The proven benefits of edge-lit LED-based light guides as BLUs (backlighting units) for LCDs are being leveraged to make the LED light source an integral part of light fixtures in SSL applications. Combined with advances in LED technology, interior light fixtures such as troffer downlights are now being designed around LEDs, rather than trying to make the new LED technology fit into existing fixtures designed for incandescent or fluorescent bulbs or tubes. This increases the utility and appeal of LED-based light fixtures and reduces time-to-market and overall maintenance costs and provides a truly sustainable solution.

**Introduction**

LEDs first became commonplace as a lighting source in the display industry, where they have replaced cold cathode fluorescent lamps (CCFLs) as the dominant backlighting technology for liquid crystal displays (LCDs). CCFLs have been displaced by LED-based BLUs (backlighting units) in virtually every LCD, including smart phones, mobile computing devices, tablet PCs, industrial displays, and even large-screen TVs. According to a survey conducted by LED Inside, the LED research division of TrendForce, the LCD TV market is expected to increase to 70% in 2012 and, according to WitsView, the panel research division of TrendForce, LED TVs’ penetration rate is expected to increase to 65-70%.

However, as Strategies Unlimited pointed out at the February 2012 Strategies in Light symposium in Santa Clara, CA, the demand for high-brightness LEDs (HBLEDs) to backlight LCD TVs and computer monitors can’t continue to escalate forever – there is already an oversupply of LCDs (see Table 1). In the next few years, it is foreseeable that solid state lighting – i.e., general illumination – could replace LCD backlights as the main market driver for LED light sources as the demand for energy efficiency increases and incandescent bulbs are phased out.

The same benefits of high-brightness LEDs (HBLEDs) that have been accepted by those familiar with the display industry also bring many benefits to general illumination. These include: a) increased brightness with less heat, b) greater uniformity of light, c) longer lifetimes, d) variations in color temperature, e) wide range dimming to suit changing ambient light conditions, f) wider operating temperature ranges, g) lower voltage / less power required, h) no mercury, and i) a thinner light source that is more efficient and easier to integrate into a wide range of designs. Not to mention the greater aesthetic appeal that they enable. Also, LED manufacturers can bin the components for flux, color and forward voltage, while fine binning for brightness and color can also be used to obtain the proper consistency.

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**By Brett Shriver, Vice President, Sales & Marketing**

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In the long run, it pays to design your fixtures around LEDs.
Edge Lighting

Edge lighting technology takes advantage of the many advances in the LED industry, such as LEDs specifically designed to couple with light guides that are surface mountable, side emitting, thinner and with wide-output-profile. The use of edge-lit light guides, in combination with pixel-based optical light extraction features, has proven highly successful in producing the most efficient, uniform and cost-effective LED BLUs. Companies experienced in using these technologies for LCD backlighting are successfully leveraging them for use in solid state lighting for general illumination applications.

Edge lighting positions the LEDs along the perimeter – or edge - of the light guide, using LEDs that focus the light into a high-performance optical light guide, Figure 1, which extracts, directs and distributes the light as required by the application.

The light guide is a device designed to transport light from a light source to a point at some distance with minimal loss. They are typically made of

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Table 1: Large-Area TFT LCD Shipments 2009-2011 (Units in Millions)

<table>
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<tr>
<th></th>
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<th></th>
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<tr>
<td>LCD Monitor</td>
<td>176.8</td>
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<td>-1%</td>
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<tr>
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<td>210.2</td>
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<td>-5%</td>
</tr>
<tr>
<td>Public Display</td>
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<td>1.7</td>
<td>2.6</td>
<td>53%</td>
<td>52%</td>
</tr>
<tr>
<td>Others</td>
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<td>11.1</td>
<td>11.0</td>
<td>4%</td>
<td>-1%</td>
</tr>
<tr>
<td>Total</td>
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<td>665.0</td>
<td>702.8</td>
<td>26%</td>
<td>6%</td>
</tr>
</tbody>
</table>

Source: DisplaySearch – Quarterly Large-Area TFT LCD Shipment Report – Advanced LED

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Fig. 1: Edge-lit light guide panel for 2 x 2-inch troffer downlight offers extreme thinness (3.5 mm).
thermoplastics such as acrylic or PMMA. Light is transmitted through a light guide by means of total internal reflection (TIR).

Edge lighting has made it possible to take existing light guide technology and expand it into a variety of general illumination applications utilizing high efficiency LEDs that focus the light into a high-performance backlight, or light guide. Because the LEDs are located on the edge of the light guide, there is better optical control for color and uniformity, fewer LEDs, better repeatability, and the thinnest possible lighting solution.

Common examples of edge-lit LED-based light guides at work in the general illumination arena include room lighting (ceiling downlights, wall sconces), under-cabinet, splash and desk task lighting, illumination of industrial and commercial enclosures (e.g., refrigerators, etc.), and architectural lighting, as well as in outdoor applications like pathway illumination and pedestrian traffic signs.

These applications were a natural design evolution for edge-lit light guides as they were developed to take light from a point source (i.e., the LED) and provide uniform distribution of it over large areas. The “large area” has expanded from a cell phone backlight to an LCD TV to illumination of an entire room or office.

