



# LED Industry & Lighting Technologies



**“Lighting is everything”...**

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## 1.0 Document Control

### 1.1 Changes From Previous Version

Version	Status	Date	Change
1.00	Drafting	2/24/2009 11:17:00 PM	
1.01	Release	11/27/2010	New logo added, main form, updated light bulb comparison on page 8, page 5 has also been revised to reflect recent development in improved LED performance.

### 1.2 Document Cross Reference

Document File Name	Location of Document/Reference	Comments
HTTP	<a href="http://www.wikipedia.com">http://www.wikipedia.com</a>	
HTTP	<a href="http://www.powerlineleds.com/led_long_life.asp">http://www.powerlineleds.com/led_long_life.asp</a>	
HTTP	EPA Reports	

### 1.3 Summary Changes To Document

Change Number	Page/Item	Change Description

## 2.0 Introduction

The purpose of this document is to describe the history of the global lighting industry and the benefits of embracing LED technology as a standard for lighting solutions. This report has been assembled from various industry sources and internet sources in the reference section of this document.

## 3.0 Types of Light Source

<a href="#"><u>Incandescent</u></a>	<a href="#"><u>Regular</u></a> · <a href="#"><u>Halogen</u></a> · <a href="#"><u>Parabolic aluminized reflector (PAR)</u></a> · <a href="#"><u>Nernst</u></a> · <a href="#"><u>Centennial</u></a>
<a href="#"><u>Fluorescent</u></a>	<a href="#"><u>Linear/tubular fluorescent</u></a> · <a href="#"><u>Compact fluorescent (CFL)</u></a> · <a href="#"><u>Electrodeless electromagnetic induction lamp</u></a>
<a href="#"><u>High-intensity discharge (HID)</u></a>	<a href="#"><u>Mercury-vapor</u></a> · <a href="#"><u>Hydrargyrum medium-arc iodide (HMI)</u></a> · <a href="#"><u>Hydrargyrum quartz iodide (HQI)</u></a> · <b>Metal halide</b> ( <a href="#"><u>Ceramic</u></a> ) · <a href="#"><u>Sodium vapor</u></a>
<a href="#"><u>Gas discharge</u></a>	<a href="#"><u>Neon</u></a> · <a href="#"><u>Xenon arc</u></a> / <a href="#"><u>Xenon flash</u></a> · <a href="#"><u>Cold cathode</u></a> · <a href="#"><u>Black light</u></a> · <a href="#"><u>Tanning lamp</u></a> · <a href="#"><u>Germicidal</u></a> · <a href="#"><u>Growth light</u></a>
<a href="#"><u>Electric arc</u></a>	<a href="#"><u>Carbon arc</u></a> · <a href="#"><u>Yablochkov candle</u></a>
<a href="#"><u>Combustion</u></a>	<a href="#"><u>Acetylene/Carbide</u></a> · <a href="#"><u>Argand</u></a> · <a href="#"><u>Candle</u></a> · <a href="#"><u>Diya</u></a> · <a href="#"><u>Natural gas</u></a> · <a href="#"><u>Kerosene</u></a> · <a href="#"><u>Lantern</u></a> · <a href="#"><u>Limelight</u></a> · <a href="#"><u>Oil</u></a> · <a href="#"><u>Safety</u></a> · <a href="#"><u>Rushlight</u></a> · <a href="#"><u>Tilley</u></a> · <a href="#"><u>Torch</u></a>
<b>Other</b>	<a href="#"><u>Sulfur lamp</u></a> · <a href="#"><u>Light-emitting diode (LED)</u></a> / <a href="#"><u>LED lamp</u></a> / <a href="#"><u>Solid-state lighting (SSL)</u></a> · <a href="#"><u>Deuterium arc</u></a> · <a href="#"><u>Plasma</u></a> · <a href="#"><u>Electroluminescent wire</u></a> · <a href="#"><u>Chemiluminescence</u></a> · <a href="#"><u>Radioluminescence</u></a> · <a href="#"><u>Artificial sunlight</u></a>

### 3.1 Common Street Lighting Types

The most common types of lights you see in street lighting and parking lighting are, High Pressure Sodium, Metal Halide, Mercury Vapor, Sodium Vapor, Fluorescent and Incandescent.

## 4.0 Light Sources and Efficiency

### 4.1 Energy Consumptions of 3 Lamp Technology Types.

**Table VI-2. Comparison of Energy Consumption by 3 Lamps  
(Production & Use)**

	CFL	Incandescent	LED-SSL
Input Power (W/lamp)	15.0	60.0	7.5
Flux (lm/lamp)	900	730	1500
Luminous Efficacy (lm/W)	60	12	200
Lifetime (hr)	8,000	1,000	20,000 <sup>1</sup>
Required luminous service (lm-hr)	1,000,000	1,000,000	1,000,000
Number of hours lamp is used to provide required service (hr/lamp)	1.11	1,370	667
Number of lamps used to provide required service	0.14	1.37	0.03
Energy consumed in use, based on required service (kWh)	16.67	82.19	5.00
Production energy for 1 lamp unit (kWh)	1.4	0.15	11.5
Production energy of lamp, based on required service (kWh)	0.19	0.21	0.38
<b>Total Energy (kWh)<sup>2</sup></b>	<b>16.86</b>	<b>82.40</b>	<b>5.38</b>

Source: (Gydesen, & Maimann, 1991); Author's calculations.

Note: The above chart is now out of date with current LED developments/improvements, LEDs now have significantly higher efficacy. 100 lm/w is now the standard.

