respond to increases in demand. For instance, two leading companies, Silan and Sanan Optoelectronics, have announced that they will scale-up their LED chip production. Silan is mainly scaling up its production line of high luminance LED chips. It is expected that the annual production of LED chips will reach 13.2 billion pieces and the annual production of epitaxial wafers will reach 0.57 million pieces. The scale-up plan of Sanan Optoelectronics is even more magnificent. It plans to build up an industrial base not only working on the research and manufacturing of LED epitaxial wafers and chips, but also extending to the development and manufacturing of downstream packaging and applications. The total investment is 12 billion Yuan, with the first stage of investment totaling 6 billion Yuan with a construction period of 4 years.

With the maturation of LED industry, there are many enterprises that have recently entered into the upstream industry of LEDs. For example, Cree announced it will build an LED chip production line in Huizhou City, and Nichia is also planning to build a factory in mainland China. In 2009, Taiwanese enterprise, TYNTEK Corporation, has established a company in Wuhan City primarily for producing LED chips. In the same year, Taiwan AOC signed an agreement with Changzhi High Tech Industry Investment Co., Ltd. to build a joint venue for manufacturing LED epitaxial wafers and chips. Taiwan Epistar also announced it would build the biggest manufacturing base in Changzhou City, and the company plans to spend 0.6 billion Yuan to purchase 30 MOCVD.

Because of this rapid development, the LED industry has become a new economic growth point in China. Local governments are thus all supportive of the LED industry's development. The profit from LED chips and epitaxial wafers accounts for about 70% of the profit for the whole industry; therefore, many enterprises and companies are anxious to enter into the upstream industry, including HAN'S LASER and ELEC-TECH INTERNATIONAL. These companies do not engage in business very related to LEDs, but have nevertheless invested in the LED industry to extend their businesses into the upstream industrial chain. The threshold of the upstream industrial chain investment is very high (about 0.1-0.2 billion Yuan) and the technology is also very difficult. Even with the right and mature equipments, it is also very hard to manufacture qualified products without good technicians.

According to the national "Advises on the Development of Semiconductor Illumination Industry," by 2015, there will be about three to five enterprises with large-scale chip production capacity and about ten enterprises with highly industrial-intensive, highly market-effective, self-owned brands. In the coming future, the production capacity of LED chips in China will likely still be in the process of rapidly increasing.

LED Packaging Industry

The LED packaging technology in China is lagging behind on the international level; however, it has also been improving very fast. The production capacity in China is already very high and continues to increase rapidly.

There are many LED packaging companies in China, but all are small in size. Most companies are using imported equipment, and most of the imported equipment are not top grade. Chinese LED packaging companies all have very limited capacity on research and development – many of them do not even have development ability and only follow or copy existing products. Most small-scale companies also have low automatic packaging technology. Therefore, the LED packaging technology in China is very behind other international standards, especially for power LED packaging and non-standard devices packaging. Because of its low price and good market adaptability, Chinese LED packaging has penetrated the global middle-low market. However, Chinese products cannot compete at the high-end of the market because China lacks brand strategies and technology renovation capacity and mainly depends on renewal of fixed assets to improve technology and increase quality. In recent years, with foreign packaging companies' movement to China, the packaging industry in China improved rapidly both in output and technology fields, and the competitive capacity strengthened distinctly. With the reduction of profit and the prick-up of competition, the LED packaging industry in China has also been restrained by a series of barriers. These include: foreign technology patents on packaging technology of white light LEDs; heat emission and packaging technology of high power LEDs; the scale of enterprises; the communication on application market between LED packaging enterprises and traditional lighting enterprises; the performance of core packaging materials; and the import of high-end chips.

