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Rosemont Copper Project
Light Pollution Mitigation Recommendation Report

Revision 1 - June 18, 2012

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Executive Summary

The Rosemont Copper Project (Project) site lies within an area of concern relative to the effects of light pollution. Because the Project will operate around the clock, additional light pollution is of concern to astronomical interests and to the environmental community in general. Several of the world's most important observatories are located nearby, and they rely on the maintaining or reducing the levels of light pollution within southern Arizona[i]. Decades of concern by the astronomy community have resulted in the development and implementation of a stringent and continuously evolving outdoor lighting ordinance in Pima County. The principles of shielding, spectral content control and responsible lighting practices to protect our valuable regional astronomical assets date back to the early 1970's[ii].

Neither the previously existing 2006 Pima County Outdoor Lighting Code (PCOLC)[iii] nor the recently adopted 2012 PCOLC[iv] have jurisdiction over the Project site for the development as proposed. However, as part of its commitment to best possible environmental practices, Rosemont Copper Company (Rosemont) will voluntarily employ an advanced light pollution mitigation plan. The plan will include the use of state of the art lighting equipment and controls to minimize environmental and astronomical impact to levels consistent with the intent of the PCOLC, and other comparable modern light pollution control standards. Importantly, the plan must also comply with the project's operational safety requirements prescribed by the Mine Safety and Health Administration (MSHA). The plan will include the use of:

- Full cut off, solid state Light Emitting Diode (LED) lighting systems.
- High fitted target efficacy (FTE) lighting systems and optics.
- Specific purpose lighting systems with optics that match task requirements.
- Adaptive lighting controls to dim or extinguish lighting when not needed, and to provide immediate 'instant on' emergency or operational lighting.
- Where color rendering is needed, use of color tuned solid state light sources for superior energy efficiency and optical control with attenuated short wavelengths to minimize Rayleigh scattering.
- When color rendering light is not needed, use of narrow band 590 nanometer amber solid state lighting to emulate low pressure sodium (LPS) but with superior optical and electrical control.
- Color adaptive lighting to shift from narrow band amber emissions to higher color rendering light when color rendering is needed.

To assess the baseline night sky condition and to allow future measurements, advanced aerial and ground based methods will be employed. Aerial surveys have already identified current sources and intensities of light pollution throughout the region as well as characterizing the baseline night sky. Measurements may be made in the future to determine the impact of the Project, its compliance with established goals and mitigation methods, and to identify other newly introduced sources of light pollution in the Tucson region and their relative impacts. The result is expected to be a lighting installation that generates a similar amount of environmental light that, per the 2012 PCOLC, would normally be allowed by a similar commercial development of the same scale in the same location using conventional lighting systems on a similarly sized parcel.

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Introduction

The Rosemont Copper Project (Project) is a new facility to be built about 30 miles southeast of Tucson, Arizona in Pima County. Because of its expected 24/7 operation, the potential for light pollution and its impact on astronomy are particularly important, as many of Arizona's professional and amateur observatories are located in the Tucson area. Protection of the night sky and associated astronomical research is especially relevant to the local optical science related business economy as well as to the environment.

The Project will be approximately 10-15 miles to the northeast of Mt. Hopkins, on which is located the Whipple Observatory. In its 2006 and draft 2011 Outdoor Lighting Code (PCOLC), Pima County identified the area around Mt. Hopkins among its most critical zones (1a and 1b) for protection of the night sky. However, the PCOLC does not have jurisdiction for this type of project, regardless of proximity to any observatory or environmental zone. In theory, the Rosemont project could employ traditional lighting practices for most of the lighting on the mine site without any special restrictions.

However, as part of its mission, Rosemont Copper Company (Rosemont) has made a commitment to the community:

> *With the latest mining technologies, Rosemont Copper will set a standard for sustainable practices, including using solar power, consuming less than half the water as traditional mines, and reclaiming the site as permanent open space by revegetating throughout the life of the mine…. Rosemont Copper's vision is to utilize sustainable mining practices to create a bridge from Arizona's mining past to a high-tech, renewable future.*[v]

Rosemont has recognized the significance of controlling light pollution as an integral part of its sustainable efforts. Preliminary lighting design efforts have been based on existing technologies and approaches to lighting. Based upon technological advances in the lighting industry, Rosemont plans to dramatically improve the performance of its lighting systems. In addition, state of the art methods have been used to establish baseline night sky conditions and local sources of light emissions. This will allow future measurements to verify the performance of site specific lighting system installations as well as allow for a comparison to other changes to the regional night environment. This will be the first major project in Arizona for which light pollution and its mitigation measures may be measured over the course of construction and full operation.

Assuming the lighting at the Project was regulated, the proposed mitigation strategy is to reduce all site lighting lumen emissions, regulated or not, to less than the amount allowed by the Pima County Outdoor Lighting Code lumen per acre table for Zone 1a.

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Background

In December 2009, M3 Engineering & Technology Corporation (M3) issued a technical memorandum, describing proposed lighting systems for the Rosemont Project. An updated memorandum (hereinafter the “DEIS Lighting Plan”) was issued in January 2011 that was included in the Draft Environmental Impact Study (DEIS). It notes that, while the Project is exempt from the PCOLC, Rosemont intends to respect the intent of the code and as much as possible, to meet it.

However, the PCOLC and the DEIS Lighting Plan are based on the use of legacy lighting systems including those using low pressure sodium and high pressure sodium lamp types. Current developments include lighting systems that employ light emitting diodes and other modern light sources, that when coupled with exceptional beam control, can be used to reduce stray light. These modern lighting systems have qualities that can be used to dramatically reduce and mitigate light pollution compared to legacy lamps and equipment. This report has been developed to recommend lighting system improvement measures using new lighting technology that will dramatically reduce the Project’s impact on the night sky. The new light sources will also address the MSHA safety issues discussed in the DEIS Lighting Plan.

As part of developing this report, the Rosemont project site was visited on August 5, 2011, to review the topography of the Project area and region. The site is located in a shallow bowl surrounded by nearby peaks and higher elevation ridgelines. The land enjoys a relatively high density of flora due to its elevation and annual rainfall. As an additional consideration, the overall shape and vertical density of the site will naturally contribute to the mitigation of lighting effects.