#### **4.2 Compact Fluorescent Energy efficiency**

The chart shows the energy usage for different types of light bulbs operating at different light outputs. Points lower on the graph correspond to lower energy use. For a given light output, CFLs use between one fifth and one third of the power of equivalent incandescent lamps. Since lighting accounted for approximately 9% of household electricity usage in the United States in 2001, widespread use of CFLs could save as much as 7% of total US household usage.

If indoor incandescent lamps are replaced by CFLs, the heat produced by the building's lighting system will be reduced. At times when the building requires both heating and lighting, the building's central heating system will then supply the heat. If the building requires both illumination and cooling, then CFLs will use less electricity themselves and will also reduce the load on the cooling system compared to incandescent lamps. This results in two concurrent savings in electrical power.

#### **4.3 Efficacy and efficiency**

For more details on this topic, see Luminous efficacy.

A typical CFL is in the range of 17 to 21% efficient at converting electric power to radiant power. Because the eye's sensitivity changes with the wavelength, however, the output of lamps is more commonly measured in lumens, a measure that accounts for the effect of the source's spectrum on the eye. The luminous efficacy of CFL sources is typically 60 to 72 lumens per watt, versus 8 to 17 lm/W for incandescent lamps.

#### 4.4 LED Bulbs

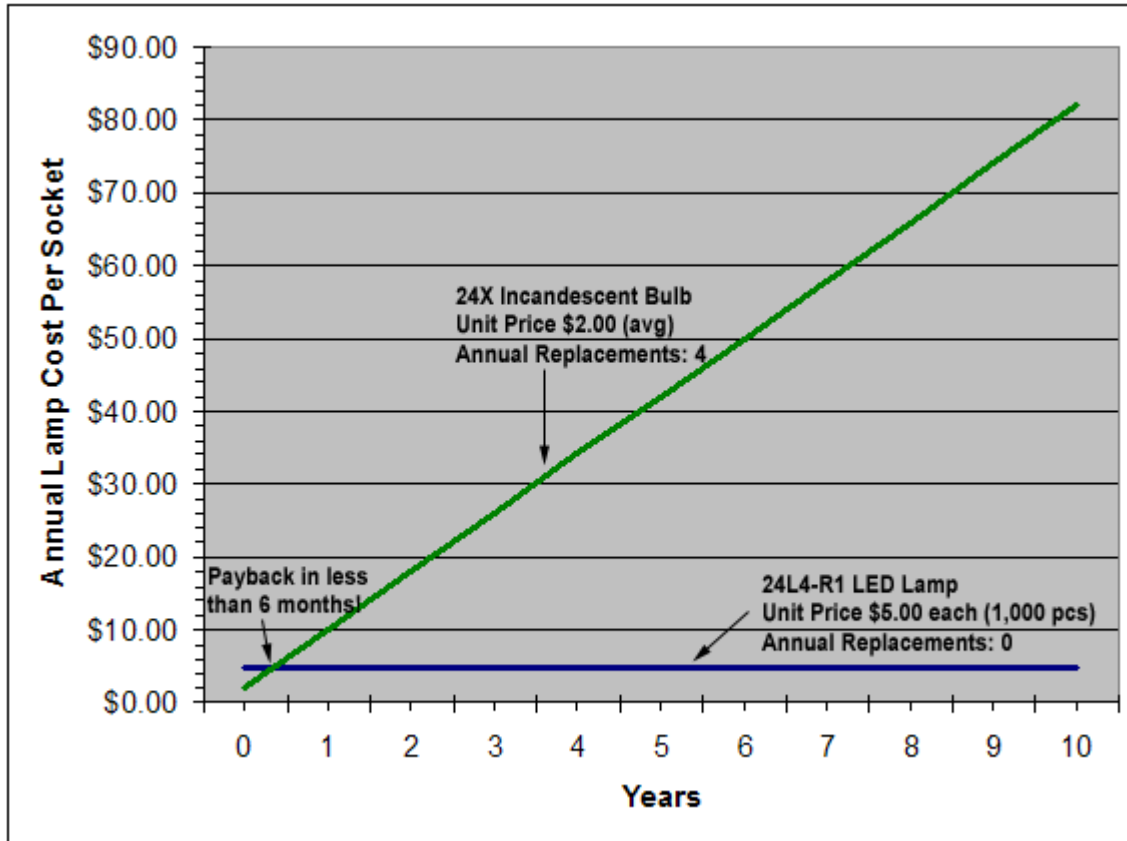
LEDs generally draw much lower current than incandescent bulbs.

DDP® LED Lamp		Incandescent Bulb	
6S6L120-CWX	11mA	6S6/120V	50mA
120PSBL-NWX	5.8mA	120PSB	25mA
387L-X1	16mA	387	40mA
1819L-X-CX	17mA	1819	40mA

While lower power consumption reduces operating costs, it also reduces wear on other components in the application such as transformers, batteries and power converters.

##### 4.4.1 Cost Savings




Based on an average incandescent bulb life of three months, converting to DDP® LEDs will pay for itself in material costs alone within the first year. This payback period is only considering the cost of the incandescent bulb. It does not take into account the labor cost associated with changing bulbs, power savings, operating downtime, incandescent bulb inventory and ordering costs, and other significant factors. The following graph depicts the average cost of replacing a \$2.00 24X incandescent bulb in one socket four times a year. The cost of the bi-polar 24L4-R1 is fixed at \$5.00 for ten years.



For a facility with only 1,000 lamps, the material savings alone would be approximately \$3,000 after the first year!

The higher the measurement the "brighter" the light is at the point measured.