Most packaging enterprises in China are able to package AlGaInP super red, orange, and yellow light LEDs, and some enterprises have capacity to package GaN-based blue, green, and white light LED. Some enterprises have invested a lot in the research and development on improving packaging structures, heat emission, lighting output efficiency, and anti-luminous output degradation. Very good results have been achieved. For instance, packaging is now capable of placing 1W white LED in batch size. The initial efficacy of this 1W white LED can reach over 100 lm/W, and the heat resistance can be controlled within 10°C/W.

LED packaging products made in China are mainly used as small-sized LCD backlights on applications such as mobile phones, and digital cameras, landscape lighting, decorative illumination on buildings, and signal lighting. Only a small part of LED packaging products can be used on high-end application areas such as normal illumination, high quality screen, and middle-to-big sized LCD lighting. In China, high-quality LED packaging products are still dependent on imports.

With the rapid development of technologies on LED epitaxial wafers, packaging, and applications, and with increased guidance by government policies and awareness of consumers, the LED lighting packaging industry in China has grown dramatically. Growth rates in recent years have been above 10% each year. In 2009, for instance, the output value of LED packaging industry in China was 20.4 billion Yuan, which was an increase of 10% over 18.5 billion Yuan in 2008. The output also increased 10% from 94 billion pieces in 2008 to 105.6 billion pieces in 2009. The output value of high light LEDs was 18.6 billion Yuan, which constituted 90% of the total sale value of LEDs in China. At the same time, the SMD and high-power LED packaging technology also improved very quickly.

LED Manufacturing Industry

With government support, LED lighting performance continues to improve and LED applications keep expanding. The number of downstream enterprises in China has increased rapidly and production capacity has improved at a high speed. The number of downstream enterprises took 70% of the whole LED industrial chain, but most of them are small-scale enterprises and took the market only because of low prices instead of high quality. The LED manufacturers in the coastal areas are mainly depending on export and manufacturing products with low additional value. Most enterprises are OEM. The competition between these enterprises is very high, and their risk-resistance capacities are very low. Although many domestic enterprises applied patents, most of these patents are practical, new-type patents or design patents with low values. They mainly focus on simple technical issues such as high-power LED heat radiation solutions and second optical design. These kinds of technology patents cannot strengthen the competition capacity of these enterprises.

With the expansion of LED applications, some traditional lighting enterprises have also entered into the LED industry. These enterprises have advantages on LED lighting technology applications and market outreach; therefore, they will impact the current existing LED manufacturing enterprises.

Presently, the LED production in China covers all LED lighting areas including back lighting, normal lighting, and special lighting. China has already become the biggest manufacturing and export country of solar LED and landscape lighting in the world, but the products have mainly focused on the low-end market.

In 2009, the semiconductor illumination industry developed very fast in China. The output value increased 30% and reached 60 billion Yuan. The LED full color monitor, solar LED, landscape illumination, electronic back light, and signal lighting were the main LED application areas. The big-size LED backlight applications also increased very rapidly. For instance, the main television brands in China all developed LED backlight televisions, and these products will become the key products for future development and promotion. Under the "10 Thousand LED Lights in 10 Cities" program, the application of LEDs on street lighting and indoor spotlighting developed quickly. The structure of semiconductor illumination in China in 2009 is shown in **Table AC2**, below:

Table AC2: The output value of semiconductor illumination in 2009

Category	Output Billion Yuan	Share %
Landscape illumination	14	23
Monitors	12	20
Illumination	7.5	13
Mobile phones	6.5	11
LED back light illumination	6.0	10
Traffic lights	3.5	6
Signals	2.5	4
Cars	1.2	2
Others	6.8	11
Total	60	100

Increases in the LED industry are mainly dependent on application development of LED lighting and backlight, as other applications develop steadily. With the rapid reduction of the price of semiconductor illumination products and the maturation of application techniques, the promotion of semiconductor illumination on city planning, household, business, and industry must be boosted. China is the potential LED manufacturing center because of its advantages on product manufacturing. The manufacturing structure will be based on multiple forms such as OEM, ODM, and self-owned brands. Although the manufacture of LED backlight modules is not advanced in China, the thin film transistor liquid crystal display (TFT LCD) industry is transferring towards China. China has an opportunity to become the biggest manufacturing base of these LCD televisions, and other components like LED backlight module will also be grouped in China.