Pre-Mitigation Lighting Requirements for the Project

The DEIS Lighting Plan identified proposed conventional lighting systems to be employed at the Rosemont Project as follows:

High Pressure Sodium Systems (HPS, color rendering is somewhat important)

- Mine pit, ~3.4 million lumens, with some light sources >100,000 lumens
- Mine process area, ~1.4 million lumens
- In plant roads, <0.1 million lumens
- Dry stack conveyor, ~ 1.2 million lumens
- Leach pad, ~ 6.0 million lumens
- Primary access road - none

Total HPS ~12.0 million lumens

Low Pressure Sodium Systems (no color rendering)

- In plant roads, ~ 2.0 million lumens
- Primary access road, ~1.4 million lumens
- Ore processing, ~ 3.5 million lumens
- Dry stack conveyor, ~2.5 million lumens
- Mine pit, ~ .2 million lumens

Total ~9.6 million lumens

Xenon Systems (color rendering is important but secondary to being mounted to heavy equipment)

- Mine pit equipment mounted, ~0.1 million lumens

This report assumes that the DEIS Lighting Plan assessment of the gross lighting requirements for the Project is correct, and that the amount of lighting identified above is appropriate for the tasks. With this in mind, some moderation of task lighting illuminance values may still be possible and further reduction in the total site lumens may be attainable. This assessment will be made during detailed facility design.

The DEIS Lighting Plan notes that LPS and HPS are light sources with poor characteristics related to starting and restarting. They require warm up when started, and if extinguished, a cool-off period before restarting. Power surges, lightning, and other interruptions, even very brief, could cause lighting systems to suddenly stop operating and remain at less than full output for some time and pose possibly unsafe working conditions. This operational limitation prevents these standard sources from being considered for on-demand or adaptive controls.

Pima County Outdoor Lighting Code Allowance

Assuming that the site would be governed by PCOLC Lighting Zone E1a, and assuming that the then- in-force 2006 PCOLC is used, the following allowances are included in the DEIS Lighting Plan:

- Site: 4,415 acres (Option 1 of Table 401.1 allows 18,000 lumens of "mostly LPS" lumens per acre; entire site considered
- Total site lumens (Option 1): 79.47 million lumens allowed, ~ 21.7 million lumens proposed in the DEIS Lighting Plan
- Total site limit on full cut off non-LPS lumens (Option 1): 13.24 million lumens allowed, ~ 12.1 million proposed in the DEIS Lighting Plan
- Total site limit on unshielded lighting: None allowed ~ Some unshielded lighting would occur for the proposed portable light plants and equipment mounted lights presented in the DEIS Lighting Plan

The lighting systems suggested in the DEIS Lighting Plan would comply with the 2006 PCOLC as long as all of the permanent and portable lighting was full cut off (fully shielded against uplight). Traditional mine task lighting, especially vehicle mounted lighting that is unregulated under the PCOLC, has not historically exhibited these characteristics.

For the purposes of demonstrating its commitment to the environment, Rosemont Copper is planning to employ lighting systems that would result in a total site lumen usage that will be lower than the currently adopted 2012 PCOLC would allow. The mitigation strategies proposed in the remainder of this report describe such systems and the resultant lumen per acre densities.

General Mitigation Strategy

The January 2011 DEIS Lighting Plan is based solely on lighting technology developed and promulgated in the last half of the 20th century. This technology is mostly called "high intensity discharge" (HID) and includes high-pressure sodium (HPS), low-pressure sodium (LPS), mercury vapor (MV) and metal halide (MH) lamps. These lamps have been identified and regulated in the PCOLC because the spectral power (color) qualities of the lamps are related to their relative effects upon astronomical observations. For instance, the PCOLC prefers LPS lamps because they emit only specific yellow wavelengths and produce less scattering of light in the atmosphere than do the polychromatic HPS, MV and MH, thereby improving conditions related to astronomy[vi]

HID sources were developed to efficiently produce abundant light in a small part of the lamp called the arc tube, enabling efficient and effective optics to direct the light where needed. HID luminaires are the predominant source in most outdoor lighting, ranging from lighting streets and highways to signs, stadiums and building facades. Present HID technology is very efficient and relatively inexpensive.

However, HID lamps suffer from a major flaw. In order to create large quantities of light within the arc tube, temperature and gas pressure inside the tube must grow through a warm-up period. The warm up time from starting until full light could take several minutes. Once at full output, the lamp must continue to constantly operate; if an interruption occurs, no matter how brief, the lamp will extinguish and will need to cool before re-igniting. This cool-down period could take several minutes. In the DEIS Lighting Plan, this flaw was described as a potential safety hazard. Additionally, the HID lamp behaves poorly when dimmed below maximum output and is unsuitable for adaptive control schemes.

The ***first principal mitigation strategy*** for the Project will be to employ 21st century light sources. It is anticipated that solid-state lighting (light emitting diodes or LED) will replace HID in many lighting applications between now and the practical operation of the mine. Other light sources such as induction, organic LED (OLED), and plasma may be considered as well. Most of these sources can be switched on and off at will, operate well in a dimmed mode, and have no starting or restarting concerns. The best mitigation strategy will be to turn off lights unless needed. The means of control can be highly automated while permitting human intervention as needed. The two key substrategies are ***on-demand*** lighting, which means activated when needed, and ***adaptive*** lighting, which changes automatically based on time of day or other regular and predictable applications.

The ***second principal mitigation strategy*** is to employ very well shielded and aimed light sources. In solid-state lighting, each "lamp" is an LED producing about 300 lumens with current technology. Each LED can be aimed in a specific direction and individually shielded to minimize or prevent uplight. Careful luminaire design and application prevents wasted light and can effectively ensure little to no upward waste light or off-site spill. A luminaire consists of an array of LEDs that are "targeted" to task locations. A new specification called "Fitted Target Efficacy" (FTE), developed by the US Department of Energy, can be used to demonstrate how much more efficiently light can be applied to outdoor lighting situations.

The ***third principal mitigation strategy*** involves spectral control. The color of solid-state lighting is more easily managed to emit (or not emit) certain wavelengths. For example, on the Big Island of Hawaii (home to the Mauna Kea world-class observatory complex), LED roadway lighting luminaires have been fitted with 500nm long-pass filters to eliminate aqua, blue and violet emissions to preserve conditions that are more favorable to astronomical observations. 500nm filtered LED fixtures generally produce a yellowish white light similar to HPS. In other cases, pure narrow-band amber LED lamps have been used to emulate LPS but with far better optical, warm up and restarting characteristics. Careful selections will have the performance characteristics of solid-state lighting, but the color quality of conventional lamps. Solid-state lighting could also permit spectral change, such that a luminaire in a critical area could be idling at a low level of narrow band amber light, and then change to color rendering lighting as needed for detailed work in that area.

The ***fourth principal mitigation strategy*** is to use the smallest necessary light source ("lumen package"). Overlighting is common using HID lamps because the smallest lamps of this type produce more light than needed in many applications. Solid-state lighting will permit better tuning of lighting to each application. For instance, bollard style or wall mounted lights used around building entrances work well with about 500-1000 lumens. The smallest applicable HID source is more than twice this amount.