Luminous efficacy or lumens/watt

	<b>Incandescent Bulb</b>	<b>CFL Bulb</b>	<b>LED Bulb</b>
			
<b>Wattage</b>	40 W	9 W	7 W
<b>Lumens</b>	550 lumens	550 lumens	700 lumens
<b>Lumens/Watt (Efficacy)</b>	14 lm/W	61 lm/W	100 lm/W

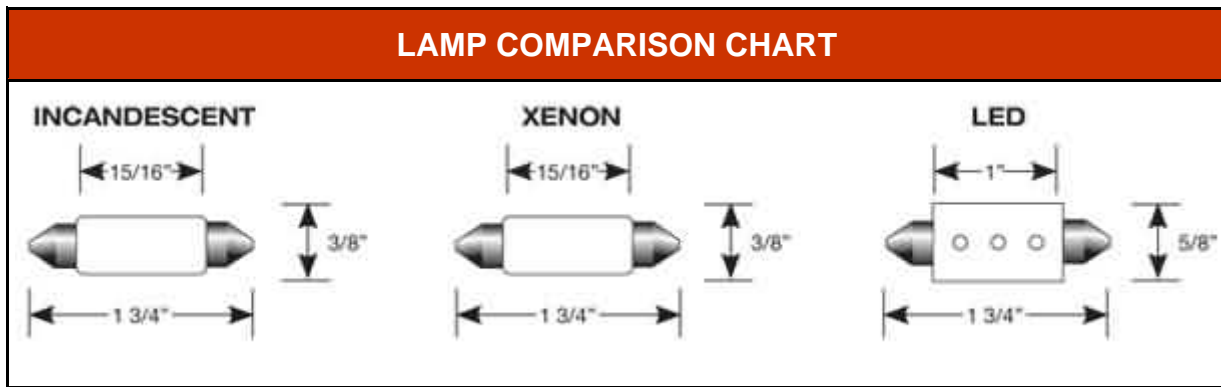
Source: [http://www.eternaleds.com/Are\\_LED\\_Bulbs\\_Brighter\\_Than\\_CFL\\_Bulbs\\_a/222.htm](http://www.eternaleds.com/Are_LED_Bulbs_Brighter_Than_CFL_Bulbs_a/222.htm)

"Luminous Efficacy" is a way to measure the amount of light you get for the amount of energy you put in. You take the total # of lumens and divide it by the wattage of the light bulb (lumens/watt). Here's a comparison of incandescent, CFL's and LED's at the moment.

Looks like CFL's are more efficient than LED's right? Wrong.

**Fixture efficacy**

In certain fixtures, an LED bulb actually gives out MORE light or is more efficient than CFL bulbs.



Type	Voltage	Wattage	Lumens	Finish	Lamp	Hours	Color
Incandescent	12VAC	3	20	Clear	Festoon	7,000	2,450K
Incandescent	24VAC	3	20	Frosted	Festoon	7,000	2,450K
Incandescent	12VAC	5	38	Clear	Festoon	7,000	2,450K
Incandescent	24VAC	5	38	Frosted	Festoon	7,000	2,450K
Incandescent	12VAC	10	80	Clear	Festoon	7,000	2,450K
Incandescent	24VAC	10	80	Frosted	Festoon	7,000	2,450K
Type	Voltage	Wattage	Lumens	Finish	Lamp	Hours	Color
Xenon	12VAC	3	25	Clear	Festoon	20,000	2,800K
Xenon	24VAC	3	25	Frosted	Festoon	20,000	2,800K
Xenon	12VAC	5	50	Clear	Festoon	20,000	2,800K
Xenon	24VAC	5	50	Frosted	Festoon	20,000	2,800K
Xenon	12VAC	10	120	Clear	Festoon	20,000	2,800K
Xenon	24VAC	10	120	Frosted	Festoon	20,000	2,800K
Type	Voltage	Wattage	Lumens	Finish	Lamp	Hours	Color
LED	12VAC*	1.7	40	N/A	Festoon	50,000	2,800K
LED	12VAC*	1.7	42	N/A	Festoon	50,000	2,950K
LED	12VAC*	1.7	45	N/A	Festoon	50,000	3,500K
LED	12VAC*	1.7	50	N/A	Festoon	50,000	5,000K
LED	12VAC*	1.7	50	N/A	Festoon	50,000	6,500K
LED	12VAC*	1.7	-	N/A	Festoon	50,000	Red

LED	12VAC*	1.7	-	N/A	Festoon	50,000	Blue
LED	12VAC*	1.7	-	N/A	Festoon	50,000	Green

Source: <http://www.phantomlighting.com/festoon-lamp-comparison-chart.htm>

## 5.0 History of the Light Bulb

In addressing the question "Who invented the incandescent lamp?" historians Robert Friedel and Paul Israel [1] list 22 inventors of incandescent lamps prior to Joseph Wilson Swan and Thomas Edison. They conclude that Edison's version was able to outstrip the others because of a combination of three factors: an effective incandescent material, a higher vacuum than others were able to achieve and a high resistance lamp that made power distribution from a centralized source economically viable.

Another historian, Thomas Hughes, has attributed Edison's success to the fact that he invented an entire, integrated system of electric lighting. "The lamp was a small component in his system of electric lighting, and no more critical to its effective functioning than the Edison Jumbo generator, the Edison main and feeder, and the parallel-distribution system. Other inventors with generators and incandescent lamps, and with comparable ingenuity and excellence, have long been forgotten because their creators did not preside over their introduction in a system of lighting." [2][3]

### 5.1 Early pre-commercial research

In 1802, Humphry Davy had what was then the most powerful electrical battery in the world at the Royal Institution of Great Britain. In that year, he created the first incandescent light by passing the current through a thin strip of platinum, chosen because the metal had an extremely high melting point. It was not bright enough nor did it last long enough to be practical, but it was the precedent behind the efforts of scores of experimenters over the next 75 years until Thomas Edison's creation of the first commercially practical incandescent lamp in 1879.[5] In 1809, Davy also created the first arc lamp by making a small but blinding electrical connection between two carbon charcoal rods connected to a 2000 cell battery; it was demonstrated to the Royal Institution in 1810.

