Light Up the Visual Factory
Lighting Solutions for Lean Manufacturing
Increase Efficiency, Reduce Costs & Improve Quality
The Visual Factory

Creating a Visual Factory using appropriate lighting is an often overlooked way to decrease waste, increase productivity, increase product quality and improve employee satisfaction in your manufacturing environment. Proper lighting makes all work tasks easier. From an occupational health and safety standpoint, proper lighting can reduce worker fatigue and headaches. Light can also highlight moving machinery and other safety hazards. Maximizing the effectiveness and efficiency of factory lighting can:

- Reduce costs
- Shorten cycle times
- Improve product quality
- Reduce power budget/carbon footprint
- Contribute to an ergonomic work environment

Boost Worker Productivity

Increase Visual Task Performance

Data has shown that proper lighting can improve the performance of visual tasks, which can decrease assembly cycle time. The speed and accuracy of recognizing objects increases with the level of illumination as shown in Figure 1. The performance score is also dependent on the type of task—small, similar objects are more difficult to accurately handle than larger, dissimilar parts.


Improve Worker Productivity

In a Cornell University study conducted at Xerox Corporation in Webster, NY, researchers investigated the effect of poor lighting on worker productivity. When inappropriate lighting was used, 24% of the workers reported they lost on average 15 minutes a day of productive work time. This adds up to approximately one week lost per year.

Improve Worker Mood and Alertness

Bright lights have been shown to increase alertness, improve cognitive function, and reduce fatigue in workplace environments. A 2008 study published in the Journal of the American Medical Association investigated the effect of lighting on the mood of elderly residents at a group care facility. Subjects exposed to bright light (1000 lux) reduced depressive symptoms by 19%.

Protect Worker Health & Safety

Many countries in the world have occupational health and safety groups dedicated to protecting worker safety. In the US, the Federal Occupational Safety and Health Administration (OSHA) has developed lighting safety standards which detail minimum lighting levels for general work areas.

<table>
<thead>
<tr>
<th>Illumination Intensity (lux)</th>
<th>Area of Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>General construction area lighting.</td>
</tr>
<tr>
<td>54</td>
<td>Indoors: warehouses, corridors, hallways</td>
</tr>
<tr>
<td>54</td>
<td>Tunnels, shafts, general underground work areas</td>
</tr>
<tr>
<td>108</td>
<td>General construction plant and shops (e.g., batch plants, screening plants, mechanical and electrical equipment rooms, carpenter shops, rigging lofts and active store rooms, mess halls, and indoor toilets and workrooms.</td>
</tr>
<tr>
<td>323</td>
<td>First aid stations, infirmaries, and offices.</td>
</tr>
</tbody>
</table>

Create an Ergonomic Work Environment

Proper lighting can improve worker comfort in all types of work environments. Ergonomic workplaces create optimal working conditions within a work environment. The level and type of light used affects worker comfort and job satisfaction levels.

Improve Product Quality

Light up the Gemba

Gemba is the Japanese term for “the real place”—the place where value is created, i.e., the manufacturing floor. A core component of lean manufacturing, the concept is that if problems are visible, actionable improvement can be taken. “Observing the gemba”, is the first step in identifying both product defects and inadequate processes which need improvement. Analytical observation cannot happen in the dark; it requires proper illumination. Oftentimes manufacturing engineers will go to great lengths to optimize fixtures and streamline work flows while treating illumination as an afterthought. The best way to avoid this mistake is to consider the required lux levels for the task or process at hand.

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Best Practices for Human Visual Inspection

Human visual inspection is used in a variety of industries as a formal quality control step. Visual inspection also occurs routinely in workstations and lean assembly cells where workers need to detect part defects during assembly. Appropriate lighting improves the ability of the human eye to detect small defects. A 2010 article in AAPS PharmSciTech showed a 13% improvement in small defect detection when bright light was used.

<table>
<thead>
<tr>
<th>Lighting Level (Lux)</th>
<th>Background Color</th>
<th>Minimum Defect Size (µm)</th>
<th>Detection Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>5900</td>
<td>Grey</td>
<td>150</td>
<td>95%</td>
</tr>
<tr>
<td>2150-4000</td>
<td>Black/White</td>
<td>165</td>
<td>83%</td>
</tr>
</tbody>
</table>

Table 2. Detection frequency as a function of lighting levels

The European Pharmacopoeia Method 2.9.20 recommends lighting levels be maintained between 2000 lux and 3750 lux for visual inspection of particulate contamination—although higher values are preferable for colored glass and plastic containers.