The ***fifth principal mitigation*** strategy is to address the environmental concerns of native flora and fauna. Specific LED lighting solutions, including limitations on the use of sub-500 nanometer lighting spectra (generally blue light) will be applied to minimize the impact to the night environment. The control of sub-500 nanometer wavelengths is a known factor in minimizing artificial lighting effects upon nighttime insects and their predators.

The ***sixth principal mitigation strategy*** is to use solid-state lighting for vehicular-mounted task lighting. LEDs are now being widely applied for vehicular headlights, taillights, and interior illumination. Solid-state task lighting can be installed on vehicles and other apparatus and is a catalogued accessory for heavy equipment use. A major side benefit of solid-state lighting is exceptionally long lamp life despite heavy shock and vibration exposure, which will reduce operating costs and minimize safety concerns. Beam shaping is also readily available for equipment mounted LED lighting. Use of this technology will impart less stray light and direct more useful light to the critical task and operation areas.

Mitigation Strategy #1: Solid State Lighting

The largest revolution in electric lighting technology since the Edison lamp is now occurring. Solid state lighting, otherwise known as light emitting diode or LED, is rapidly replacing conventional electric light sources in increasing types of indoor and outdoor lighting applications.

Historically, outdoor lighting has been a primary application for high intensity discharge (HID) lighting, including primarily low-pressure sodium (LPS), high-pressure sodium (HPS), mercury vapor (MV), metal halide (MH), and ceramic metal halide (CMH). All of these lamps are among the most efficient and long life products in the industry and are capable of considerably large amounts of light per lamp. But all have a warm up time, and once operating, they cannot be turned off without needing a cooling off and re-warm up time ("restrike" period). Consequently, HID lamps are typically left "on" all night, whether needed or not. HID lamps are also poor candidates for dimming, as the result is poor performance, lower energy efficiency, and unwanted color shift.

Sensitivity to power system changes is a problem with HID sources, and for years, additional lighting systems using an instant-on source have been installed coincidentally with HID lamps to ensure safety lighting is provided while HID lamps restrike.

LED lighting, on the other hand, operates on completely different electrical principles. As a result, LED lighting can be turned on and off as needed, multi-level switched in various modules within the same luminaire, and can also be dimmed to meet lighting requirements.

The primary and historical reasons for using HID are energy efficiency and lamp life. All current HID lamps (HPS, LPS, MH and CMH) can generate over 100 lumens per watt and can have lamp life in excess of 20,000 hours (roughly 4-5 years assuming all night use). Until recently, LED lighting, which can have lamp life in excess of 50,000 hours, lacked the efficacy and optical efficiency to compete. But that is no longer the case. System efficacy of LED now approaches or exceeds 100 lumens per watt while maintaining all of the desirable characteristics of lamp life, including instant starting and dimming. Moreover, optical efficiency (see Mitigation Strategy #2) requires fewer net lumens of LED to illuminate the same area as compared to an HID source.

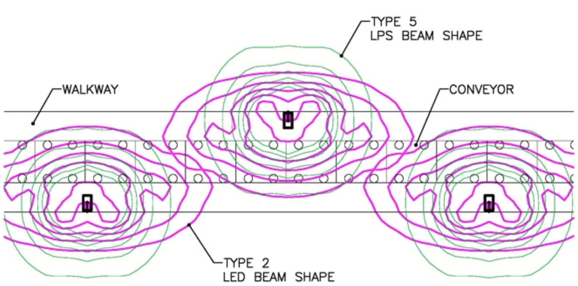
Mitigation Strategy #2: Fitted Target Efficacy

The second mitigation strategy will be to employ FTE to reduce total site lumens without compromising lighting performance, human visual performance, safety or security.

All conventional HID lamps are gross sources that generally emit light in a spherical distribution. Conventional luminaires use refractors, reflectors, lensing and/or shields to redirect light toward the intended area of illumination. For outdoor lighting, the effectiveness of this redirecting effort is not only critical for efficiently illuminating the target, but also for preventing wasted/spilled light from being emitted into the sky and onto nearby land and buildings. The principle of "full cut off" is based upon luminaire designs that prevent any light from being emitted above the horizontal plane. Below the horizontal plane, light from conventional lamps is distributed somewhat ineffectively, with a considerable amount of light not striking the task area and being wasted on the site. All light is eventually reflected upward by the site, especially from light colored rock and concrete. Thus any unneeded light creates excess light pollution even if originally aimed downward.

Recognizing the potential for significant improvements in the optical efficiency of LED lighting systems, the US Department of Energy (DOE) devised a new system for addressing the application efficiency of lighting systems. It is called Fitted Target Efficacy (FTE)[vii] in which the performance characteristics of lighting systems can be most accurately compared. In general, systems with higher FTE use light and energy more effectively than those with lower FTE. The result is fewer lumens needed to produce the same task light level. In most cases, properly applied LED lighting systems have higher FTE than conventional lamps and legacy light sources.

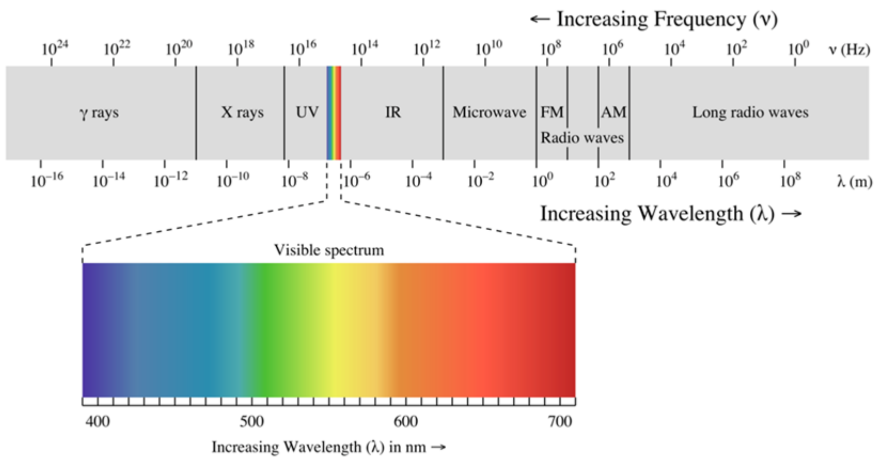
Illustration 1 below shows an example of the FTE concept. This illustration compares a conventional LPS light source with "Type 5" symmetrical optics (as included in the DEIS Lighting Plan) versus a high performance LED system with "Type 2" optics currently being evaluated for the conveyor system at Rosemont. The LED Type 2 optics more closely match the shape of the conveyor and walkway task target areas, while the LPS Type 5 optics emit a significant amount of lumens that miss the target area. It is intended that LED luminaires with custom beam shapes that closely follow specific task area dimensions will be specified and installed at the site. This strategy will also be applied to portable light plant assemblies.