Over the first three-quarters of the 19th century many experimenters worked with various combinations of platinum or iridium wires, carbon rods, and evacuated or semi-evacuated enclosures. Many of these devices were demonstrated and some were patented. [6]

In 1835, James Lindsay demonstrated a constant electric light at a public meeting in Dundee, Scotland. He stated that he could "read a book at a distance of one and a half feet". However, having perfected the device to his own satisfaction, he turned to the problem of wireless telegraphy and did not develop the electric light any further. His claims are not well documented.

In 1840, British scientist Warren de la Rue enclosed a coiled platinum filament in a vacuum tube and passed an electric current through it. The design was based on the concept that the high melting point of platinum would allow it to operate at high temperatures and that the evacuated chamber would contain fewer gas molecules to react with the platinum, improving its longevity. Although an efficient design, the cost of the platinum made it impractical for commercial use.[7] [8]

In 1841, Frederick de Moleyns of England was granted the first patent for an incandescent lamp, with a design using platinum wires contained within a vacuum bulb. [9]

In 1845, American John W. Starr acquired a patent for his incandescent light bulb involving the use of carbon filaments.[10] He died shortly after obtaining the patent. Aside from the information contained in the patent itself, little else is known about him.

In 1851, Jean Eugène Robert-Houdin publicly demonstrated incandescent light bulbs on his estate in Blois, France. His light bulbs are on permanent display in the museum of the Chateau of Blois.

In 1872 A. N. Lodygin invented an incandescent light bulb. In 1874 he obtained a patent for his invention. [11]

In a suit filed by rivals seeking to get around Edison's lightbulb patent, German-American inventor Heinrich Göbel claimed he developed the first light bulb in 1854: a carbonized bamboo filament, in a vacuum bottle to prevent oxidation, and that in the following five years he developed what many call the first practical light bulb. Lewis Latimer demonstrated the bulbs that Göbel had purportedly built in the 1850s had actually been built much later, and found the glassblower who had constructed the fraudulent exhibits.[12] In a patent interference suit in 1893, the judge ruled Göbel's claim "extremely improbable."

## **5.2 Commercialization**

Joseph Wilson Swan (1828–1914) was an English physicist and chemist. In 1850, he began working with carbonized paper filaments in an evacuated glass bulb. By 1860 he was able to demonstrate a working device but the lack of a good vacuum and an adequate supply of electricity resulted in a short lifetime for the bulb and an inefficient source of light. By the mid-1870s better pumps became available, and Swan returned to his experiments. With the help of Charles Stearn, an expert on vacuum pumps, in 1878 Swan developed a method of processing that avoided the early bulb blackening. This received a British Patent No 8 in 1880.[13] On 18 December 1878 a lamp using a slender carbon rod was shown at a meeting of the Newcastle Chemical Society, and Swan gave a working demonstration at their meeting on 17 January 1879. It was also shown to 700 who attended a meeting of the Literary and Philosophical Society of Newcastle on 3 February 1879. These lamps used a carbon rod from an arc lamp rather than a slender filament. Thus they had low resistance and required very large conductors to supply the necessary current, so they were not commercially practical, although they did furnish a demonstration of the possibilities of incandescent lighting with relatively high vacuum, a carbon conductor, and platinum lead-in wires. Besides requiring too much current for a central station electric system to be practical, they had a

very short lifetime.[14] Swan turned his attention to producing a better carbon filament and the means of attaching its ends. He devised a method of treating cotton to produce 'parchmentised thread' and obtained British Patent 4933 in 1880.[15] From this year he began installing light bulbs in homes and landmarks in England. His house was the first in the world to be lit by a lightbulb and so the first house in the world to be lit by Hydro Electric power. In the early 1880s he had started his company.[16]

In North America, parallel developments were also taking place. On July 24, 1874 a Canadian patent was filed by a Toronto medical electrician named Henry Woodward and a colleague Mathew Evans. They built their lamps with different sizes and shapes of carbon rods held between electrodes in glass cylinders filled with nitrogen. Woodward and Evans attempted to commercialize their lamp, but were unsuccessful. They ended up selling their patent (U.S. Patent 0,181,613 ) to Thomas Edison in 1879 [17].

Thomas Edison (1847-1931) began serious research into developing a practical incandescent lamp in 1878. Edison filed his first patent application for "Improvement In Electric Lights" on October 14, 1878 (U.S. Patent 0,214,636 ). After many experiments with platinum and other metal filaments, Edison returned to a carbon filament. The first successful test was on October 22, 1879,[18] and lasted 13.5 hours. Edison continued to improve this design and by Nov 4, 1879, filed for a U.S. patent (granted as U.S. Patent 0,223,898 on Jan 27, 1880) for an electric lamp using "a carbon filament or strip coiled and connected ... to platina contact wires." [19] Although the patent described several ways of creating the carbon filament including using "cotton and linen thread, wood splints, papers coiled in various ways," [19] it was not until several months after the patent was granted that Edison and his team discovered that a carbonized bamboo filament could last over 1200 hours.

