LEDs: The State of Play

By: Mike Wood

Are solid-state lighting sources really ready to take over in the theatre?

It can't have escaped your attention that LED-based luminaires are making inroads into just about every category of theatrical lighting. Step by step, they are proving to be viable alternatives to more traditional light sources. I'm sure you have your own opinions about where they are successful and where they aren't. Where additive color mixing works, and where nothing else will do but gel. Where you can get away with less-than-perfect color rendering, and where you can't. Where you are really getting efficiency improvements, and where you just purchased a large can of snake oil. We all know that LEDs and other forms of solid-state lighting (SSL) are enjoying a meteoric rise in popularity. We also believe that they are more efficient than other, more traditional, light sources and will save power. Is this all really true? If so, are we prepared to accept lower-quality light for the sake of efficiency? Do we want quality or quantity of light in our theatres? I also want to spend a little time in this article discussing why some luminaire categories have been quick to switch over to solid-state lighting sources and why others haven't yet succeeded.

The future of LEDs

Before we get into a discussion about SSL use in theatrical luminaires in particular, let's take a quick look at why SSL technology is so exciting and what its ultimate potential might be. We are a fortunate generation to be part of such a dramatic change.

Figure 1 (below) is from the US Department of Energy and shows both the historical and predicted efficacies of commercial white light sources. You can see that no technology is stagnant; everything is slowly increasing in efficacy. However, nothing else is even close to the almost vertical rise of LEDs over the last few years. If there were any lingering doubts that LEDs are a truly disruptive technology, then that stratospheric curve should dispel them. The question is not if solid-state light sources will dominate our world of lighting, but when. This chart oversimplifies the situation; it only looks at white light, and it is only concerned with general lighting. However, the underlying curve shape will be similar for our industry, although the time line may be delayed. (Note: Efficacy is reported in units of lumens per watt, lm/W, and gives a measure of how much light the source can produce for each watt of power that it consumes. It's one of the most useful measures of efficiency that you can have and is something you should insist every lighting manufacturer tell you about their product.)

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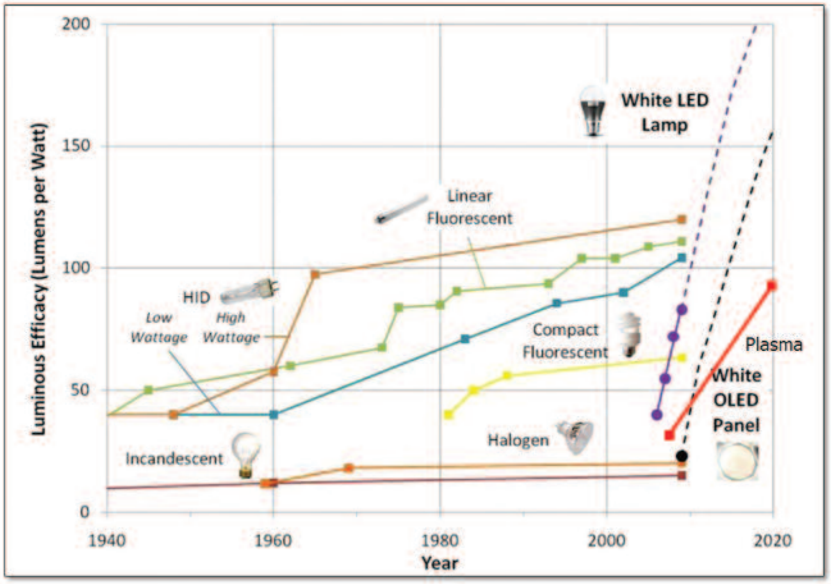

Figure 1: Historical efficacy of light sources

Immediately, we see a subtle, but important, difference between what we do with lighting in entertainment and how the rest of the world uses it. With very few exceptions, the commercial lighting world only cares about white light; only we theatrical users care about color, so most of the available market research data and fundamental R&D is concerned with white light. The commercial white light data is still interesting to us, as it provides a strong pointer as to what we might expect to see in our world, too. Let's take a closer look at the efficacy data for white light LEDS. Figure 2 (opposite) shows the expected efficacies for LEDs over the next 20 years for both warm color temperatures and cool color temperatures of commercially available products, as well as for the best