Ill. 1, Plan View of Conveyor Segment

Mitigation Strategy #3: Spectral Tuning and Management

Light consists of a spectrum of electromagnetic radiation with wavelengths between 380 nanometers (indigo blue) and 780 nanometers (burgundy red). All living organisms are affected by light in some way, but different parts of the spectrum have different impacts on beings. In astronomy, the different wavelengths carry considerable information that can be used to gather astronomical information. (*See illustration 2 image Wikipedia*).

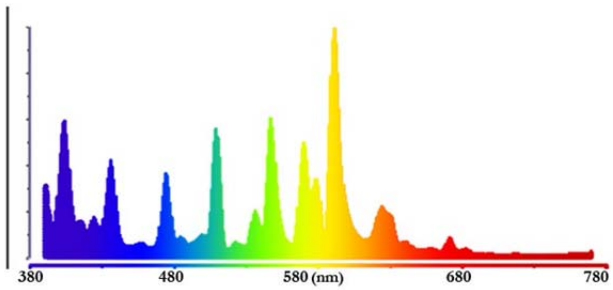


Ill. 2

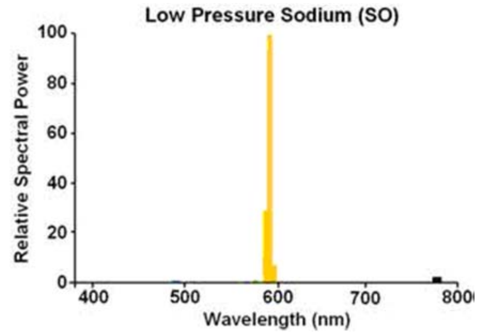
In practice, wavelengths of 500 nanometers and shorter (blue and green) are of concern for several reasons[viii], including

- Atmospheric scattering is increased, the primary cause of light pollution and negative effects upon astronomical observations;
- Visual attraction of insects and potential attraction of their predators; and
- Inappropriate stimulation of endocrine system and daytime hormones in animals and humans.

The human visual system works within the entire spectrum. A metal halide lamp, for example, produces white light thereby emitting including almost every color as shown in Illustration 3 below. LPS lighting, on the other hand, is monochromatic, with virtually all of its light emitted around 590 nanometers per Illustration 4. Still, LPS provides adequate lighting for general nighttime human activity, although there is no color vision.



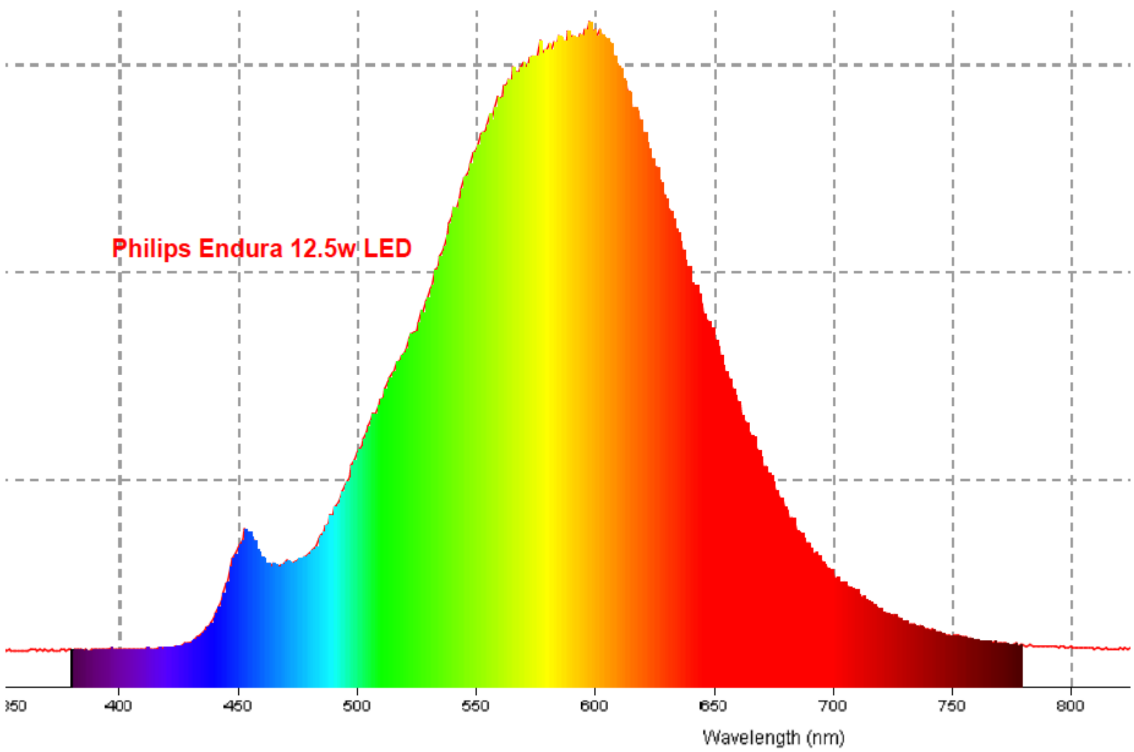
Ill. 3



Ill. 4

(Images from (l) HID Hut and (r) Wikipedia)

Solid-state lighting (LED) lamps can also be designed to produce white light. A "typical" white LED complying with the 2012 PCOLC limit of 3500K-color temperature has the following spectrum (*Illustration 5*):



