MAGNETIC INDUCTION LIGHTING

VERSUS

LED STREET LIGHTING

Overview –

Rapid advances in energy efficient lighting have generally displaced traditional street fixtures using high pressure sodium (HPS), metal halide (MH), and mercury vapor (MV) with light emitting diode (LED) and magnetic induction light (MIL). LED has received the most attention as substantial research and development has accelerated and popularized this technology. In contrast, MIL was introduced in the late 1890s and was patented by the renowned inventor Nikola Tesla in 1891. The perceived lack of patentability associated with MIL has been a barrier to entry by large and well known lighting companies like Phillips, Sylvania, Osram, and GE. Although limited MIL offerings are available from these companies, the extraordinary life-cycle of MIL bulbs can exceed 100,000 hours (11 years operating 24 x 7 x 365), acting as a deterrent due to the implied poor business model; i.e. no anticipated replacement cycle.

Both LED and MIL have encountered rough starts in initial deployments as several reliability issues became apparent. Most notable are early failure rates that exceeded expectations based upon lamp specifications. For LED, many of the individual diodes expired within very short periods, leaving lumen output compromised. LED performance in hot climates such as the U.S. Southwest led to decisions by municipalities like Tempe, Arizona to use MIL. By the same token, many MIL fixtures failed completely due to poorly manufactured parts imported from China that included bulbs, drivers (ballasts), and casings. The bulky nature of some MIL bulbs and fixtures has caused negative reactions to their appearance.

The American Association of State Highway and Transportation Officials (AASHTO) has published close to 400 pages of recommendations for street, roadway, and highway lighting. To be sure, there are hundreds of supplements and updates pertaining to newly developed lighting technologies, but the bulk of the standards has been developed based upon traditional HPS, MH, and MV fixtures. Further, at the time most lighting plans were implemented, no emphasis was placed upon Dark Sky compliance nor was there as much understanding about the effects of different artificial light sources upon human behavior and driving performance.

Unquestionably, energy efficient lighting for outdoor and indoor applications continues evolving ever faster. For this reason, very little remains static regarding the advantages of one technology over another. Still, there are fundamental features of MIL and LED that can form a foundation for making sound decisions. These fall into three distinct categories of 1) technical performance, 2) ergonomics, and 3) economics. More recently, greater weight has been placed upon ergonomic aspects of roadway illumination as opposed to purely technical performance. This is highlighted in studies dealing with difference between scotopic and photopic vision and the merging of both into mescopic standards. Formerly accepted principles of light dispersion and visual perception have been challenged by new evidence of the human visual response. Moreover, there are studies to suggest unshielded LED lighting can be dangerous to the eye. This can become a paramount consideration when considering potential legal exposure.

This paper is designed to provide a basis for evaluating new Street-Bright™ MIL technology and comparing the value proposition relative to LEDs. Street-Bright™ technology is based upon new MIL science specifically targeted toward streets, roadways, and highways. In particular, Street-Bright™ fixtures have been created to address existing infrastructure that includes electricity, existing mountings (pole heights, distances, and hardware), and pavement surfaces. Sophisticated LumenTec® spectral tuning can take into consideration specific surroundings that include Dark Sky ordinances, pavement color (black-top, cement, dirt/gravel, etc.), and rural/city environments.

To be clear, this paper is not an engineering report and does not provide details about LED lighting that can be found in available marketing material from various manufacturers. This paper highlights negative LED features that are not generally circulated. At the same time, specific features of Street-Bright™ MIL technology are provided to emphasize positive features and advantages over LED alternatives. With this in mind, the reader can independently verify material in this presentation and draw objective conclusions.