Companies who are experienced in developing LED-based edge-lit LCD backlighting are leveraging that core competence to make the HBLED light source an integral part of light fixtures in general illumination applications rather than a replaceable part to be designed around, reducing the time-to-market and increasing the appeal of LED-based light fixtures in general.

That is not to say that it is simply a matter of taking LED backlights from LCDs and inserting them into SSL applications. LEDs produced for LCD backlighting are specified and tested under different terminology and conditions than what is accepted by the general illumination industry. LED backlights for LCDs are specified using the CIE color coordinates or wavelength. The CIE system characterizes colors by a luminance parameter Y and two color coordinates x and y, which specify the point on the chromaticity diagram, the CIE 1931 XYZ color space created by the International Commission on Illumination (CIE) in 1931. LEDs for general lighting fixtures are specified by Color Temperature. Color Temperature is defined in terms of the temperature of a black body at which it emits light of a specified spectral distribution, which is used to specify the color of a light source. It is usually measured in degrees Kelvin (K). IESNA LM79 provides for the total luminous flux, electrical power, efficacy and chromaticity.

LEDs used in LCD backlighting have their life expectancy listed as a half life (L50) value, whereas LEDs in general illumination products generally use an L70 lifetime expectancy – 70% lumen maintenance – which corresponds to a 30% reduction from the initial light output. IESNA LM80 covers lumen maintenance measurement for LED packages, arrays and modules.

Now, many LED manufacturers are offering 100 mA devices with flat tops and no lens – ideally suited to edge-lit light guides – that have been specified, tested and binned to SSL specifications, including LM79 and LM80, whereas these were previously only available tested to the CIE color coordinates.
This has enabled a company like GLT to successfully go from LCD backlighting into the general illumination market.

**Designing Around the LED**

There has been a lot of work by companies trying to take LEDs and fit them into an old technology, e.g., trying to put LEDs into an Edison fixture base and doing a drop-in replacement. If you go to LightFair International, Strategies In Light or any lighting show, you’ll see dozens of companies selling Edison bulb replacements or fluorescent tube replacements using LEDs. They’re out there, and everybody can buy them, but that’s not where we see the industry going. Long term, in our opinion, the replacement market has a short life expectancy.

As seen at LightFair 2012 in Las Vegas, a number of companies are still marketing “green” retrofit solutions for incandescent and fluorescent lighting fixtures. We regard this as a short-term strategy for a short-lived market, as these technologies will soon be obsolete, and that includes CFL, metal halide and halogen.

Many users want LEDs as the light source in their luminaire fixtures, but without having to re-design the fixtures to around the LEDs. Rather, they turn to solutions that “shoe-horn” the LEDs in to the existing incandescent or fluorescent fixture design to keep costs down. However, in the long term, this is neither the most efficient nor the most economical way to go.

For example, let’s take the common 60W light bulb. You can buy an LED light bulb that has the same basic form factor and screws into that good old socket in your lamp just like those 60W incandescents always did. But you’re still tied to old technologies – the whole concept of a bulb that screws into a socket goes back to Thomas Edison. What if you replaced your old lamp with a new one that is designed to use LEDs, period?

Or take office lighting. Many companies offer solutions like LED Fluorescent Light Technology, “energy saving” LED tubes can be installed just like conventional T8 Fluorescents, fitting existing sockets, usually with a “slight wiring modification”. Why does LED Fluorescent Light Technology sound like such an oxymoron?

Many companies are starting to realize that in order to take advantage of the true benefits of an LED package, they have to design the luminaire to actually work with the LED rather than just trying to take a luminaire that was designed to use a fluorescent tube or an incandescent bulb and shoe-horning an LED into it – and causing inefficiencies that aren’t necessary by trying to take a new technology and fit it into an old package. Over the last year there has been a movement toward products that are a retrofit of the entire luminaire rather than just the light source.

**The Best Long-Term Solution**

We’ve done a lot of recessed ceiling light designs for offices and other commercial and industrial applications where we’ve worked directly with the fixture manufacturers to do a top-down design of the entire luminaire around the end light source – the LED. One of the fixtures which we’ve seen huge sales growth in the last year for is the industrial 2’ x 2’ troffer-
Measuring Efficiency

The edge-lighting approach achieves maximum efficiency in light dispersion. But how do you measure efficiency? Our customers don’t necessarily ask us about the efficiency of the LED. They ask us about the efficiency of the system.

Where there is a core competence (such as LCD backlighting) that’s being extended into the general illumination market, we see more sophisticated system design and more customized solutions to provide every ounce of efficacy from the device level through the optical and thermal electrical system design to really maximize the performance of luminaires.

Application efficiency – i.e., the actual amount of light delivered to the targeted area in relation to the total light output of the fixture – is the true measure of performance. It includes:

• luminous efficacy (lm/W)
• the optimal efficiency of the total fixture
• Output distribution angle control

Luminous efficacy, sometimes referred to as brightness, is measured in lumens per watt (lm/W), and is a measure of how well a light source produces visible light. Lumens per watt are calculated based on the total output of light from the final product as measured within an integrating sphere vs. the power that is input into the product. Currently, the base target for most BLU suppliers is >70 lm/W, as this is the requirement to achieve Energy Star performance on a luminaire.