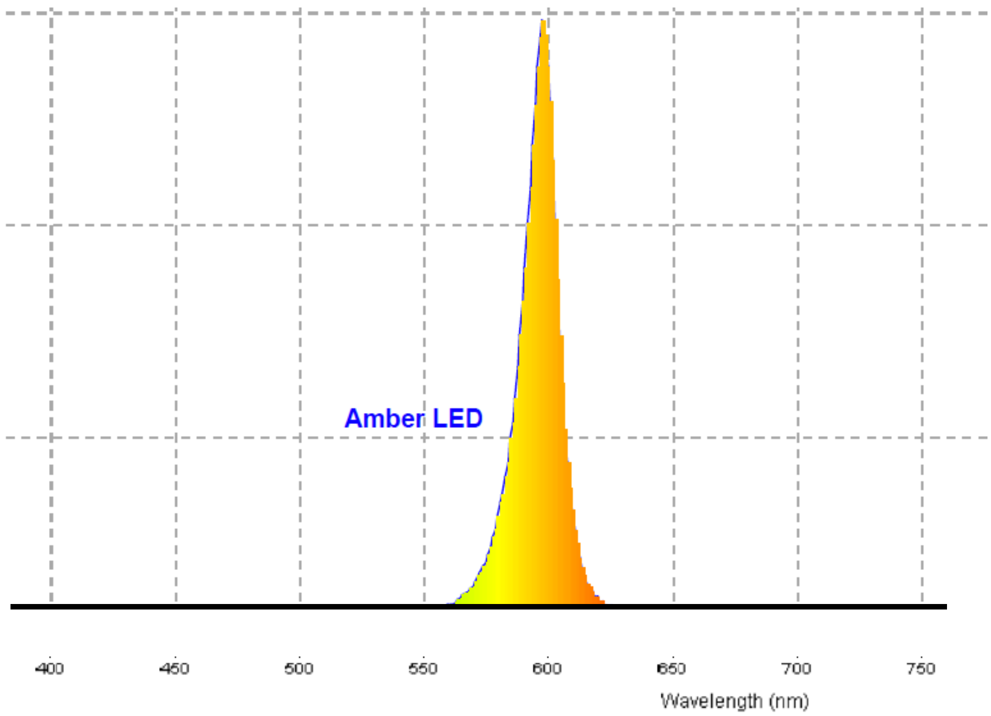
Ill. 5

Commercially available 12.5 watt 3500K screw-in LED lamp
(Spectral graph as measured by Monrad Engineering staff)

The technology of LED permits "spectral tuning", and specific choices of radiation can be achieved for application purposes. For the Rosemont Project, two such specific light sources will constitute most of the lighting: Narrow Band Amber and Filtered White LED.

Narrow Band Amber LED (ALED)

The intent of LPS lighting is to limit the spectrum to a few wavelengths in a narrow "band" of radiation, thus permitting astronomic filtration and clear view of the rest of the spectrum. Additionally, LPS is preferred because the 590 nm band (yellow-orange) causes less Rayleigh scattering and associated light pollution. While not ideal for human scotopic vision, LPS has long been accepted as a suitable outdoor lighting system. ALED creates a spectrum very similar to LPS. Refer to spectral graph in Illustration 6 below. Astronomers appear to be pleased with this development, to the extent that the use of ALED has recently been approved as an equivalent to LPS in Flagstaff, AZ. The Flagstaff outdoor lighting code is very similar to (if not more restrictive than) the PCOLC[ix].



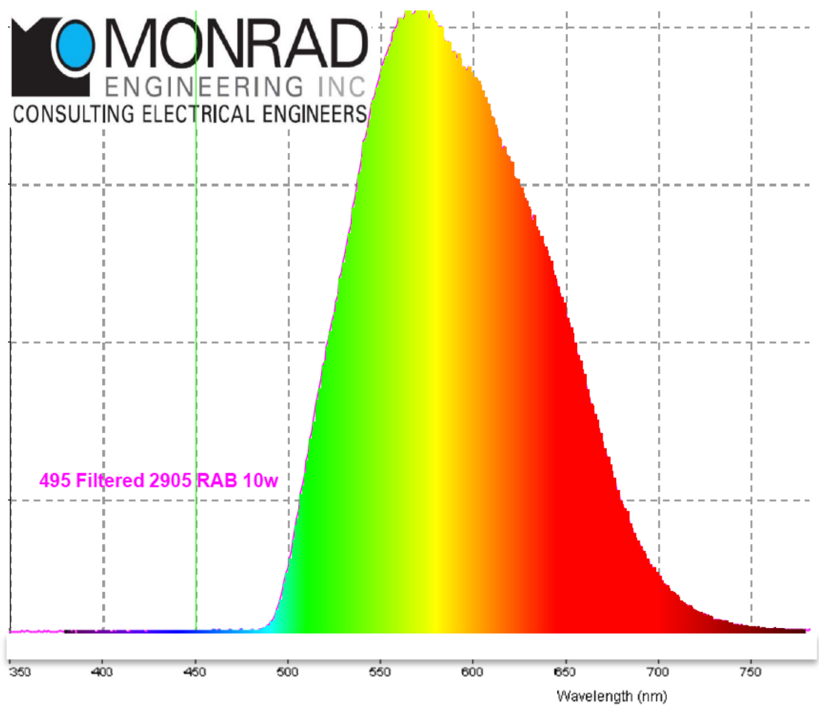
Narrow Band Amber LED luminaire
(Spectral graph as measured by Monrad Engineering staff)
Ill. 6

The technical advantages of LED lighting – instant on and off, dimming and long life – make the use of ALED ideal for the Project. The selection of ALED will permit better lumen package selection, beam shaping and/or dynamic control for area lighting, roadway conflict points and other applications where color discrimination is not important.

Filtered White LED (FLED)

In order to reduce short wavelength emissions without compromising moderate color discrimination and human night vision, in-house mockups have been successfully conducted with 3000K and 3500K white LED with an optical grade yellow filter. Effectively eliminating optical radiation at all wavelengths less than 495 nanometers (See Illustration 7), this FLED lighting system approaches the appearance and color rendering of dimmed incandescent lamps while permitting all of the dynamic control and lamp life benefits of LED.

Designing such luminaires is relatively easy. In many cases, replacing the normal protective lens with a filtering lens is all that is needed. In more complex systems where individual LED devices have micro optics, the optical system can have its own filter.



Ill. 7

2905K LED luminaire with Hoya 495nm long-pass optical glass filter (Spectral graph as measured by Monrad Engineering staff)

In summary, the change from legacy HID sources described in the 2011 DEIS Lighting Plan to selected LED sources is a principal part of the mitigation strategy. LED sources are better tailored to the lighting tasks as they can be specifically designed to reduce or eliminate over lighting. Since a significant portion of the lighting at the Rosemont Project will need to have color rendering, spectral control will reduce the amount of light pollution, including atmospheric scattering effects as compared to any other color rendering light source that would ordinarily be used.

Mitigation Strategy #4: Lumen Package Optimization

In applications where large areas are lighted with heavy-duty lighting equipment, the lamp wattage and associated lumen package increments of HID lighting play a major role in typical overlighting practices. In the case of the LPS and HPS lamps used in the DEIS Lighting Plan for the Rosemont Project, the following illustration shows the limited number of standard wattage increments:

Standard LPS and HPS Lamp Wattage Increments		
LPS		**HPS**
18		35
35		50
55		70
90		100
135		150
180		250
		400
		1000

Ill. 8

Over the last few years, lamp manufacturers have introduced a number of in-between wattage lamps to improve the match between lamp and application, but the increase in complexity, including different ballasts, sockets, etc., has been a deterrent.