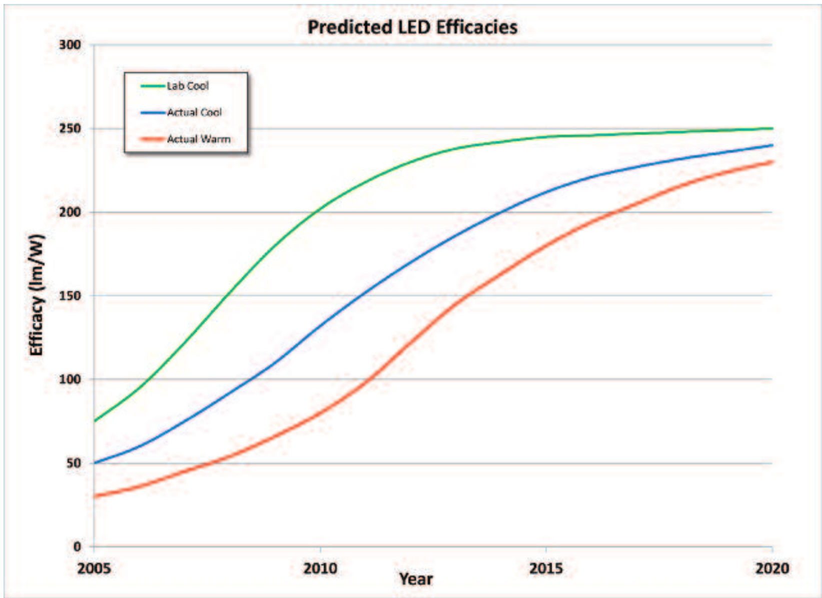

Figure 2: Predicted white LED efficacies

that can be done in the laboratory.

There's a very important point hidden in this chart. Notice that the top, lab development, curve doesn't go on increasing forever. It looks like it will level off at around 250 lm/W within the next five years. Why is that? Well, we are approaching the theoretical limit of efficacy. Once we get to the point when every electron coming in to the LED results in a photon leaving, then we are as good as it is possible to get: 100% quantum efficiency. Current LEDs are nearing 80% and will soon reach 90% quantum efficiency. That's really quite incredible!

Real luminaires

All the data we've just looked at is just for the light source and doesn't tell you anything about how much light will actually come out of the front of the luminaire and be usable. What does the future show for efficacies in real luminaires, not just in the laboratory?

Take a look at Figure 3 (below). I've put this chart together from a number of different sources and, I have to admit, taken a best-guess approach to fill in some of the blanks. The first interesting point to come out of this is that most current LED-based luminaires are actually not that efficient compared to other light sources. (They may offer other advantages, but, for the moment, I'm solely concerned with efficacy) They are very similar in efficacy to incandescent-source units, and fall far short of HID and other sources. However, jump forward 10 years to 2020, and the story looks very different. The prediction based on current data shows that, by 2020, we might be expecting to see white light efficacies that approach 150 lm/W as actual output from a real luminaire. To put that in perspective, those are figures at least three times better than anything we have today.

Entertainment luminaires

That sets the groundwork and explains the rise in efficacy we have seen from LEDs over the last few years. As that improvement has progressed, it has facilitated the increasing use of LEDs in entertainment luminaires. The order of luminaire type adopting LEDs has basically followed the complexity of the optical systems. The first units to reach a useful level of light output with LEDs were the open-face washes and cyclorama floods. These became commonly available at brightness and quality levels that meant you could use them without compromise about two to three years ago. Yes, I know that units were available long before that but, in my opinion, they had some limitations.