Reduce Costs

Banner LED lighting has a low cost of ownership, requires low/no maintenance, and is highly energy efficient—reducing energy consumption. When lighting design is considered; appropriate, efficient lighting can be used where needed, and extraneous light can be eliminated—another way to reduce waste and cost.

Low Cost of Ownership

Banner LED lights will illuminate areas for up to 50,000 hours. Depending on usage that translates into 5-10 years or more without requiring maintenance—resulting in a low cost of ownership and a higher return on investment than fluorescent or incandescent lighting.

Reduced Power Budget

Lighting accounts for 5 to 10% of total energy use worldwide. In homes and offices from 20 to 50 percent of total energy consumed is due to lighting. Companies across the globe are tightening energy consumption regulations. In 2006, the European Union (EU) pledged to cut its annual consumption of energy by 20% by 2020. LED lights have been advocated by some experts as the newest and best environmental lighting technology.

Types of Lighting

- **Incandescence** – The incandescent light is the 60 Watt light bulb that many of us grew up with. Illumination is achieved by heating a filament wire to a high temperature until it glows.

- **Fluorescence** – Many commercial buildings still use flickering, bright white fluorescent tube lights. In a fluorescent light, mercury atoms are excited, producing short-wave ultraviolet light which hits a phosphor coating on the inside of the tube, converting the UV light to visible light.

- **LED** – Most industry experts see LED lighting as the dominant lighting technology in the future. LEDs are a semiconductor based light source. When a light-emitting-diode (LED) is switched on, the current is directly released in the form of photons—visible light.

The Problem with Incandescence

Incandescent lights are notoriously inefficient. Most varieties convert less than 10% of the inputted energy into visible light; the majority of the energy is converted into heat. In 2012 the United States Congress implemented a legislative ban on the use of 100W incandescent light bulbs. Lower Watt versions will follow, and many European and Asian countries are enacting similar legislation.

The Problem with Fluorescence

Fluorescent lighting is considerably more efficient than incandescent lighting; however fragile housings (with potential mercury exposure), recycling requirements, UV emission and shorter lifetimes versus LED options (more frequent replacement), have consumers looking for a better alternative.

- Fragile Housings
- Recycling Required
- Health and Safety Issues
- Ultraviolet Emission
- Ballast Inefficiency
- Limited life
- Flicker or Hum Problems (older models)
LEDs—The Industrial Lighting Choice for Today & Tomorrow

LED technology is being embraced as the industrial lighting solution. LED lights offer very long service life, extreme vibration resistance, and can be used to brightly light small areas that were previously difficult to light properly with fluorescent options.

- Ultra-long lifetimes (5-10+ years)
- Energy efficient/low power consumption
- Low/no maintenance
- Shatterproof and vibration resistant
- ‘Green Solution’—no disposal of toxic mercury
- Lack of UV or IR emissions

Energy Efficiency

The efficacy of a light source is defined as how many watts are used to generate brightness. The units of efficacy are Lumens/Watt. Higher numbers are more energy efficient. A lamp is a light bulb or bare fluorescent tube. A luminaire is a lighting fixture which contains a lamp and the electronics necessary to light the fixture. In general, LED luminaires are more energy efficient than both standard incandescent and compact fluorescent light fixtures. At first glance, CFL tubes may appear more energy efficient, however when the necessary ballast is used, they become significantly less efficient.

Ultra-long Life

Banner LED lights can last over 50 times longer than incandescent lights. Over the course of the LED lifetime, the tube fluorescent light may need to be replaced and disposed of up to 5 times (possibly more if the fluorescent light is turned on and off frequently). LED lighting saves on replacement part costs, disposal cost and maintenance labor costs.

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Lamp Efficacy</th>
<th>Luminaire Efficacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescence (Std. Tungsten)</td>
<td>8-13</td>
<td>8-13</td>
</tr>
<tr>
<td>18-32W Tube CFL</td>
<td>69-75</td>
<td>34-41</td>
</tr>
<tr>
<td>LED</td>
<td>53.0</td>
<td>53.0</td>
</tr>
</tbody>
</table>


How Much Light Is Enough?

Lumens vs. Watts?

A Watt is a measure of the amount of energy per unit time. For lighting, the Watt is a measure of the amount of energy needed to power a light. A Lumen is a measure of the amount of light the human eye detects. The Watt is the input, the Lumen is the perceived outputted brightness.