Hiram S. Maxim started a lightbulb company in 1878 to exploit his patents and those of William Sawyer. His United States Electric Lighting Company was the second company, after Edison, to sell practical incandescent electric lamps. They made their first commercial installation of incandescent lamps at the Mercantile Safe Deposit Company in New York City in the fall of 1880, about six months after the Edison incandescent lamps had been installed on the steamer Columbia. In October 1880, Maxim patented a method of coating carbon filaments with hydrocarbons to extend their life. Lewis Latimer, his employee at the time, developed an improved method of heat-treating them which reduced breakage and allowed them to be molded into novel shapes, such as the characteristic "M" shape of Maxim filaments. On January 17, 1882, Latimer received a patent for the "Process of Manufacturing Carbons," an improved method for the production of light bulb filaments which was purchased by the United States Electric Light Company. Latimer patented other improvements such as a better way of attaching filaments to their wire supports.[12]

In Britain, the Edison and Swan companies merged into the Edison and Swan United Electric Company (later known as Ediswan, which was ultimately incorporated into Thorn Lighting Ltd). Edison was initially against this combination, but after Swan sued him and won, Edison was eventually forced to cooperate, and the merger was made. Eventually, Edison acquired all of Swan's interest in the company. Swan sold his United States patent rights to the Brush Electric Company in June 1882. Swan later wrote that Edison had a greater claim to the light than he did, in order to protect Edison's patents from claims against them in the United States. In 1881, the Savoy Theatre became the first public building in the world to be lit entirely by electric lights.[20]

U.S. Patent 0,223,898 by Thomas Edison for an improved electric lamp, January 27, 1880  
In 1882, the first recorded set of miniature incandescent lamps for lighting a Christmas tree was installed. These did not become common in homes for many years.

The United States Patent Office gave a ruling October 8, 1883, that Edison's patents were based on the prior art of William Sawyer and were invalid. Litigation continued for a number of years. Eventually on October 6, 1889, a judge ruled that Edison's electric light improvement claim for "a filament of carbon of high resistance" was valid.

In the 1890s, the Austrian inventor Carl Auer von Welsbach worked on metal-filament mantles, first with platinum wiring, and then osmium, and produced an operative version in 1898. In 1898 he patented the osmium lamp and started marketing it in 1902, the first commercial metal filament incandescent lamp.

In 1897, German physicist and chemist Walther Nernst developed the Nernst lamp, a form of incandescent lamp that used a ceramic glower and did not require enclosure in a vacuum or inert gas. Twice as efficient as carbon filament lamps, Nernst lamps were briefly popular until overtaken by lamps using metal filaments.

In 1903, Willis Whitnew invented a metal-coated carbon filament that would not blacken the inside of a light bulb.

On December 13 1904, Hungarian Sándor Just and Ferenc Hanaman were granted a Hungarian patent (No. 34541) for a tungsten filament lamp, which lasted longer and gave a brighter light than the carbon filament. Tungsten filament lamps were first marketed by the Hungarian company Tungstram in 1905, so this type is often called Tungstram-bulbs in many European countries.[21]

In 1906, the General Electric Company patented a method of making tungsten filaments for use in incandescent light bulbs. Sintered tungsten filaments were costly, but by 1910 William David Coolidge (1873–1975) had invented an improved method of making tungsten filaments. The tungsten filament outlasted all other types of filaments and Coolidge made the costs practical.

In 1913 Irving Langmuir found that filling a lamp with inert gas instead of a vacuum resulted in twice the luminous efficacy and reduction of bulb blackening. In 1924, Marvin Pipkin, an American chemist, patented a process for frosting the inside of lamp bulbs without weakening them, and in 1947 he patented a process for coating the inside of lamps with silica.

In 1930, Hungarian Imre Bródy filled lamps with krypton gas in lieu of argon. He used krypton and/or xenon filling of bulbs. Since the new gas was expensive, he developed a process with his colleagues to obtain krypton from air. Production of krypton filled lamps based on his invention started at Ajka in 1937, in a factory co-designed by Polányi and Hungarian-born physicist Egon Orowan. [22]

By 1964, improvements in efficiency and production of incandescent lamps had reduced the cost of providing a given quantity of light by a factor of thirty, compared with the cost at introduction of Edison's lighting system [23]

## 5.3 Cartels

Main article: Phoebus cartel

Between 1924 and 1939 the international market for incandescent light bulbs was controlled by the Phoebus cartel, which dictated wholesale prices and whose members controlled most of the world market for lamps.

## 5.4 Construction

Incandescent light bulbs consist of a glass enclosure (the envelope, or bulb) with a filament of tungsten wire inside the bulb, through which an electric current is passed. Contact wires and a base with two (or more) conductors provide electrical connections to the filament. Incandescent light bulbs usually contain a stem or glass mount anchored to the bulb's base which allows the electrical contacts to run through the envelope without gas/air leaks. Small wires embedded in the stem in turn support the filament and/or its lead wires. The bulb is filled with an inert gas such as argon to reduce evaporation of the filament.

An electrical current heats the filament to typically 2000 K to 3300 K (about 3100-5400°F), well below tungsten's melting point of 3695 K (6192°F). Filament temperatures depend on the filament type, shape, size, and amount of current drawn. The heated filament emits light that approximates a continuous spectrum. The useful part of the emitted energy is visible light, but most energy is given off as heat in the near-infrared wavelengths.

Three-way light bulbs have two filaments and three conducting contacts in their bases. The filaments share a common ground, and can be lit separately or together. Common wattages include 30-70-100, 50-100-150, and 100-200-300, with the first two numbers referring to the individual filaments, and the third giving the combined wattage.

While most light bulbs have clear or frosted glass, other kinds are also produced, including the various colors used for Christmas tree lights and other decorative lighting. Neodymium-containing glass is sometimes used to provide a more natural-appearing light.

Many arrangements of electrical contacts are used. Large lamps may have a screw base (one or more contacts at the tip, one at the shell) or a bayonet base (one or more contacts on the base, shell used as a contact or used only as a mechanical support). Some tubular lamps have an electrical contact at either end. Miniature lamps may have a wedge base and wire contacts, and some automotive and special purpose lamps have screw terminals for connection to wires. Contacts in the lamp socket allow the electric current to pass through the base to the filament. Power ratings for incandescent light bulbs range from about 0.1 watt to about 10,000 watts.