LED International Standards Development

International Electrotechnical Commission (IEC)

The IEC is an international standards and conformity assessment body for all fields of electrotechnology that was established in 1906. It was the first established international electrotechnical standards organization in the world.

(1) IEC TC34

The leading TC for lighting is: IEC TC 34: Lamps and related equipment. It has four sub-working groups: SC 34A: lamps; SC 34B: lamps caps and holders; SC 34C: Lamp accessories; and SC 34D: Luminaires.

In recent years, IEC TC 34 has developed and issued a series of standards related to LEDs, which include:

- IEC 62031-2008 LED Modules for general lighting - Safety specifications
- IEC/PAS 62612-2009 Self-ballasted LED-lamps for general lighting services – Performance requirements

- IEC 60838-2-2-2006 Miscellaneous lampholders - Part 2-2: Particular requirements – Connectors for LED modules
- IEC 61347-2-13 Lamp controlgear - Part 2-13: Particular requirements for d.c. or a.c. supplied electronic controlgears for LED modules
- IEC 62384-2006 D.C. or A.C. Supplied electronic control gear for LED modules – Performance requirements
- IEC 62386-207-2009 Digital addressable lighting interface - Particular requirements for controlgear - LED modules (device type 6)

In addition, there are two IEC standards in the development process:

- IEC 62663-1 Ed. 1.0 Non-self-ballasted LED lamps - Part 1: Safety requirements
- IEC 62663-2 Ed. 1.0 Non-ballasted single capped LED lamps for general lighting - Part 2: Performance requirements

(2) IEC/TC47: semiconductor devices

Because there are not many certification demands on semiconductor optoelectronic devices, SC47E has not carried out the relevant standards-development work on LEDs.

(3) IEC TC76: optical radiation safety & laser equipment

Since 1993, IEC TC 76 started to work on LEDs. Currently, all products sold to Europe must comply with IEC 60825.

Internationale de l'Éclairage (CIE)

The CIE is a worldwide technical, scientific, and cultural, non-profit, autonomous organization. It aims to carry out research exchanges and cooperation on lighting engineering within its member countries. The CIE has developed the LED standard: "CIE 127-1997: Measurement of LEDs."

Technical specifications developed or being developed by CIE include: "Color Index of White Light LED lighting sources" and "Testing Measures on LED Intensity, Optics Performance and Photometric Performance."

LED Standards Development in China

China's Standardization Framework

Authorized by the China State Council and managed by the General Administration Of Quality Supervision, Inspection And Quarantine (AQSIQ), the Standardization Administration of China (SAC), a vice-ministerial-level department, performs nationwide administrative responsibilities and carries out unified management for standardization work across the country. Standardization administration departments in each province, autonomous region, and municipality are responsible for administrating the standardization work of its administrative regions.

National Technical Committee TC 224

National Technical Committee 224 on Lighting of the SAC is mainly in charge of standardization research for the content, performance, operation, and security of lighting sources, as well as accessories and luminary products. In addition to managing more than 300 national standards, it is also responsible for the formulation, publicity, and implementation of relevant national and industrial standards. The Committee directs these four sub-committees:

- SAC/TC224/SC1: Lighting Sources and devices
- SAC/TC224/SC2: Luminaries
- SAC/TC224/SC3: Testing
- SAC/TC224/SC4: Illumination Basis

There are eleven LED lighting standards and one industrial standard that have been developed by SAC TC224, which were issued between 2008 and 2010. Between these twelve standards, three of them adopted IEC standards, one adopted an IEC draft, one adopted but edited the IEC standards, two adopted OEC and CIE standards, and five were developed independently from international standards. Besides these standards, one LED national standard is in the process of formulation and it will likely adopt the IEC standard.