	Bare lamp lm/W			Luminaire lm/W		
	2010	2015	2020	2010	2015	2020
Incandescent – high voltage	20 – 30	20 – 30	20 – 30	12 – 18	12 – 18	12 – 18
Incandescent – low voltage	25 – 35	25 – 35	25 – 35	15 – 20	15 – 20	15 – 20
HID	80 – 120	80 – 130	90 – 140	40 – 50	45 – 55	55 – 60
Plasma	40 – 80	45 – 90	50 – 100	20 – 30	25 – 40	30 – 50
LED – white (Phosphor converted)	80 – 130	140 – 180	200 – 240	20 – 40	70 – 90	120 – 150
LED – colors (RGB, RGBA, RGBAC)	40 – 80	100 – 180	150 – 250	10 – 20	30 – 60	75 – 125
Ideal theoretical 5800K white source		250			150	
Discontinuous spectrum white light source		350			200	

Figure 3: Predicted luminaire efficacies

Either they were too low in output to directly replace conventionally sourced units, or they were too noisy (because of fans), or they drifted in output color, or they suffered from any of a number of other problems. Some of those problems are still with us today but, in general, you can now light a cyc as well, if not better, with an LED-based luminaire than you could with one using an incandescent lamp. Our use of color in these fixture types is the LED's friend here, as it helps the efficacy equation considerably. Cyc lights are rarely used in white and additive color-mixing LED systems remain at about the same efficacy as you change colors, whereas adding subtractive gels always loses efficacy. On a deep blue cyc, an additive LED system may be considerably more efficient than an equivalent gelled incandescent luminaire, even if they were the same efficiency in white light.

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Note: This color performance question is precisely what proposed PLASA standard E1.41 Recommendations for Measuring and Reporting Photometric Performance Data for Entertainment Luminaries Utilizing Solid State Light Sources seeks to address. The draft standard defines a new metric, color efficiency, which allows you to determine how much good a luminaire is at producing color.

The next category to be converted to LED light sources was the wash light, and, to my mind, the breakthrough from interesting product to useful tool came with the addition of beam angle control. Once you have a reasonably bright luminaire with color and beam angle ability, then you have a real theatrical luminaire. Interestingly, with a couple of exceptions, the wash units with the most sophisticated optics are currently only available as moving lights with automated pan and tilt. I'm sure this is mostly for economic reasons. There's some logic to it, as the form factor and cost of a moving light are more readily adaptable to the needs of an LED-based unit than a static unit. You already have power supplies and motors in a moving light, so the extra resources needed for LED sources don't add much to the cost burden. Now that the technology is available, I fully expect it to filter down to more reasonably priced static units. We now have a range of color-changing PAR-can-equivalent products that do an excellent job. However, remember that you must always look at the efficacy figures for your usage. Although they are great in mid and deep colors, an LED-based unit using just additive mixing to produce white light from a range of primary colors is, very likely, not as efficient as an incandescent lamp. In 2011, it's still hard to beat an incandescent PAR can in white light!

Framing spotlights

Leaving aside such niche products as followspots and beam lights, the last major theatrical luminaire category that LEDs have to conquer are the framing spotlights or ellipsoidals or profile spots—whatever your local name for them is. This luminaire category is a fascinating area of current development. As we've just discussed, LEDs have successfully conquered the flood and wash luminaire types and can, in many applications, compete on direct terms with luminaires using conventional light sources. However, the optics of a framing spotlight are much harder to emulate with LED-based units using multiple light sources. Luminaires using them still have some way to go before they can compete head to head with the output and utility of the conventional sourced units. The stakes are high; the ubiquitous incandescent "ellipsoidal" spotlight is by far the most common theatrical luminaire on the planet, and so is an obvious, and potentially lucrative, target for the manufacturer who can crack that particular nut. It seems to me, in the same way 2009 was the year of the LED cyc light and 2010 was the year of the LED wash light, that 2011 could well be the year of the LED-based framing profile. We've already seen a few units come to market, and I'm sure many more are on the way. LED sources have reached a critical point in brightness and power density that makes such a unit possible and the path is getting clearer. So far, in my opinion, there has not been a fully compelling product in the sector; the output has been too low, or the price and size have been too high to gain full acceptance—making them useful for a limited sector of the market, but not for everyone. I'm equally of the opinion that this won't be the case for long.