## 5.5 Filament

The first successful light bulb filaments were made of carbon (from carbonized paper or bamboo), later replaced with tungsten. To improve the efficiency of the lamp, the

filament usually consists of coils of fine wire, also known as a 'coiled coil.' For a 60-watt 120-volt lamp, the uncoiled length of the tungsten filament is usually 22.8 inches or 580 mm [24], and the filament diameter is 0.0018 inches (0.045 mm). The advantage of the coiled coil is that evaporation of the tungsten filament is at the rate of a tungsten cylinder having a diameter equal to that of the coiled coil. Such a filament has a lower surface area than the actual surface area of the filament, and so evaporation is reduced. If the filament is then run hotter to bring back evaporation to the same rate, the resulting filament is a more efficient light source.

There are several different shapes of filament used in lamps, with differing characteristics. Manufacturers designate the types with codes such as C-6, CC-6, C-2V, CC-2V, C-8, CC-88, C-2F, CC-2F, C-Bar, C-Bar-6, C-8I, C-2R, CC-2R, and Axial.

Filament of a 200 watt incandescent lightbulb highly magnified  
Filament of a 50 watt incandescent lightbulb in the SEM in stereoscopic / anaglyph mode, magnification 50x

Filament of a 50 watt incandescent lightbulb in the SEM in stereoscopic / anaglyph mode, magnification 500x. Electrical filaments are also used in hot cathodes of fluorescent lamps and vacuum tubes as a source of electrons or in vacuum tubes to heat an electron-emitting electrode.

## 5.6 Efficiency comparisons

Approximately 90% of the power consumed by an incandescent light bulb is emitted as heat, rather than as visible light.[53]

Luminous efficacy of a light source is a ratio of the visible light energy emitted ( the luminous flux) to the total power input to the lamp.[54] It is measured in lumens per watt (lm/W). The maximum efficacy possible is 683 lm/W for monochromatic green light at 555 nanometres wavelength, the peak sensitivity of the human eye. (This is the definition of the lumen.) For white light, the maximum luminous efficacy is around 240 lumens/watt. Luminous efficiency is the ratio of the luminous efficacy to this maximum possible value. It is expressed as a number between 0 and 1, or as a percentage.[55] However, the term luminous efficiency is often used for both quantities.

A closely related idea is the luminous efficacy of radiant energy, also measured in lumens/watt. Not all wavelengths of visible electromagnetic energy are equally effective at stimulating the human eye; the luminous efficacy of radiant energy is a measure of how well the distribution of energy matches the perception of the eye.

The chart below lists values of overall luminous efficacy and efficiency for several types of general service, 120 volt, 1000-hour lifespan incandescent bulb, and several idealized light sources. A similar chart in the article on luminous efficacy compares a broader array of light sources to one another.

Type	Overall luminous efficiency	Overall luminous efficacy (lm/W)
------	-----------------------------	----------------------------------

# LED Industry & Lighting Technologies

By: Simon Speight

11/27/2009

40 W tungsten incandescent	1.9%	12.6 <sup>[56]</sup>
60 W tungsten incandescent	2.1%	14.5 <sup>[56]</sup>
100 W tungsten incandescent	2.6%	17.5 <sup>[56]</sup>
glass halogen	2.3%	16
quartz halogen	3.5%	24
high-temperature incandescent	5.1%	35 <sup>[57]</sup>
ideal <a href="#">black-body</a> radiator at 4000 K	7.0%	47.5 <sup>[58]</sup>
ideal black-body radiator at 7000 K	14%	95 <sup>[58]</sup>
ideal monochromatic 555 nm (green) source	100%	683 <sup>[59]</sup>

Unfortunately, the spectrum emitted by a blackbody radiator does not match the sensitivity characteristics of the human eye. Tungsten filaments radiate mostly infrared radiation at temperatures where they remain solid (below 3683 kelvins). Donald L. Klipstein explains it this way: "An ideal thermal radiator produces visible light most efficiently at temperatures around 6300 °C (6600 K or 11 500 °F). Even at this high temperature, a lot of the radiation is either infrared or ultraviolet, and the theoretical luminous efficiency is 95 lumens per watt."<sup>[57]</sup> No known material can be used as a filament at this ideal temperature, which is hotter than the sun's surface. An upper limit for incandescent lamp luminous efficacy is around 52 lumens per watt, the theoretical value emitted by tungsten at its melting point.<sup>[60]</sup>

For a given quantity of light, an incandescent light bulb produces more heat (and consumes more power) than a fluorescent lamp. Incandescent lamps' heat output increases load on air conditioning in the summer, but the heat from lighting can contribute to building heating in cold weather.<sup>[61]</sup>

Quality halogen incandescent lamps have higher efficacy, which will allow a 60 W bulb to provide nearly as much light as a non-halogen 100 W. Also, a lower-wattage halogen

lamp can be designed to produce the same amount of light as a 60 W non-halogen lamp, but with much longer life.

Alternatives to standard incandescent lamps for general lighting purposes include:

Fluorescent lamps, and Compact fluorescent lamps  
High-intensity discharge lamps  
LED lamps

None of these devices rely on incandescence to produce light. Instead, all these devices produce light by the transition of electrons from one energy level to another. These mechanisms produce discrete spectral lines and so are not associated with the broad "tail" of invisible infrared emissions produced by incandescent emitters, which is energy not usable for illumination. By careful selection of which electron energy level transitions are used, the spectrum emitted can be tuned to either mimic the appearance of incandescent sources or else produce different color temperatures of white for visible light.