China's national and industrial LED standards that have been already issued include:

- GB 19651.3-2008 Miscellaneous lamp holders – Part 2-2: Particular requirements-Connectors for LED modules (IEC 60838-2-2:2006, IDT)
- GB 19510.14-2009 Lamp controlgear – Part 14: Particular requirements for d.c. or a.c. supplied electronic controlgear for LED modules (IEC 61347-2-13:2006, IDT)
- GB 24819-2009 LED modules for general lighting – Safety specifications (IEC 62031:2008, IDT)
- GB/T 24823-2009 LED modules for general lighting-Performance requirements
- GB/T 24824-2009 Measurement methods of LED modules for general lighting (CIE 127-2007， NEQ)
- GB/T 24825-2009 D.C. or A.C. supplied electronic controlgear for LED modules- Performance requirements (IEC 62384:2006,MOD)
- GB/T 24826-2009 Terms and definitions of LEDs and LED modules for general lighting (IEC 62504:2008 NEQ)
- GB 24906-2010 Self-ballasted LED-lamps for general lighting services>50V-safety specifications (IEC 62560, IDT)
- GB/T 24908-2010 LED for general lighting services-Performance requirements
- GB/T 24907-2010 LED-lamps for road lighting -Performance specifications
- GB/T 24909-2010 LED lamps for decorative lighting
- QB/T 4057-2010 LEDs for general lighting-Performance requirements

Standards under development include:

- Digital addressable lighting interface - Part 207: Particular requirements for control gear - LED modules (device type 6) (IEC 62386-207-2009, IDT)

The technical specifications already developed or being developed are:

- Draft standard "Self-ballasted LED reflector lamps" for seeking comments
- Draft standard "LED downlight lamps" for seeking comments
- Second version of Technical specification for LED road lighting products in demonstration project
- Rules for LED road and tunnel lamps in-site testing and inspection
- Technical specification for LED road lighting products in cold region
- LED Tunnel lamps

- Second version of Measurement methods for integral LED road lights

MIIT Technical Standard Working Group on Semiconductor Lighting

With the rapid development of LED industry, the Ministry of Industry and Information Technology in China established a Technical Standard Working Group on Semiconductor Lighting.

Currently, there are nine industrial standards on semiconductor lighting developed by the Technical Standard Working Group:

- SJ/T 11393-2009 Semiconductor optoelectronic device standards on semiconductor lighting developed by the Technica
- SJ/T 11394-2009 Measure methods of semiconductor light emitting diodes
- SJ/T 11396-2009 The sapphire substrates for nitride based light-emitting diode
- SJ/T 11397-2009 Phosphors for light emitting diodes
- SJ/T 11398-2009 Technical specification for power light-emitting diode chips
- SJ/T 11399-2009 Measurement methods for chips of light emitting diodes
- SJ/T 11400-2009 semiconductor optoelectronic devices-blank detail specification for lower-power light-emitting diodes
- SJ/T 11401-2009 Series program for semiconductor light emitting diodes
- SJ/T 11395-2009 Semiconductor lighting terminology

LED Testing Laboratories in China

Below is a list of laboratories that can undertake testing for semiconductor devices and LED lighting products in China:

- National lighting Test Center (Beijing)
- National Center of Supervision & Inspection on Electric Light Source Quality (Shanghai)
- China National Lighting Fitting Quality Supervision Testing Centre (CLTC) (Shanghai)
- China National Lighting Fitting Product Supervision Testing Center (Zhongshan)
- China National Center for Quality Supervision and Test of semiconductor devices (Shijiazhuang)

In 2010, approved by AQSIQ, there are four testing laboratories will be established further to conduct LED testing:

- China National center for Quality Supervision and Test of Semiconductor light emitting devices (Xiamne)
- Key Testing laboratory for Semiconductor Optoelectronics products (Jiangmen)
- National Center for Quality Supervision and Testing of Semiconductor lighting source products (Dongwan)
- National Center for Quality Supervision and Testing of Semiconductor lighting products (Changzhou)

Policies and Planning for LED Industry Development

Facing the stress from energy shortage, environmental deterioration, and financial crisis, governments around the world have looked upon emerging industries and the environmental protection industries as essential for achieving the rapid development of the economy. The LED industry is one of China's strategic emerging industries. Low-carbon economy and adjustment of industry provide a steady prospect to LED illumination.