Many people are unfamiliar with the Lumen metric. The left side of Figure 3 shows the amount of Lumens produced by a typical incandescent light fixture, the right side shows the amount of light produced by a typical T8 fluorescent tube fixture.

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Avg. Life (hrs)</th>
<th>Avg. Life 24hrs/day (years)</th>
<th>Avg. Life 12hrs/day (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescence</td>
<td>1,000</td>
<td>0.11</td>
<td>0.22</td>
</tr>
<tr>
<td>Tube Fluorescent</td>
<td>10,000 – 30,000</td>
<td>1.14 – 3.42</td>
<td>2.28 – 6.84</td>
</tr>
<tr>
<td>LED</td>
<td>50,000</td>
<td>5.7</td>
<td>11.4</td>
</tr>
</tbody>
</table>

Table 4. Average lifetime of different light sources. Actual values will vary significantly depending on manufacturer and model number.

Why Banner LED Lights?

Banner Engineering is a worldwide leader in industrial automation solutions. Our design engineers understand the unique lighting requirements in industrial settings, and our impressive staff of application engineers and sales professionals can provide you the expertise you need to solve your lighting problems.

- Shatterproof, industrial lighting
- Washdown safe, sealed IP69k models
- High quality, attractive housings
- Wide variety of colors, intensities and dimensions
- Wide selection of mounting and electrical connections

--- WE WILL PROVIDE A SOLUTION FOR YOU ---
Illuminance & Lux Levels
Lumens are used to describe the total perceived brightness of a light. Illuminance describes the light density onto a surface and is a measure of light per unit area. The unit of illuminace is the lux (lumens/m²). Illuminance, or the amount of illuminance on the target area is a key parameter for lighting engineering. Lux levels can easily be measured using a lux meter. A few typical lux levels are listed in the chart below.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Lux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear daylight</td>
<td>10,000+</td>
</tr>
<tr>
<td>Overcast daylight</td>
<td>1,000</td>
</tr>
<tr>
<td>Hallway</td>
<td>100</td>
</tr>
<tr>
<td>Twilight</td>
<td>10</td>
</tr>
<tr>
<td>Full moon</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 5. Typical lux levels for common outdoor ambient conditions. Source: IES Handbook.

What Lux Level is Optimal?
The Illumination Engineering Society (IES) recommends illumination levels for hundreds of specific applications in industrial settings. Here are a few common examples.

<table>
<thead>
<tr>
<th>Application</th>
<th>Recommended Lux Ages 25-65</th>
<th>Recommended Lux Ages 65+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warehouse</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Work area</td>
<td>150</td>
<td>300</td>
</tr>
<tr>
<td>General assembly</td>
<td>1,000</td>
<td>2,000</td>
</tr>
<tr>
<td>Detailed assembly</td>
<td>2,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Fine inspection</td>
<td>5,000</td>
<td>10,000</td>
</tr>
</tbody>
</table>

Table 6. Recommended lux levels for general work conditions. Source: IES Handbook.

Note that the recommended lux levels are age dependent. As we age, changes to the eye reduce our ability to efficiently use light. Workers over 65 need about twice as much light for the same application as a younger worker.

Work Area Lighting
The lux level recommended for “work area” is based on having enough light for workers to move in and around work cells. It is likely that this is the lux level the overhead factory lighting was designed to, but it may be an order of magnitude less than what is required for high quality assembly. Additional task lighting or work lighting must be added to all work cells to supplement the standard overhead lighting in order to meet the recommended lux levels.

Angle of Light
A significant difference between an incandescent light bulb or a fluorescent tube and Banner LED lighting is that the LED lighting is directional. A 60 Watt light bulb or a T8 tube emits light in all directions ~360°. However, if a 120° angle LED is used, 2/3 fewer Lumens are needed to create the same level of brightness on a surface.

Luminous Intensity and Candelas
Luminous intensity is the power emitted by a light source in a particular direction. The SI unit of luminous intensity is the candela (lumen/steradian). A steradian is related to the surface area of a sphere in the same way a radian is related to the circumference of a circle. There are ~12.56 steridians in every sphere.

![Diagram of steradian](image)

Figure 5. A steradian is defined as a solid angle for which the ratio of the sphere surface to its radius squared equals 1.

How Much Is Too Much?
Luminance is a measure of the luminous intensity per unit area with SI units of candela per square meter (cd/m²). For indoor lighting, it is generally agreed that luminances higher than 10,000 cd/m² cause visual discomfort.

![Diagram of luminance](image)

Figure 6. Illustration of luminous intensity versus luminance. All of the large squares in the yellow region have equal luminous intensities, however the small blue squares have significantly different luminance levels.