Warning – Unshielded LED Lighting Can Damage the Retina

In the May 13, 2013 edition of *Live Science*, Assistant Editor Marc Lallanilla reported on the research of Dr. Celia Sánchez-Ramos of Complutense University (Madrid, Spain) regarding potential dangers of directly viewing unshielded LED lighting. Simply put, the intense concentrated light of LEDs can permanently damage the retina, causing blind spots and color de-sensitivity. As the LED installed base rapidly expands, more and more emphasis is being placed upon health risks associated with directly viewing LEDs. While still under peer review, this revelation has raised concerns about possible liabilities associated with newly deployed or anticipated LED roadway lighting. Now, lighting designers and consultants are increasingly faced with the tradeoff between installing energy efficient LED fixtures and potential liability associated with *eye-damage claims.* There is particular concern that children may fixate on outdoor LED lighting like street lamps, causing serious permanent retinal damage. Problems stem from high intensity ultraviolet and near-ultraviolet light as well as the small footprint of individual LED components. The uneducated public may have a propensity to admire an LED fixture and, in the process, eye damage may occur.

High intensity of a single diode can cause retinal damage.

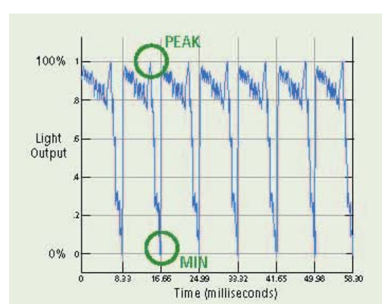
The legal question raised is whether a municipality or private entity "knew or should have known" LED *could* damage the eye. Strangely, the more sophisticated the decision-making process (i.e. hiring lighting engineers and consultants), the greater the potential legal exposure. This is because a credentialed engineer or consultant is *assumed to have the knowledge base* to provide an objective evaluation of any dangers.

There is no way to measure legal exposure before the fact. However, there is the issue of whether the risk of *any exposure* is worth the gamble. The consequence may be narrowly limited to individual monetary claims or as broad as an order to de-install entire LED lighting infrastructure.

Warning - LEDs are Subject to "Flicker" and/or Strobe Effect

High frequency flicker is associated with significant health hazards that include strobe epilepsy, migraine headaches, nausea, impaired visual acuity, poor concentration, sleep disorders, mood swings, eye strain, and a lack of eye/hand coordination. The problem is serious enough for the IEEE Standards Working Group, IEEE PAR1789, to take up "Recommending practices for modulating current in High Brightness LEDs for mitigating health risks to viewers." This process has been put in place to advise the lighting industry, ANSI/NEMA, IEC, EnergyStar and other standards groups about the emerging concern over flicker in LED lighting. The objective is to develop electronics and associated standards that can either eliminate the flicker or mitigate biological impacts by raising the frequency to levels that are imperceptible to the brain.

For most high intensity LED street lighting, flicker presents several advanced challenges. "Strobe Effect" is the motion distortion that occurs when moving objects are viewed under the offending light. This disrupts visual perception and the ability to judge time and distance. Since many LED arrays are subject to flicker rates of 60 and 120 cycles per second, the strobe effect will be proportional to the speed at which a vehicle or other objects are traveling. Perception distortion is compounded by the motion of the reference vehicle (one being driven) relative to the moving vehicle (one being viewed) combined with the duration of the flicker (cycle time).



A vehicle traveling at 30mph covers 44 feet per second. Although movies are thought to cover the perceptive range of human vision at 24 frames per second, the actual eye/brain visualization is far more sensitive. For example, a trained pilot can see a flash of light lasting only 1/1,000th of a second (light on dark) while most of us can perceive a strobe up to 1/200th of a second (dark on light). Perception mechanics are not precise from individual to individual, but a 60 cycle strobe will generally remove .7333 feet per second from a static object at a viewer's acuity of 60 frames per second. If the object is a car traveling at 45mph, the conversion is 66 feet per second causing a loss of 1 foot.

Although these missing visualizations may seem trivial, visual perception is not simply object to object because the brain interpolates between each viewing cycle. At the same time, the eye moves through a 180 degree forward visual axis, altering the extent of the peripheral visual plane. This is how magicians appear to perform slight of hand beyond the conscience visual perception. However, such visual misinterpretations while driving can present dangerous situations.