From the view of the development of LED industry, semiconductor illumination has entered the growth stage with the rapid development of technologies. There are more and more enterprises entering into this industry because of semiconductor illumination's wide application. National and local governments have established a series of policies to promote the LED industry to secure its healthy development.

National Policies

"Advises on the Development of Semiconductor Illumination Industry"

The first guideline of the semiconductor illumination industry, "Advises on the Development of Semiconductor Illumination Industry" (Advises), was published on 12 October 2009 (*See* Attachment). The Advices specify the objective of the development of national semiconductor illumination industry and seven political measures that can support that objective. The Advises demonstrate how the semiconductor illumination industry has become a national strategy and indicates how the semiconductor illumination industry in China has entered a stage of rapid development.

The Advises indicate that the National Development and Reform Commission, the Ministry of Finance, the Ministry of Technology, the Ministry of Industry and Information, and the Ministry of Housing and Urban-Rural Development should extend the input and conduct of social investment actively, which will bring more industrial investment. LED enterprises mostly consist of private companies, which means they are able to directly respond to market demands and adjust accordingly. However, the biggest issue with private enterprises in this industry is the shortage of finance; therefore, the activation of investment is necessary. Additionally, the Advise cautions against local governments to carrying out LED projects blindly, only for "outstanding achievement" purposes. Authorities should therefore strengthen the guidance of the semiconductor illumination industry, implement the regulation of national industry and project management strictly, arrange them properly to avoid the blind extension and the repeated construction, improve the degree of industry concentration, and promote the specialization, differentiation, and clustering of local industry. Other recommendations include requiring the government to enhance illumination on urban roads, discuss the development and refurbishment of landscape illumination, and unify plans and designs to avoid making unnecessary or unwanted changes, such as over brightness of illumination applications.

The core of semiconductor illumination is the epitaxial wafer, and the manufacture of the epitaxial wafer is mainly limited by reliance on foreign patents and imported MOCVDs. Developed countries predominantly control mainstream technical patents, and their patents have been increasing in numbers every day. Some experts indicate that with the mass application of LED products in the Chinese semiconductor illumination industry, China has paid huge amounts in hidden patent fees. This reliance on foreign patents and imports for core technologies is thus a major limitation on growth for China's industry. China needs to break away from utilizing foreign patents and imports and localize equipment manufacturing for the industry to truly be competitive on an international level.

To address these limitations, the Advises list the essential technologies and equipment that China should develop independently. This includes research and development on MOCVD equipment, new substrates that are MOCVD-supported, GaN, and OLED. Research and development of GaN and OLED would support essential theoretical study of semiconductor illumination applications, including photometry, colorimetric, and surveying. Development would also conquer key technologies in the semiconductor illumination industry, such as large power chip and devices, driving circuit and its standardized modules, and technologies about system integration and application.

As to the localization of MOCVD, the main idea of the Advises is to "absorb" and then "create." The precondition of this idea is to build a self-development platform and establish a creative mechanism.

The Advises indicate that the establishment of a semiconductor illumination standard, the examination of products, and the authorization works should all be promoted positively. The service system has also been listed as the prior developing sector, which means the related services, such as examination platforms of illumination products, the diagnosis of energy saving, energy management contract, will be extended at the same time. The Advises also brings forward measures of human resource, policies, and international cooperation, which create a positive environment for enterprises development.