## **5.7 Measures to Discontinue Use**

Due to the higher energy usage of incandescent light bulbs in comparison to more energy efficient alternatives, such as compact fluorescent lamps and LED lamps, some governments have passed introduced measures to phase out their use. Brazil and Venezuela started to phase them out in 2005,[62] and other nations are planning scheduled phase-outs: Ireland and Switzerland[63] in 2009; Argentina[64], Italy and the United Kingdom[65] by 2011; Canada in 2012;[66] and the U.S. between 2012 and 2014.[67]

## **5.8 Efforts to improve efficiency**

Due to the measures noted above, there have been recent efforts to improve the efficiency of incandescents. For example the consumer lighting division of General Electric announced that they are working on a "high efficiency incandescent" (HEI) lamp, which they claim could ultimately be as much as four times more efficient than current incandescents, although their initial production goal is to be approximately two times more efficient.[68][69]

The U.S. Department of Energy is also currently developing a filament lamp at Sandia National Laboratories with improved efficiency from 5% to 60%.[70][71]

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## 6.0 What is an LED

A light-emitting diode (LED), is an electronic light source. The LED was discovered in the early 20th century, and introduced as a practical electronic component in 1962. All early devices emitted low-intensity red light, but modern LEDs are available across the visible, ultraviolet and infra red wavelengths, with very high brightness.

LEDs are based on the semiconductor diode. When the diode is forward biased (switched on), electrons are able to recombine with holes and energy is released in the form of light. This effect is called electroluminescence and the color of the light is determined by the energy gap of the semiconductor. The LED is usually small in area (less than 1 mm<sup>2</sup>) with integrated optical components to shape its radiation pattern and assist in reflection.[2]

LEDs present many advantages over traditional light sources including lower energy consumption, longer lifetime, improved robustness, smaller size and faster switching.

However, they are relatively expensive and require more precise current and heat management than traditional light sources.

Applications of LEDs are diverse. They are used as low-energy replacements for traditional light sources in well-established applications such as indicators and automotive lighting. The compact size of LEDs has allowed new text and video displays and sensors to be developed, while their high switching rates are useful in communications technology.

## **6.1 Discoveries and early devices**

Oleg Losev created one of the first LEDs in the mid 1920s. Electroluminescence was discovered in 1907 by the British experimenter H. J. Round of Marconi Labs, using a crystal of silicon carbide and a cat's-whisker detector.[3] Russian Oleg Vladimirovich Losev independently created the first LED in the mid 1920s; his research, was distributed in Russian, German and British scientific journals,[4][5] but no practical use was made of the discovery for several decades. Rubin Braunstein of the Radio Corporation of America reported on infrared emission from gallium arsenide (GaAs) and other semiconductor alloys in 1955.[6] Braunstein observed infrared emission generated by simple diode structures using gallium antimonide (GaSb), GaAs, indium phosphide (InP), and silicon-germanium (SiGe) alloys at room temperature and at 77 kelvin.

In 1961, experimenters Bob Biard and Gary Pittman working at Texas Instruments,[7] found that GaAs emitted infrared radiation when electric current was applied and received the patent for the infrared LED.

The first practical visible-spectrum (red) LED was developed in 1962 by Nick Holonyak Jr., while working at General Electric Company.[8] Holonyak is seen as the "father of the light-emitting diode".[9] M. George Craford, a former graduate student of Holonyak, invented the first yellow LED and improved the brightness of red and red-orange LEDs by a factor of ten in 1972.[10]. In 1976, T.P. Pearsall created the first high-brightness, high efficiency LEDs for optical fiber telecommunications by inventing new semiconductor materials specifically adapted to optical fiber transmission wavelengths.[11]

Up to 1968 visible and infrared LEDs were extremely costly, on the order of US \$200 per unit, and so had little practical application.[12] The Monsanto Corporation was the first organization to mass-produce visible LEDs, using gallium arsenide phosphide in 1968 to produce red LEDs suitable for indicators.[12] Hewlett Packard (HP) introduced LEDs in 1968, initially using GaAsP supplied by Monsanto. The technology proved to have major applications for alphanumeric displays and was integrated into HP's early handheld calculators.

## **6.2 Efficiency and operational parameters**

Typical indicator LEDs are designed to operate with no more than 30–60 milliwatts [mW] of electrical power. Around 1999, Philips Lumileds introduced power LEDs capable of continuous use at one watt [W]. These LEDs used much larger semiconductor die sizes to handle the large power inputs. Also, the semiconductor dies were mounted onto metal slugs to allow for heat removal from the LED die.

One of the key advantages of LED-based lighting is its high efficiency, as measured by its light output per unit power input. White LEDs quickly matched and overtook the efficiency of standard incandescent lighting systems. In 2002, Lumileds made five-watt LEDs available with a luminous efficiency of 18–22 lumens per watt [lm/W]. For comparison, a conventional 60–100 W incandescent lightbulb produces around 15 lm/W, and standard fluorescent lights produce up to 100 lm/W. (The luminous efficiency article discusses these comparisons in more detail.)

In September 2003, a new type of blue LED was demonstrated by the company Cree, Inc. to provide 24 mW at 20 milliamperes [mA]. This produced a commercially packaged white light giving 65 lm/W at 20 mA, becoming the brightest white LED commercially available at the time, and more than four times as efficient as standard incandescents. In 2006 they demonstrated a prototype with a record white LED luminous efficiency of 131 lm/W at 20 mA. Also, Seoul Semiconductor has plans for 135 lm/W by 2007 and 145 lm/W by 2008, which would be approaching an order of magnitude improvement over standard incandescents and better even than standard fluorescents.[14] Nichia Corporation has developed a white light LED with luminous efficiency of 150 lm/W at a forward current of 20 mA.[15]

It should be noted that high-power ( $\geq 1$  W) LEDs are necessary for practical general lighting applications. Typical operating currents for these devices begin at 350 mA. The highest efficiency high-power white LED is claimed[16] by Philips Lumileds Lighting Co. with a luminous efficiency of 115 lm/W (350 mA).