Luminous efficacy is only one component of the luminaire’s total application efficiency. In order to achieve high application efficiency, a lighting fixture must direct as much of the light to the target area as possible instead of scattering it in all directions, focusing on the target area to avoid wasted light emissions. So it’s not just about improving the efficiency of the LED, it’s about improving the optical efficiency of the total fixture so that the efficiency that’s quoted by the LED supplier also equates to system efficiency. It doesn’t matter if the LED has a 180 degree spread of light if you’re only doing

The luminaire is really where solid state lighting is going to go and take off. Because that’s where you can take advantage of using LEDs the way they were meant to be utilized as opposed to trying to cram them into an old light bulb form factor.
going to use 90 degrees of that, so it's about creating the optics to couple the LED properly in the final fixture so that the light that's actually reaching the end user and is in compliance with the IESNA LM79 standard is as efficient as possible, as shown in Figure 4.

Specular optics embedded in the light guide can direct the light in the specific direction desired. As shown in Fig. 5, pixel-based light extraction technology can be optimized to deliver light within the acceptance angle of the optical system. In order to reach maximum application efficiency, the luminaire manufacturer must work together with each supplier in the system to achieve the highest possible efficiency. This includes those responsible for the power supply, LEDs, drivers, light guide panels (LGPs) and films.

CRI and Cost
The color rendering index (CRI) is very important to the aesthetic appeal of the luminaire. CRI is currently the only internationally agreed upon metric for rendering evaluation of color, being a quantitative measure of the ability of a light source to reproduce the colors of various objects faithfully in comparison with an ideal or natural light source. Light sources with a high CRI are generally considered desirable for luminaires where color is critical. CRIs approaching 100 are being claimed by some luminaire and backlight manufacturers.

However, in our experience, acceptable CRI is actually much lower than commonly believed. In the luminaires that we've been working on – typically, the lower-cost luminaires – CRIs are typically 80. When you get into the higher efficiency, higher cost products, then you get up to about 85 CRI, but the highest CRI that we've specified on any product that we've sold is around 85 right now.

As in most other things, there is what people say they would like to have, and then there is what people are willing to pay for, and there is often a pretty wide disparity between the two. For instance, when we show customers the price differential between a luminaire with 50 lm/W brightness and a CRI of 80 at a unit cost of approximately $125, and a luminaire with 60 lm/W and 85 CRI for approximately $175 per unit, a lot of people have gone to the lower cost module without much hesitation. For high-volume products, in the real world, the most important specification is often price. For example, pricing for our UL-certified OL2 Series troffer 2x2 foot downlight assemblies begins at about $122 each in volumes of 100 pieces, compared to $45 to $80 per unit for similar conventional fluorescent troffers. Given the much greater lifetime of LEDs and the effective elimination of costs for re-lamping, customers have found that to be very competitive. Also, having designed this troffer around the LED light sources from the ground up, we have been able to design in higher-brightness LEDs as they have become
available into the same package, such as our 6060 Series, which has enabled us to offer higher brightness without higher cost.

That brings up another selling point – maintenance. In a lot of the environments where companies are considering a retrofit of LEDs to an Edison fixture, they have to pay an electrician to come in and change all their ballasts and fluorescent tubes. If you’re changing out a fluorescent tube into an LED, it requires you to replace the ballast with a power supply. So, at that point, if customers determine that they still have to bring in an electrician to replace the ballast in order to use a retrofit bulb, it just doesn’t make sense from a cost standpoint, and it provides a rationale for a new fixture designed around the LED rather than a retrofit bulb.

True SSL modules are being developed from the LED level all the way up through the end luminaire manufacture. And that’s where it needs to be. When those modules start hitting the market, you’ll see some pretty good adoption rates. For example, we have a luminaire that we developed the light guide for that is being sold into the Japanese market where the LEDs alternate between cool and warm color temperatures. There’s a dimming circuit and a feedback loop and you can use a remote control and change the color of the luminaire anywhere from warm white at 3000 Kelvin to cool white at 6000 Kelvin (see Fig. 5), and that’s what the end users love about it – they can pick what color they want. They don’t have to have a luminaire on the ceiling where they’re stuck with one color forever. It’s kind of like incandescent fixtures where they can change out the bulb if they don’t like the color that they purchased, except that they don’t have to buy new fixtures.

There is also an ambient room light sensor built into the product. When you open the window blinds in a room and the sunlight comes in, the circuitry automatically detects the ambient room light and decreases the power to the luminaire so that it maintains an equal level and saves power.

When we first started talking to the lighting suppliers, they had the LED suppliers trying to sell them LEDs, the driver suppliers trying to sell them drivers, and light guide companies trying to supply them with light guides, but there wasn’t anybody putting it all together in a system. Where we see things moving forward right now is lighting companies partnering with the LED, driver and light guide manufacturers to form more of a partnership rather than a supplier mentality. And that’s what needs to happen – everybody getting together and developing a truly efficient system and then presenting that to the market.

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