The Advises indicate that semiconductor illumination products and key equipment should be listed in a catalog of energy saving products, which would justify the creation of relevant, promoting policies like financial subsidies. The Advises also suggest adding semiconductor illumination products to a government procurement list of energy-saving products. The list can divide semiconductor illumination products into different categories such as road and mine enterprises, and business centers and households. Early publication of a list and relevant policies would help accelerate the application of products.

Although the Advises indicates the direction of industry development would create a better environment for enterprises, the market mechanism is the real power to adjust the industry development. Therefore the primary consideration for enterprises is to have the core competitiveness by various aspects, such as human resource, fund, technologies, and prospection.

"Notices for Applying Demo Projects of Semiconductor Lighting Products"

On 30 August 2010, the General Office of the National Development and Reform Commission, General Office of Ministry of Housing and Urban-Rural Development and the General Office of the Ministry of Transport jointly issued the "Notices for Applying Demo Projects of Semiconductor Lighting Products." To implement the "Further Intensify the Efforts to Ensure the Emission Reduction Targets from '11th Five-year Plan'" and the "Notices for Issues of the Suggestions on Semiconductor Lighting Industry," the National Development and Reform Commission, Ministry of Housing and Urban-Rural Development, and Ministry of Transport decided to launch demo projects of semiconductor lighting products to promote green lighting projects and the sound and orderly development of semiconductor lighting industry. The LED reflector lamps, street lights, and tunnel lights will have open domestic tender. Each province and municipality can apply alternative projects for every type according to the "Implementation Plan of Semiconductor Lighting Demonstration Projects" and the "Technical Requirements of Semiconductor Lighting (2010 Edition)."

20 indoor semiconductor lighting projects, 15 street semiconductor lighting projects, and 15 tunnel semiconductor lighting projects will be selected as the demonstration projects in areas with different climate conditions. Either new or refurbished indoor semiconductor projects having no less than 5 thousand LED lights and street or tunnel projects with no less than 500 hundred LED lights are qualified to be demonstration projects. The technical maturity of LED lighting products of demonstration projects in the practical application should be tracked and analyzed to identify and summarize problems. Larger-scale application of LED lighting products can then be carried out at an appropriate time.

Demonstration projects will be carried out through the Energy Management Contract Alliance (EMC), and will be entitled to enjoy the preferential policies of national EMC regulations, as well as apply for the program fund support from National Development and Reform Commission.

Local Government Policies and Plans

To promote the semiconductor illumination industry, local governments have established a series of policies and measures. These vary depending on varying levels of local governments' roles in the national semiconductor illumination industry. The three main types of local government investment include: 1) financial support for technical research; 2) subsidies for purchasing essential equipment; and 3) subsidies for application of the products.

With the trend of new economic and industry development, it is necessary for local governments to carefully discuss a proper way to invest in the industry. The purpose is to solve the problems of LED technology, capital investment, and system integrations. This would help establish a long-term mechanism of energy saving, and improve the self-creative capability, upgrade the traditional illumination industry, create new industry, and promote the healthy and rational development of industrial structure.

The local government investments of Yangzhou City, Nanchang City, Shijiazhuang City, Ha'erbin City, Chongqin City, Ningbo City, Jiangmen City, and Wuhu City are individually discussed below.

Yangzhou City

Yangzhou City established special funds to help enterprises to purchase MOCVD equipments that could be used to manufacture advanced LED epitaxial wafers. This fund encourages enterprises to speed up industrialization and to improve the technologies in upstream industrial chain of LEDs, to enlarge the LEDs market of Yangzhou City rapidly, and to promote the construction of national semiconductor illumination industry and implementation of the "10 Thousand LED Lights in 10 Cities" program. For the eligible blue and green light MOCVD, the subsidy is 10 million Yuan/equipment. For the red and yellow light MOCVD, the subsidy is 8 million Yuan/equipment.