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* International Standard of Units
Use Light Where You Need It

Inverse Square Law
The further away the light source is from the targeted area, the less bright the source light seems. The intensity of light observed from a stable source falls off as the square of the distance from the object. This is known as the inverse square law. If the distance between the light source and the target is doubled, the observed intensity is decreased to \((\frac{1}{2})^2\) or \(\frac{1}{4}\) of the original value. For this reason relying on distant high bay light for all of your industrial illumination needs is extremely inefficient.

How Many Lumens Do I Need to Achieve the Appropriate Lux Level?
The simplest way to roughly estimate the number of lumens needed is to multiply the desired lux level by the lighted area \( (m^2) \).

1. Measure the dimensions of the area to be illuminated.
   \([A = \text{lighted area} \ (m^2)]\)
2. Use Table 6 to determine the optimal lux level for the application.
   \([LL = \text{optimal lux level}]\)
3. Calculate lumens needed at 1 meter, \([L_{1m}]\)
   \[L_{1m} = LL \times A\]

To adjust the estimated lumens needed using the inverse square law, follow the additional step below.

4. Determine how far away the light must be:
   \([d = \text{lamp distance from lighted area}]\)
   The light intensity decreases \(\sim \frac{1}{d^2}\)
5. Calculate approximate lumens needed \([L_A]\)
   \[L_A = LL_{1m} \times d^2\]

The example above assumes a solid angle of 1 steridian (or a beam angle of approximately ~65 degrees). To account for other beam angles:

6. Determine beam angle of the light \([\theta \ - \text{in degrees}]\)
7. Convert beam angle into steridians \([Sr]\)
   \[Sr = 2\pi(1-\cos \frac{\theta}{2})\]
8. Multiple lumens needed at 1 steridian by the number of steridians for the light.
   \[L_f = SR \times L_A\]

Small spots will require less lumens to achieve the same lux level. The size of a spotlight as a function of distance \((d)\) can also be estimated using the beam angle.

\[2 \times d \times \tan(\frac{\theta}{2})\]

The lumen method (also called the zonal cavity method) is a more complex method used to calculate the average illuminance in a room from existing luminaires. Factors considered in the calculation include luminaire efficiency, light fixture spacing, and reflectances in the room.

What Do I Need to Know About Color?
For most industrial applications, the short answer is: not much. Unless color perception has a significant effect upon the work task necessary, the color quality of industrial lighting fixtures is not a critical factor. This is why fluorescent fixtures (which have a reputation for poor color performance) are common in industrial environments.

Color Temperature
The color temperature is a way to characterize the color of a light source. Yellow-red colors are considered warm, and blue-green colors are considered cool. Color temperature is measured in Kelvin (K) temperature. Higher Kelvin temperatures (>5000 K) are considered cool and lower color temperatures (2700–3000 K) are considered warm. Cool light (higher color temperatures) is preferred for visual tasks because it produces higher contrast than warm light. Warm light is more flattering to skin tones and clothing6.

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Color Rendering Index
Different light sources make the color of objects appear differently. The Color Rendition Index (CRI) is a 1–100 scale that was intended to measure a light source's ability to reproduce the colors of various objects in comparison to an ideal or natural light source. In general, higher values are considered more optimal. However, due to how the index is specified, some light sources with lower CRIs actually render color in a fashion which is more aesthetically pleasing. Because of this, many experts are not in favor of CRI as a general lighting parameter, and prefer other, more complicated metrics for color rendering specifications.

LEDs & Color
LED light sources can be developed with a myriad of colors, color temperatures and color rendering indexes. This is one of many advantages of solid-state lighting technology over more conventional techniques. Banner LED lighting offers one of the widest selections of color options in the industry.

Where Can I Use LED Lighting?

Machine/Robotic Cell
Banner’s high quality LED lighting is particularly well suited for machine/robotic cell lighting. Washdown safe & shatterproof housings, IP69k ratings, low voltage draw, and a variety of flexible mounting options make Banner lights the product of choice for these applications.

Enclosure/Panel Lighting
Electrical panels and industrial enclosures are applications where the robust housings, small size and low power draw of Banner’s LED lights prove useful. They provide the necessary illumination for safe and efficient maintenance work inside the enclosures. Easy mounting options and cascadable configurations make installation trouble free.