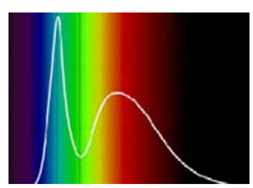
Since LED streetlight deployment is new, the consequence of strobe effect has not been fully evaluated. However, there is strong anecdotal evidence that strobe effect disrupts visual perception and acuity. For highway driving above 65mph, the amount of missing interpolative perception may significantly contribute to night time accidents. It should also be noted that some LED street lighting systems offer dimming capabilities for enhanced energy savings. Dimming LEDs increases strobe effect and may not be advisable based upon current knowledge and evidence.

Warning – LED Street Lighting Can Have a Hypnotic Influence

Standards for roadway lighting already take into consideration the slow strobe of passing lights. For example, a 120-foot separation between highway lamp poles will have a peak to trough intensity cycle of 1.26 when traveling at 65mph; 95.333 feet per second. Repetitive patterns can have a hypnotic effect upon human subjects. LED road lighting produces high intensity at the source and exhibits high glare. Intense white LED arrays like those most commonly used for roadway fixtures have a high ultra-violet and near ultra-violet bias. This has been correlated with sleep inducement.

To be sure, LED can be well directed onto an intended target and the illumination pattern can be reasonably well controlled. However, LEDs use intense single diodes in an array to achieve high lumen output. This makes light diffusion difficult without the use of diffusion lenses. Most LED roadway fixtures do not have diffusion lenses because they would lower overall lumen output. This intensifies the potential hypnotic influences of LED. LEDNews.org reports on using patterned LED arrays to induce hypnosis and cause dizziness in subjects.

One of the most significant drawbacks to LED is overcoming the emission gap resulting from the green-yellow region of the visible spectrum (515-600 nm). Even when multiple LEDs of different colors are combined to



LED spectral bias

simulate white-light, or one or two different colored LEDs are used to activate phosphors to produce white light, current designs lack efficient production of blue-red or green-yellow photons for true white-light color. The result is a highly distorted or uneven white light that can cause negative reactions in people who are sensitive to the spectral irregularities.

More Research is Required –

When considering the safety associated with street, roadway, and highway lighting, the allure of saving energy using new LED fixtures should be tempered with knowledge that we do not fully understand the human interaction with this lighting source in its present state of technical development. Unquestionably, LED manufacturers are grappling with issues of flicker and spectral output. It is fair to say that there has not been sufficient deployment of LED lighting to develop data to more fully and accurately evaluate potential negative consequences. Even the lifecycle cost of LED lighting needs more time to be proven since many new LED designs have yet to test the estimated lifecycle limits.

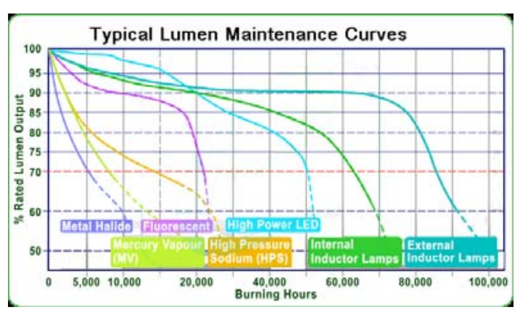
Technical Performance –

Technical performance generally covers the following features:

1) Efficiency as measure by lumen output per watt
2) Lumen maintenance over the life cycle
3) BUG rating and IES performance
4) Color rendition index (CRI) pertaining to color perception
5) Total electric consumption (in-rush current, operating current, ballast overhead)
6) Environmental performance (temperature, humidity, wind)
7) Overall maintenance

Efficiency - High intensity LED arrays have made gains in efficiency over the past decade. As of 2014, lumens per watt have ranged from 90 to 115. By comparison, Street-Bright™ MIL bulbs and drivers produce 90 to 95 lumens per watt. When taken as a complete system (driver and array), LED fixtures may lose efficiency due to driver overheads. This will vary by manufacture. Street-Bright™ ballasts exhibit very high efficiency with a power factor greater than .98 (98%).