In comparison, LED lighting systems are comprised of a few or many independent solid-state light sources. Each unit is between 1 and 3 watts, and each one can be aimed and shielded separately. This process lends itself to fitted targeted efficacy. Moreover, it permits only the minimum necessary number of LED devices to meet the desired lumen package to suit the task. LED modules may also be scaled upward in quantity to accommodate large lumen package requirements associated with high task illuminance levels or large area lighting needs.

The process of FTE and superior optical control can also be applied to HID sources, and when engineered correctly, can result in superior performance. For instance, the University of Arizona stadium was recently relighted with a new HID lighting system using state of the art optics to replace a 40 year old lighting system. While light levels on the field were increased by 40%, the overall energy use of the system was reduced by 30% and the amount of measurable off-site glare created by the stadium lighting was reduced by over 70%.

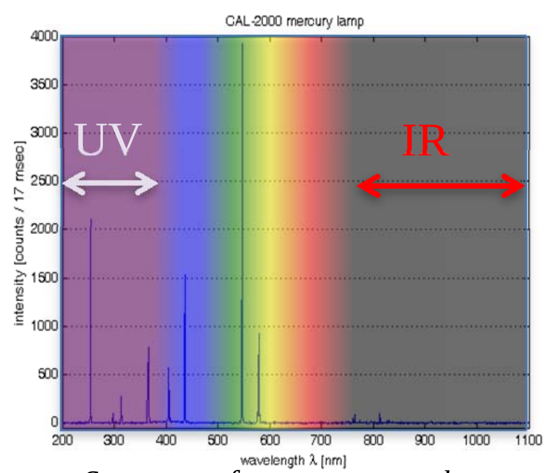
Mitigation Strategy #5: Known Habitat Considerations

The control of obtrusive light is of special concern since even low levels of light can interrupt natural circadian cycles and other behavior. This section is primarily concerned with the impact of light pollution on moths, insects in general, and bats.

Moths are an important element in the regional native pollinator ecosystem /plant life cycle and are prevalent in the region. In general, moths and other insects often exhibit flight-to-light behavior. In some species, this behavior modification affects feeding, mating, breeding and other observable change. In other species, there is an apparent circadian shift that changes behavior phase[x]. For instance, moths may lose essential defensive behaviors when near artificial light, making them vulnerable to predators; billions of moths and other nocturnal insects are killed each year at lights[xi].

In addition to moth behavior change affecting feeding and reproduction, the collection of moths about a light source is also an attraction for bats. Bat rhythms are also naturally affected by light and spectrum, but in this particular coincidence of species and light, concentrations of insects could introduce concentrations of bats at the site that may not be in the best interests of the bats. Although the Lesser Long-nosed bat, well known in the region, is a nighttime nectar feeder, there are likely other species of native bats (and insect predating birds) that may be negatively affected by unusual concentrations of insects during the night.

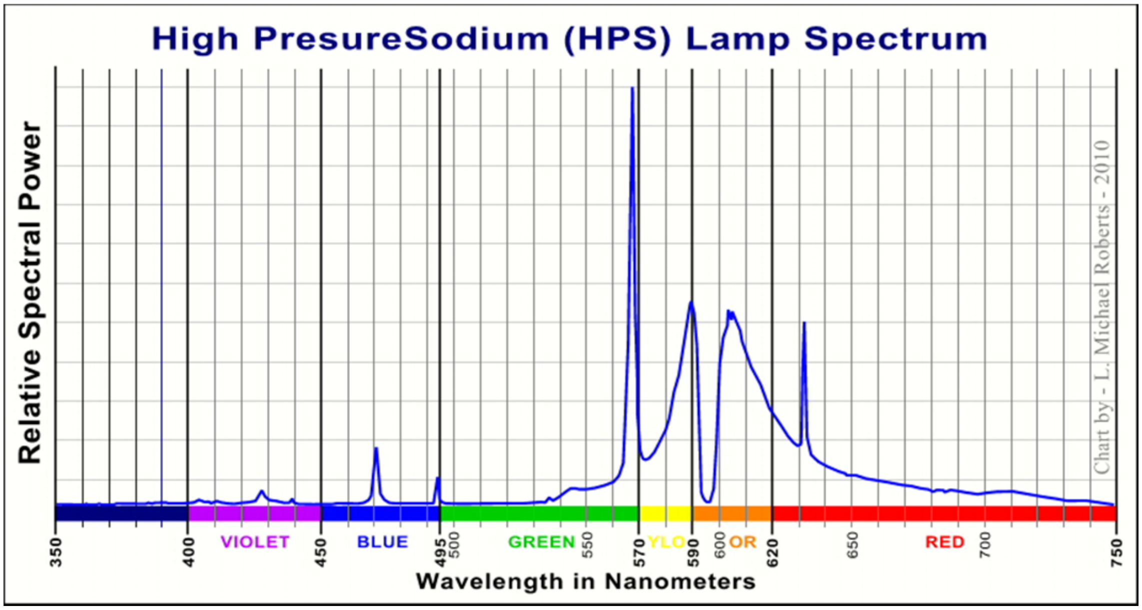
The spectrum of light sources is critical in determining the attraction of moths. In a 2006 compendium[xii], scientists report on experiments in which moths were attracted by various lighting systems and then counted. Among conventional HID lighting systems, the mercury vapor (MV) lamp (*Ill. 9 right*) attracts moths about 25 times more than 'normal' night sky conditions. MV relies on green-yellow, yellow and blue radiation to produce visible light while exhibiting considerable UV radiation between 250 and 400 nm and short wave blue at 405 and 420 nm. For the purposes of this report, it is assumed that metal halide (MH) lamp (*Ill. 3 spectral curve*) exhibits essentially the same UV as the mercury vapor lamp.



Spectrum of mercury vapor lamp typically used for streetlighting.

The Mostly Color Channel, June 2007.
Ill. 9

HPS lamps, on the other hand, attracted about 55% fewer moths than mercury vapor lamps. The high-pressure sodium lamp (*Ill. 10 spectral curve, below*) exhibits comparatively small amounts of short wavelength light (UV, violet and blue). However, it is still enough to attract moths and insects, although in much smaller amounts.



(From Wikipedia under GNU license)

Ill. 10

When fitted with a UV filter, a mercury vapor lamp attracted only about 10% of the moths attracted by the unfiltered mercury vapor lamp. This is an important finding. The UV and short wave blue radiation of the high-pressure sodium lamp, while quite limited compared to the standard mercury vapor, nonetheless attracted 4 times as many moths as the UV filtered mercury vapor lamp. This strongly suggests that the complete elimination of UV and very short wave visible light would almost totally mitigate the effects of light on the night environment of native moths, and probably, most other insects.