What makes an LED-based framing spotlight so much harder to produce than a wash or cyc light? The primary difference is pretty fundamental: In both cyc and wash lights, we are trying to produce a diffuse, soft light source, and thus are encouraged to mix up and mush all the light we have available into a diffuse beam. This lends itself neatly to trying to combine many discrete light sources in many different colors into a single light source. We want the source to be big for a wash light—bigger sources mean better soft edged shadows—and we want the light to have a woolly, undefined edge. The problem with framing spotlights is that we want the complete opposite! Ideally, we want a small, well defined source that will produce crisp, clean images of a gobo or shutters. We want a tightly controlled beam that will pass through an A-or-B sized gobo and then through a projection lens system resulting in a tight 10° beam. We want a clean, fully homogenized, output that can be used to illuminate a performer without multiple colored shadows. Finally, the framing spotlight is very often the key light on the actor, so needs to have impeccable color rendering and must look perfect on skin tones. All in all, not an easy task.

If we take a very broad view of framing spotlight optics, particularly those using ellipsoidal optics, we see there is always a tendency to produce an image of the light source in the output. In incandescent sourced units, you can see the outline of the lamp filament, perhaps as slightly brighter and darker areas in the image, while in units using radially mounted HID lamps you will often see two bright spots—one for each electrode. Even the theoretically perfect point source, most closely approximated by an axial HID lamp or plasma source, has these problems and will produce an image with an intense central hot spot unless the manufacturer takes measures to smooth it out in some manner. Whatever the light source, something must be done to help reduce that lamp image, and a faceted reflector has become the most common technique. Whatever technique is used, you can be sure that it has the side effect of reducing the light output. Optical systems are very unforgiving and you never get something for nothing. (Anyone who is old enough to have used the first CCT Silhouette ellipsoidals will remember that you got a perfect image of the grid filament in the beam unless the reflector was dimpled using a ball-peen hammer to break it up.)

This tendency to image the source is a real problem when trying to use an LED array. How do we take all those individual LEDs in red, green, blue, white, and perhaps other colors, and combine them into a light source that behaves like a single lamp? If you don't do something, then you see all those individual colored dots in the output—the objective lens system cannot discriminate and will focus them just as well as it focuses the gobo and shutters. Unfortunately, just about any way you homogenize the colors tends to result in losses or compromised performance. So far, despite some incredibly innovative solutions, those losses and compromises have resulted in products that, although undoubtedly useful for some applications, don't fully fit the bill to allow global adoption. In many cases, to get the quality result we need, the manufacturer has to throw away so much light in the combining optics that the result isn't, despite the marketing rhetoric, really good enough to do the job. Others show distinct color patterning in the beam, or multiple edges to shutter cuts, and yet others have poor soft-edge performance. (The use of framing spotlights is incredibly varied, and I suspect they are used defocused to produce soft edges more than they are used to project hard edged images) However, I'm quite sure that this situation won't last for much longer. The inexorable rise of both efficiency and output of LED sources means that, at some point soon, if not in whichever new product launched today, we will be able to afford to take those losses in our stride and throw away enough light to get the result we want.

Let me end with some generic advice to anyone buying any type of LED luminaire. First, think about why you are buying it. If you want it because of the color mixing, the ability to instantly change color, and the integrated operation with no dimmers required, then go right ahead. If, however, your primary motivation is "green" energy reduction and increased efficiency over existing products then you should check that you are really getting what you pay for. Just because the product box has "LED" written on it doesn't mean that you are actually getting increased efficacy. Take care when you read the data sheet, in particular:

Check the output lumens. Don't just look at the center footcandles/lux. A peaky beam gives you more intensity in the center and can disguise the overall lack of light.

Check the efficacy. If a manufacturer is claiming high efficacy then they should prove it by providing the information. How many lm/W does it provide? Is it really better than the conventional alternatives?

Whatever happens this year and whether 2011 is really the year of the LED based framing spotlight or not. With the number of manufacturers working on the product category, that light is coming, and coming soon.

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