Lumen Maintenance - A critical factor for any roadway lighting is the lumen maintenance over the projected lifecycle. It is well accepted within the lighting industry that magnetic induction has the highest lumen maintenance, retaining up to 90% of original lumen output for better than 80% of the projected lifecycle of 100,000 hours. Street-Bright™ technology is designed to exceed the industry standard.



LED arrays can lose 20% to 40% of their original lumen output within the first 50% of their projected lifecycle. This means the photometric pattern assumed at the time of installation will substantially deteriorate well before the lamp expiration. Although some LED fixtures are now claiming 100,000 lifecycle expectancy, these claims have not been field tested. Real world experience has shown lamp life averaging between 10,000 and 25,000 hours. Newer designs may achieve 50,000 hours, but with considerable performance deterioration.

BUG Rating – The lighting industry has become increasing aware of the need to comply with new Dark Sky standards and ordinances as well as creating a more universal set of metrics to describe outdoor lighting operformance. The BUG acronym stands for **b**acklight, **u**p-light, and **g**lare. Backlighting is the amount of light that bleeds behind the intended illumination area. Up-light is the amount of light that extends upward into the sky and adversely affects Dark Sky compliance. Glare is the amount of non-diffused brightness that can cause visual impairment.

Previous comparisons between LED and MIL technologies assumed that LED fixtures can exercise more control over light distribution. To be sure, the placement of diodes in conjunction with reflector geometry can achieve accurate directional control over the illuminated surface. However, LEDs generally suffer from excessive glare that is particularly bad for roadway lighting where it is critical to maintain the highest visual acuity. Simply put, glare can be blinding.

Street-Bright™ MIL fixtures use a large-format light source as opposed to high intensity concentrated sources. By the geometry alone, glare is reduced because the bulb creates a broad light field that can be directed through the reflector geometry. Counterintuitive to industry understanding, a more fully diffused light source can provide the least amount of glare and the maximum visual acuity. Thus, Street-Bright™ technology incorporates a new nano-material reflector coating that has a 96% reflectivity index and creates a more diffused and dispersed lighting pattern.

Reflector technology has been created to minimize backlight and up-light bleed to make Street-Bright™ fixtures more fully adherent to Dark Sky standards and regulations. For example, the same technology used in Ultra-Tech™ Snow-Bright™ fixtures for ski slope illumination have zero (0) backlight and zero (0) up-light BUG ratings. Street-Bright™ glare is literally negligible. Depending upon the particular lighting pattern (Type 1 through 5), Street-Bright™ technology provides minimal light pollution. Moreover, the unique LumenTec® spectral tuning is animal friendly.

Color Rendition Index (CRI) – The human eye sees using cone and rod receptors. Cones distinguish color while rods provide for contrast and definition. Visual acuity depends upon the combination of color, contrast, and depth perception which all depend upon light levels. Lighting measurement has mostly concentrated on gross lumen output without regard for color sensitivities. This means that a powerful light source in the near ultra-violet range can have a high lumen rating, but cannot be effectively used for visual perception. The CRI measures the degree light falls within the visually effective lumen

(VEL) range. While the eye can see in the blue and red spectrums, the highest acuity falls within the green/yellow range. However, it is the precise combination of color that provides the greatest ability to distinguish color and yields the highest CRI. Common high pressure sodium roadway lighting has the lowest CRI because the light has an extreme orange bias and is considered "monochromatic." LEDs can have CRI values from 75 to 85, representing a very good ability to distinguish color. Unfortunately, most high intensity LED arrays still suffer from ultra-violet and near ultra-violet bias. This causes a distinct distortion in color accuracy. Street-Bright™ lamps have a CRI exceeding 90. The full spectrum design uses a particularly bright light. This allows Street-Bright™ to use lower energy and lumen output with better color rendition and overall visual acuity.