Additionally the proposed lighting design for the Rosemont Project will employ either narrow band amber ALED (*Ill. 6*) or 500nm filtered LED (*Ill. 7)*, both of which generate no blue, violet or UV light. Like the filtered mercury vapor lamp reported above, it is presumed that the filtered LED will have significantly fewer insect attraction effects than would the HPS light sources assumed in the DEIS Lighting Plan. An attraction ratio of less than 3 times normal night activity is estimated. Accordingly, there would likely be less impact due to atypical "aerial" and "fallen-to the ground" based moth predation by native bats[xiii]. The consensus of researchers is that, while lighting may alter the hunter-prey environment of moths and bats and perhaps benefit one or the other, in the long run unfiltered light would probably create "… conservation problems for both (species)…"[xiv]

Mitigation Strategy #6: Improved Lighting for Vehicular Lighting

Vehicular mining equipment typically utilizes a mix of HID, halogen, and /or xenon light sources for task lighting and warning lighting systems. Lumen packages per fixture can range from hundreds of lumens to over 100,000 lumens and multiple light sources are generally present on any given piece of equipment.

Equipment mounted HID lighting fixtures usually consist of flood light fixtures with generic optical systems. Glare control and light pollution reduction considerations are usually secondary to the needs of the operator for task lighting in his various fields of view.

Based upon conventional heavy mining equipment lighting technologies, the DEIS Lighting Plan included an allowance of over 3 million lumens of equipment mounted HID lighting within the mine pit with an uplight factor of 30%. Although equipment mounted lighting systems are not regulated by the Pima County Outdoor Lighting Code (PCOLC), the combination of the total lumen emissions and the Rayleigh scattering associated with the significant uplight components are inconsistent with the goals of the PCOLC.

In the interest of longer life spans for equipment mounted lighting systems, equipment manufacturers are now offering LED lighting options in lieu of conventional xenon, halogen and even HID sources. Given the modular nature of LED systems, lumen packages can be scaled up (or down) to meet the variety of task lighting applications that may be required across the gamut of equipment mounted systems. Coincident with the introduction of LED technology into these applications is the highly desirable aspect of precise beam control.

The specification of LED lighting with precise beam spreads to suit the task lighting needs for all equipment mounted lighting systems is proposed to minimize stray light, place more light on the task target, reduce total lumens emitted into the environment, minimize off-site spill light, and greatly curtail the negative effects upon astronomical interests from the upward scattering of light.

Summary of Mitigation Accomplishments

There will be five specific accomplishments of the mitigation strategies:

Total Lumen Reduction

A significantly more efficient lighting design strategy than that proposed in the 2011 DEIS Lighting Plan is recommended. An assessment relative to compliance with the intent of the currently adopted 2012 Pima County Outdoor Lighting Code (PCOLC) is presented:

Recap A – Utilize developed site acreage per PCOLC and summarize all lighting sources (including equipment mounted task lighting system lumens that are not specifically regulated by the PCOLC):

> Developed Site: 500 acres
>
> Total site lumens (Option 3, 12,500 lumens per acre of any light source x 500 acres): 6.25 million lumens allowed, 5.79 million proposed.
>
> Total site limit on unshielded lighting: None allowed, none proposed for fixed lighting systems. Equipment mounted task lighting systems and portable task lighting systems will use spectrally tuned high performance optical systems with sharp cutoff beam shaping to minimize stray light emissions and lumen packages will be sized to suit the task needs.

Lighting Spectrum Control

Light pollution is caused more by short wavelength light (blues and greens) than long wavelength light (reds and yellows) due to Rayleigh scattering in the atmosphere. Among HID lamps, designers can choose narrow band LED, astronomy friendly LPS or among a variety of wide band, astronomy un-friendly lamps. Moreover, environmental impacts on most flora and fauna are known to skew toward the short wavelengths of less than 500 nanometers.

These mitigation measures include the use of narrow band amber LED (ALED) in lieu of LPS for the reasons described previously. Moreover, non-LPS task and ambient lighting systems will be restricted to solid-state LED lighting using nominal 500 nanometers short wavelength filtering (FLED) with virtually no light emissions at wavelengths shorter than 500 nanometers. This strategy will reduce the Project environmental and astronomical impact compared to high-pressure sodium, metal halide, fluorescent and all other conventional non-LPS lighting sources that may have otherwise been used on this site per Table 401.1 of the PCOLC.

Full Cut Off Optical Systems

The prescription of full cutoff luminaires for all fixed lighting will be coupled with the specification of FLED and ALED light sources.

The excellent beam control afforded by currently available LED optical systems that are suitable for the portable task lighting mining applications will minimize direct uplight components from the site, despite the transient nature of portable work light plant usage. The specified equipment will promote precise physical aiming of the portable luminaires and Rosemont staff will be trained on the proper application of the work light plants. The beam shapes will be well defined so as to provide positive feedback to the users during the task lighting aiming process.

Likewise, all equipment mounted task lighting is proposed to utilize similar high-performance sharp-cutoff optical assemblies and LED technologies to efficiently target task areas while minimizing wasteful upward light components. Due to the transient nature of the equipment mounted lighting and the mobile mining tasks, some fraction of upward directed light is anticipated at various times. However, 30% uplight factor currently reported in the Draft Environmental Impact Statement skyglow model warrants reconsideration. The lumen summary and associated uplight factors included within the Appendix Recap ‘A’ of this document should be utilized for updating of the skyglow model.

It is noted that direct uplight components from numerous portable and equipment mounted task lighting systems will be curtailed by the evolution of the mine pit excavation and placement of surrounding materials by the end of the first year of operation.

Baseline Data Monitoring

Collection of quantitative data of existing night sky conditions may allow for the ongoing monitoring of night sky quality in the region and to document the effects of the lighting systems within the Project and other regional developments as they may occur[xv].

Protocol for the data collection is described as follows:

- During October and November of 2011, STEM Laboratory, Inc., under contract to Monrad Engineering, Inc. (both of Tucson, Arizona), conducted a unique and comprehensive sky brightness survey of an approximately 250 square mile area around the Santa Rita Mountains of southern Arizona, centered roughly on the Rosemont Project site. The intent of this survey was to serve as a baseline of artificial lighting and sky brightness in the region against which future surveys could be compared, thus being able to characterize and quantify changes associated with continuing development in the area.

Three modes of data collection were used: mobile ground observations, airborne mapping, and static ground observations [Craine and Craine 2012]. The first two techniques provided sky brightness (zenith direction) single channel photometry measures. These mobile measurements were made every few seconds while the car or airplane carrying the photometers travelled along a prescribed path. The resulting grids of measures were used to create three dimensional maps of sky brightness of the region surveyed. The three dimensions were latitude, longitude, and sky brightness.