Nanchang City

From 2009, Nanchang City has been allocating at least 20 million Yuan per year as special funds to support the research and industrialization of semiconductor illumination products, and to promote demonstration and application of semiconductor illumination products. Authorized research centers, laboratories and institutes can get subsidies from 200 thousand to 1 million Yuan.

Shijiazhuang City

Shijiazhuang City established a special fund with more than 10 million Yuan for the research and development of the semiconductor illumination.

Ha'erbin City

Ha'erbin City encourages LEDs illumination enterprises to create and innovate LEDs technologies by providing enterprises with an incentive equal to 30% of their total research investment.

Chongqing City

Chongqing City established a 10 million Yuan special fund for LEDs technologies and provides subsidies to the enterprises undertaking LEDs projects.

Ningbo City

Ningbo City established a 20 million Yuan special fund and defined the LEDs as well as semiconductor illumination industry as one of the "five advanced technology industries" under the 11th Five-Year Plan.

Jiangmen City

Jiangmen City provides subsidies to the projects that have purchased five or more brand new MOCVD equipments used for manufacturing LED epitaxial wafers. Subsidies include 10 million Yuan/equipment for green and blue MOCVD, and 8 million Yuan/equipment for red and yellow MOCVD.

Wuhu City

Wuhu City provides subsidies to Sanan Optoelectronics and ELEC-TECH INTERNATIONAL, 10 million Yuan/equipment to blue and green MOCVD, and 8 million Yuan/equipment to red and yellow MOCVD.

Local Government's Guidance on Promotion of LED Products

Guangdong Province

The Guangdong government has issued the "Advises on Accelerating the Development of LEDs industry in Guangdong Province." Starting in July 2010, Guangdong plans to arrange a special fund for 3 years to subsidize the LEDs application covering the whole province. The total amount of the subsidy will reach 60 million Yuan and will be issued in three periodic stages:

- From July 2010 to June 2011, the government plans to provide a 30% discount as a subsidy on LED luminaires, which will reach 30 million Yuan; subsidies to each city will not exceed 50 million Yuan.
- From July 2011 to June 2012, the government will provide a 20% discount as the subsidy of LED luminaires. The total amount of subsidies will reach 20 million Yuan, and subsidies to each city will not exceed 30 million Yuan.
- From July 2012 to June 2013, the government will provide a 10% discount as the subsidy on LED luminaires, and subsidies to each city will not exceed 20 million Yuan.

The objects of subsidies are the cities, which were selected to take part in Guangdong Lighting Demonstration Projects.

The Advises indicate a target for LED industry development in Guangdong as "double in one year, significant development in three years, and great jump in five years." According to the planning, the total production valve of LEDs industry and its related industries will reach 300 billion Yuan in Guangdong, and there will be approximately 50 enterprises with more than 1 billion Yuan annual production value by 2012. By 2015, Guangdong will act as the global LEDs packaging center and is projected to become the biggest base of LEDs production and application.

Currently, the LED industry in Guangdong province is the largest one in China. There are more than 2,600 LED manufacturers, and the production value of LEDs industry in 2009 was 3.9 billion Yuan, with a growth rate of more than 25%.

The government's financial departments at the province level and city level will provide subsidies in the range of 20%-30% discount to schools, government departments, and industrial and commercial enterprises depending on their scale. A 30%-50% discount will be provided to community projects.

Shenzhen City provides 10% discount on LED luminaires as a subsidy to enterprises that are involved in LED demonstration projects initiated and invested by the government. Shenzhen City also provides discounts on loans for a period of three years. For LED demonstration projects initiated and invested by the enterprises, the subsidy on LED luminaires is a 30% discount.

Dongwan City will select key areas to carry out LED demonstration projects gradually and provide a 10% discount on LED luminaires as a subsidy. For those non-government companies and enterprises taking part in the demonstration projects and purchasing LEDs according to Dongwan's standards, the subsidy will reach up to a 30%.