The lighting spectral balance is usually referenced as the "color temperature." The measurement is provided in degrees Kelvin and is associated with the light output of a black object glowing at a known temperature in Kelvin. Warm lighting has a low temperature while cold bright lighting has a high temperature. The scale is also correlated with natural sunlight such that a bright hazy day would measure 6,500K while a late sunset might drop to 2,100K. LED street lighting usually falls between 4,000K and 5,000K. Street-Bright™ fixtures are rated at 6,500K and higher. Equally important, the spectral balance is tuned for different road surfaces from blacktop that has high light absorption to cement with lower absorption and higher reflectivity.

Electric Consumption –

The main objective for moving to new lighting technologies is to reduce energy consumption. Knowing this, lighting manufactures always try to paint their technology in the best light (no pun intended). Electricity consumption is not simply the amount of energy consumed per hour. It is a combination of in-rush current required to strike (light) the lamps as well as maintenance current. There are also considerations for the amount of "useful" electricity versus total electricity, measured as Power Factor (PF). A PF of 1.0 is perfect. Anything less than .90 shows less efficiency. Street-Bright™ drivers (ballasts) have a PF exceeding .95.

In-rush current is the amount of initial electricity needed to activate a lamp. High pressure sodium and metal halide lights have very high in-rush current requirements, meaning there is a surge in electrical consumption upon turning them on. LED and MIL fixtures have low in-rush current which is important for keeping demand charges low and for conforming to existing electrical infrastructure.

As mentioned, LED arrays are very efficient, with lumens per watt of 95 and better. Former MIL bulbs had high lumen ratings measuring about 85 lumens per watt. More effective drivers, phosphorus formulations and magnets have currently boosted Street-Bright™ lumen production to just over 95 per watt.

Environmental Performance – Street and highway conditions include ambient outside temperature, humidity, road dust and chemicals, wind, and accidents. Early MIL fixtures used snap-clasps to fasten the lens cover to the lamp frame. This caused failures from water migration and wind. Based upon earlier experiences, designs have been improved. Street-Bright™ fixtures use a double seal to protect against moisture penetration and a wind resistant shape to present the least amount of drag. Operating temperatures range from -40°F to 160°F with no degradation in performance. The coatings are salt and chemical resistant.

There are a variety of LED road luminaries. Each has its features. However, common to all LEDs is heat sensitivity. Above 100°F, some LEDs have a higher failure rate. Temperatures in excess of 120°F can be problematic. For this reason, Tempe, Arizona opted to use MIL fixtures rather than LED. LEDs are very sensitive to moisture. A small amount of humidity can cause total failure. Since LED street lighting is new, there has not been enough real world experience to fully determine all aspects of environmental performance.

Overall Maintenance – Like most MILs**,** Street-Bright™ fixtures have a rated life-cycle of 100,000 hours. This has been demonstrated by installations dating back to the early 1980s that remain in operation today. Maintenance savings over conventional HPS and MH lighting is approximately 600% to 800%. Since most LEDs are rated at 50,000 hours and under, MIL will reduce maintenance by 100% or more. LEDs that are boasting 100,000 hour life-cycles have yet to prove such resilience in actual operation. As mentioned, MIL maintains lumen output over the lifecycle whereas current LEDs do not. MIL can easily be recycled as regular glass and metal waste after removing the isolated mercury capsule… LEDs cannot. As disposal costs become a increasing consideration, the Street-Bright™ advantage is significant.

Conclusion – The world of lighting is constantantly and rapidly changing. Although MIL technology was conceived in the late 19th Century, its clear advantages over other artificial lighting make it prudent to consider Street-Bright™ fixtures. The specific characteristics of Street-Bright™ compared with available LED roadway lighting make it clear that MIL offers major safety features that can become extremely important as deployment becomes more widespread and impacts better known.

There are too many serious questions about the quality of light produced by available LED fixtures that must be addressed by the prudent designer, engineer, and decision maker. Street-Bright™ technology is the more prudent, cost-effective, and safe approach.

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