- The mobile ground measurements were made by attaching a STEM SBM Model 4 sky brightness meter to the roof of a vehicle and driving roads roughly surrounding the survey area: I-10 and Sahuarita Road to the north, State Route 83 to the east, and I-19 to the west. These data are used to tie the airborne observations to the sky brightness values obtained from the ground.

- The airborne measurements were made by mounting a STEM LANM Model 5 dual channel photometer to the wing of an airplane and flying a dense grid of flight paths over the survey area. The photometer collected up-looking data comparable to the mobile ground data, but with a much higher fill factor in the survey area. In addition, the airborne photometer provided luminance measures looking down from the airplane along the flight path, providing insight to light sources on the ground. The airborne data were used to generate isophotal maps of the sky brightness distribution throughout the entire survey region.

- The ground static data were collected at five specific sites called out in the Draft Environmental Impact Statement (DEIS) for the Rosemont area. At each of these sites, an all sky, CCD camera made calibrated digital images of the sky dome. These images capture the sky brightness at the site of interest as seen at all altitude and azimuth angles, and can be used to produce differential photometry by comparing these baseline observations to subsequent complementary data sets.

- Temporal follow-up observations, using all of the techniques employed in the collection of these baseline data, will allow accurate measurement of overall changes in sky brightness over the course of time. Because a comparatively large area is surveyed, it will be possible to better understand contributions to the sky brightness light budget arising not just from a single project, but rather all of the development in the survey region.

Lighting "On Time" Reduction

All outdoor lighting codes, including the PCOLC, assume the preponderance of lighting is on all night. This is because of the technical limitations of HID lighting upon which all codes are based. However, state-of-the-art solid-state lighting allows lighting to be dimmed or turned off while conventional HID lighting would typically be left on from dusk to dawn. "Dynamic" or "Adaptive" lighting, using motion sensing and other control initiating methods, can reduce the amount of lighting that is actually on and fully illuminated by more than 50%. While there is no statistical data to support any claim of resultant lighting use reduction and energy savings, rough estimates of at least 30% are often accomplished. These potential reductions are not addressed in the PCOLC and, if captured via dynamic or adaptive controls, would be in addition to the site lumen density reductions noted in this report.

Appendix

See attached "Recap A" for site lumen density assessments, spectral content, and estimated uplighting components.

RECAP 'A'

Revision 1 - June 18, 2012

LUMENS PER ACRE TABLE - All Inclusive: Incorporates Developed Site Acreage With All Fixed, Portable and Equipment Mounted Task Lighting Sources

500 NM FILTERED LED (FLED)

	Total Lumens
In-Plant Road & Primary Access Road Conflict Points (Only)	109,400
Ore Processing	1,976,730
Dry Stack Conveyor	1,541,760
Mine Pit	936,373
Leach Pads	105,538

590 NM AMBER LED (ALED)

In-Plant Road & Primary Access Road Conflict Points (Only)	109,400
Ore Processing	629,050
Dry Stack Conveyor	382,900
Mine Pit	0
Leach Pads	0

	Total Developed Acreage	500
	Total Initial Lumens	5,791,151
	Lumens per Acre	11,582
(General	Code Limit	12,500
Note 1)	Percentage of Limit	92.7%

Lamp Type	Total Lumens	Lumens/ Acre
FLED	4,669,801	9,340
ALED	1,121,350	2,243

KEYNOTES:

1. ORE PROCESSING SUMMARY
   LUMENS FLED 1,976,730
   LUMENS ALED 629,050
   (INCLUDES 100,000 LUMENS OF FLED PORTABLE WORK LIGHTS, MAXIMUM 5% DIRECT UPLIGHT FACTOR AT 90 DEGREES TO 100 DEGREES)
2. MINE PIT SUMMARY
   LUMENS FLED 936,373
   LUMENS ALED 0
   (ALL MINE PIT LUMENS ARE FLED EQUIPMENT MOUNTED, MAXIMUM COMPOSITE 7.5% DIRECT UPLIGHT FACTOR AT 90 DEGREES TO 110 DEGREES NOMINAL)
3. In-Plant Roads & Primary Access Road Conflict Points
   LUMENS FLED 109,400
   LUMENS ALED 109,400
4. PRIMARY ACCESS ROADS - NO CONTINUOUS LIGHTING SYSTEMS
5. LEACH PAD SUMMARY
   LUMENS FLED 105,538
   LUMENS ALED 0
   (MAXIMUM 5% DIRECT UPLIGHT FACTOR AT 90 DEGREES TO 100 DEGREES)
6. DRY STACK CONVEYOR SUMMARY
   LUMENS FLED 1,541,760
   LUMENS ALED 382,900

GENERAL NOTES

1. REFER TO 'LUMENS PER ACRE TABLE' FOR PIMA COUNTY OUTDOOR LIGHTING CODE (OLC) COMPLIANCE CALCULATION, OPTION 3
2. BASIS FOR LUMENS PER ACRE CALCULATION:

   TOTAL DEVELOPED ACREAGE = 500

End Notes

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[i] **An Assessment of the Impact of Growth on the Dark Skies of Pima County**, International Dark-Sky Association, October 6, 2006
[ii] **Astronomy and Outdoor Lighting**, A.A. Hoag and A.R. Peterson, April 1974
[iii] Pima County Outdoor Lighting Code, 2006
[iv] Pima County Outdoor Lighting Code, 2012
[v] http://www.rosemontcopper.com/mining_act_1872.html
[vi] Luginbuhl, Walker and Wainscoat, *Lighting and Astronomy*, **Physics Today,** December 2009
[vii] Overview and Usage of the Fitted Target Efficacy (FTE) Performance Metric, http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/fte_performance_metric.pdf
[viii] **Visibility, Environmental, and Astronomical Issues Associated with Blue-Rich White Outdoor Lighting**, International Dark Sky Association, May 4, 2010
[ix] Flagstaff Zoning Code, 2011, http://flagstaff.az.gov/documentview.aspx?did=14707
[x] **Batty About Bats**, University of Arizona pub 1456, November 2008
[xi] *National Geographic Today*, April 17, 2003
[xii] **The Ecological Consequences of Artificial Night Lighting**, ed. Katherine Rich and Travis Longcore, Island Press, 2006
[xiii] Ibid
[xiv] Ibid
[xv] Craine, ER and Craine, BL "STEM Laboratory Sky Brightness/Light-at-Night Projects" STEM Laboratory Annual Report 2011, [Tucson, AZ], STEM Tech Rep-12-0101, 25p (2012).