Guandong has also established special funds, which are generally efficient measures funding projects in addition to subsidies and other financial measures. For instance, initiated by Guangdong Science and Technology Department, Guangdong Green Industry Fund was established in the end of 2009. It is the first industrial investment fund integrated finance and technologies, and has a 5 billion Yuan foundation including government initial fund of 50 million Yuan and public society fund of 4.95 billion Yuan. Guangdong Development Bank and China Everbright Bank provided co-funding of 20 billion Yuan as well. In order to utilize this 25 billion Yuan Green fund, Guangdong Province introduced EMC model and founded the EMC Union in Guangdong Province.

Wuhan City

Wuhan City's local government has set up a special fund to popularize LED applications in Wuhan. The fund is mainly used as subsidy and loan discount for demonstration projects. The total amount of this fund is 60 million Yuan, with plans to issue 20 million Yuan annually.

Chengdu City

The local government provides subsidies to the districts or counties where LED demonstration projects are implemented in accordance with the government requirements. The subsidy provides a 10% discount of the total cost on LED lights. Additionally, the government provides a 10% discount off the bidding prices for LED lights purchased by the public sectors and enterprises. The government also provides a 25% discount off the bidding price for LED lights purchased for households.

Xiamen City

Xiamen City has been implementing the LED lighting demonstration programs, which mainly focused on street and tunnel lighting. The first government investment was 80 million Yuan, which was used to procure around ten thousand LED luminaires.

Xi'an City

The Temporary Management Measures on Special Funds for LED Demonstration Programs in Xi'an City (Measures) was implemented on 19th March 2010. According to the Measures, the local government was to provide at least 250 million Yuan per year as special funds for the LED Demonstration Programs. 90% of the funds were to be used as subsidies for LED lighting programs, while the remaining 10% was to be allocated towards research and development, industrialization, and research and generalization of technical standards. The total investment of Demonstration programs that apply government subsidies was to not be less than 5 million Yuan. The subsidies are to be used to procure luminaires for street lighting, lighting in tour areas, square lighting, indoor lighting, and large public areas lighting.

REFERENCES

Asian Development Bank (ADB) and The Energy Resource Institute (TERI). (2010, October 29) "Lighting for All" Scheme to Bring Clean Energy to 50 Million Asians. Retrieved from http://www.adb.org/media/Articles/2010/13378-asian-affordable-electricities/.

Frost & Sullivan. (2010, November 12) Asia Pacfic region to develop 350 new airports over a decade, with more than USD 100 billion in investments. Retrieved from http://www.frost.com/prod/servlet/press-release.pag?Src=RSS&docid=214361260

McCullough, Jeff. (2009) CALiPer Testing Update – LED Linear Fluorescent Replacement Lamps. [PowerPoint presentation] Presented at the LightFair on May 5-7, 2009. Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/lightfair7_mccullough-caliper2.pdf.

Narendran, N. and others. (2001) What is the Useful Life for White Light LEDs? *IESNA Lighting Handbook: Reference and Application, 9th Edition*. Rensselaer Polytechnic Institute, Troy: NY. Retrieved from http://www.lrc.rpi.edu/solidstate/SSLPublications.asp.

Navigant Consulting, Inc. (January 2011) Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications. Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy: Washington D.C.

Steele, R. (October 2009) Strategically Speaking: Insights into LEDs & Lighting. *LEDs Magazine*.

Strategies Unlimited. (2010) High-brightness LED Market Review and Forecast. Mountain View, California.

United States Agency for International Development. (2007) Confidence in Quality: Harmonization of CFLs to Help Asia Address Climate Change. Bangkok, Thailand.

United States Agency for International Development
Regional Development Mission for Asia
Athenee Tower, 25th Floor
63 Wireless Road, Lumpini, Patumwan
Bangkok 10330 Thailand