Worker Lean Cell Assembly
More and more manufacturing environments are moving away from inefficient high bay lighting, and are instead using the power where they need it: at the assembly cell. LED lighting is chosen over fluorescent lighting which needs to be replaced more frequently, and poses a potential worker hazard from shattered glass and exposed mercury if the fluorescent bulb is broken.

Maintenance Lighting
Solid-state LED lighting can provide bright illumination in a tight spot, lighting up nooks and crannies where it is not possible to place conventional light sources. Convenient magnet mounting options create portability—allowing you to have light exactly where you need it.

Mobile Applications
Bright light, robust housings and low power consumption make Banner LED lighting an attractive choice for mobile applications like in-cabin lighting, and safety lighting on mobile sources.

General Illumination
Banner LED lighting is suitable for a variety of general illumination applications because it is energy efficient, easy to install, and requires almost no maintenance—with lifetimes from 5 to 20 years depending on daily usage requirements. High quality housings and bright illumination with a variety of color options set the Banner line apart.
Upgrade to LED lighting
LED lighting is quickly becoming the lighting of choice for industrial applications. LEDs use about 1/3 the energy of incandescent lighting and last up to 50 times as long. Banner LED lights feature more robust housings than fluorescent lights and do not produce hazardous waste if dropped or broken.

<table>
<thead>
<tr>
<th>Product</th>
<th>LED Work Light Strip</th>
<th>Area Light</th>
<th>Work/Spot Lights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>WLS28</td>
<td>WLA</td>
<td>WL50/WL50F/WL50S</td>
</tr>
<tr>
<td>Description</td>
<td>Bright, shatterproof, highly efficient LED illumination for industrial control cabinets, machine tools and work cells</td>
<td>High-power, solid-state LED lighting. Super-bright illumination with a small footprint</td>
<td>Handy LED lights for small areas or multiple locations</td>
</tr>
<tr>
<td>Additional Information</td>
<td>Waterproof and push-button models, magnetic or swivel bracket options</td>
<td>Waterproof models and lensed versions</td>
<td>Lensed versions, push-button models and magnetic, velcro or swivel bracket options</td>
</tr>
<tr>
<td>Lifetime</td>
<td>~50,000 hours (11+ years @12 hrs/day)</td>
<td>~50,000 hours (11+ years @12 hrs/day)</td>
<td>~50,000 hours (11+ years @12 hrs/day)</td>
</tr>
<tr>
<td></td>
<td>Warm White: 2600-4300K</td>
<td>Warm White: 2600-4300K</td>
<td>Green: 520-535 nm</td>
</tr>
<tr>
<td></td>
<td>Green: 520-535 nm</td>
<td>Green: 520-535 nm</td>
<td>Red: 620-630 nm</td>
</tr>
<tr>
<td></td>
<td>Yellow: 585-595 nm</td>
<td>Yellow: 585-595 nm</td>
<td>Yellow: 585-595 nm</td>
</tr>
<tr>
<td></td>
<td>Blue: 460-475 nm</td>
<td>Blue: 460-475 nm</td>
<td>Blue: 460-475 nm</td>
</tr>
<tr>
<td>Lumens (White)</td>
<td>225-1800</td>
<td>650-2600</td>
<td>105-295</td>
</tr>
<tr>
<td>Beam Angle (°)</td>
<td>120</td>
<td>120 or 11</td>
<td>5/11/20/120</td>
</tr>
<tr>
<td>Lens Material</td>
<td>Clear or diffusing acrylic</td>
<td>Clear or diffusing acrylic</td>
<td>Acrylic</td>
</tr>
<tr>
<td>Housing Material</td>
<td>Anodized aluminum</td>
<td>Sealed thermoplastic</td>
<td>Sealed polycarbonate</td>
</tr>
<tr>
<td>Additional Ratings</td>
<td>CE, UL</td>
<td>CE, UL</td>
<td>CE, UL</td>
</tr>
<tr>
<td>Shock/Vibration</td>
<td>All models meet Mil. Std. 202F requirements method 201A. (Vibration: 10 to 60 Hz max., double amplitude 0.06)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature Range</td>
<td>-20 to 50°C</td>
<td>-20 to 50°C</td>
<td>-20 to 50°C</td>
</tr>
<tr>
<td>Dimensions (mm)</td>
<td>21 x 28 x 145-1130 (8 lengths)</td>
<td>26 x 180 x 105/190/275/360</td>
<td>50 mm diameter</td>
</tr>
<tr>
<td>Power</td>
<td>12-30V dc</td>
<td>12-30V dc</td>
<td>12-30V dc</td>
</tr>
</tbody>
</table>