Cree issued a press release on November 19, 2008 about a laboratory prototype LED achieving 161 lumens/watt at room temperature. The total output was 173 lumens, and the correlated color temperature was reported to be 4689 K.[17][unreliable source?]

### **6.3 Life time and failure**

Main article: List of LED failure modes

Solid state devices such as LEDs are subject to very limited wear and tear if operated at low currents and at low temperatures. Many of the LEDs produced in the 1970s and 1980s are still in service today. Typical lifetimes quoted are 25000 to 100000 hours but heat and current settings can extend or shorten this time significantly. [18]

The most common way for LEDs (and diode lasers) to fail is the gradual lowering of light output and loss of efficiency. Sudden failures, however rare, can occur as well. Early red LEDs were notable for their short lifetime. With the the development of high power LEDs the devices are subjected to higher junction temperatures and higher current densities than traditional devices. This causes stress on the material and may cause early light output degradation. To quantitatively classify lifetime in a standardized manner it has been suggested to use the terms L75 and L50 which is the time it will take a given LED to reach 75% and 50% light output respectively.[19]

Other white LEDs

Another method used to produce experimental white light LEDs used no phosphors at all and was based on homoepitaxially grown zinc selenide (ZnSe) on a ZnSe substrate

which simultaneously emitted blue light from its active region and yellow light from the substrate.[29]

## **6.4 Organic light-emitting diodes (OLEDs)**

Main article: Organic light-emitting diode

If the emitting layer material of the LED is an organic compound, it is known as an Organic Light Emitting Diode (OLED). To function as a semiconductor, the organic emitting material must have conjugated pi bonds. [30] The emitting material can be a small organic molecule in a crystalline phase, or a polymer. Polymer materials can be flexible; such LEDs are known as PLEDs or FLEDs.

Compared with regular LEDs, OLEDs are lighter, and polymer LEDs can have the added benefit of being flexible. Some possible future applications of OLEDs could be:

- Inexpensive, flexible displays
- Light sources
- Wall decorations
- Luminous cloth

OLEDs have been used to produce visual displays for portable electronic devices such as cellphones, digital cameras, and MP3 players. Larger displays have been demonstrated,[31] but their life expectancy is still far too short (<1,000 hours) to be practical[citation needed].

Today, OLEDs operate at substantially lower efficiency than inorganic (crystalline) LEDs.[32]

## **6.5 Advantages**

**Efficiency:** LEDs produce more light per watt than incandescent bulbs; this is useful in battery powered or energy-saving devices.[37]

**Color:** LEDs can emit light of an intended color without the use of color filters that traditional lighting methods require. This is more efficient and can lower initial costs.

**Size:** LEDs can be very small (smaller than 2 mm<sup>2</sup>[38]) and are easily populated onto printed circuit boards.

**On/Off time:** LEDs light up very quickly. A typical red indicator LED will achieve full brightness in microseconds.[39] LEDs used in communications devices can have even faster response times.

**Cycling:** LEDs are ideal for use in applications that are subject to frequent on-off cycling, unlike fluorescent lamps that burn out more quickly when cycled frequently, or HID lamps that require a long time before restarting.

**Dimming:** LEDs can very easily be dimmed either by Pulse-width modulation or lowering the forward current.

**Cool light:** In contrast to most light sources, LEDs radiate very little heat in the form of IR that can cause damage to sensitive objects or fabrics. Wasted energy is dispersed as heat through the base of the LED.

**Slow failure:** LEDs mostly fail by dimming over time, rather than the abrupt burn-out of incandescent bulbs.[40]

**Lifetime:** LEDs can have a relatively long useful life. One report estimates 35,000 to 50,000 hours of useful life, though time to complete failure may be longer.[41] Fluorescent tubes typically are rated at about 10,000 to 15,000 hours, depending partly on the conditions of use, and incandescent light bulbs at 1,000–2,000 hours.[citation needed]

**Shock resistance:** LEDs, being solid state components, are difficult to damage with external shock, unlike fluorescent and incandescent bulbs which are fragile.

**Focus:** The solid package of the LED can be designed to focus its light. Incandescent and fluorescent sources often require an external reflector to collect light and direct it in a usable manner.

**Toxicity:** LEDs do not contain mercury, unlike fluorescent lamps.

## **6.6 Disadvantages**

**High price:** LEDs are currently more expensive, price per lumen, on an initial capital cost basis, than most conventional lighting technologies. The additional expense partially stems from the relatively low lumen output and the drive circuitry and power supplies needed. However, when considering the total cost of ownership (including energy and maintenance costs), LEDs far surpass incandescent or halogen sources and begin to threaten compact fluorescent lamps[citation needed].

**Temperature dependence:** LED performance largely depends on the ambient temperature of the operating environment. Over-driving the LED in high ambient temperatures may result in overheating of the LED package, eventually leading to device failure. Adequate heat-sinking is required to maintain long life. This is especially important when considering automotive, medical, and military applications where the device must operate over a large range of temperatures, and is required to have a low failure rate.

**Voltage sensitivity:** LEDs must be supplied with the voltage above the threshold and a current below the rating. This can involve series resistors or current-regulated power supplies.[42]

**Light quality:** Most cool-white LEDs have spectra that differ significantly from a black body radiator like the sun or an incandescent light. The spike at 460 nm and dip at 500 nm can cause the color of objects to be perceived differently under cool-white LED illumination than sunlight or incandescent sources, due to metamerism,[43] red surfaces being rendered particularly badly by typical phosphor based cool-white LEDs. However, the color rendering properties of common fluorescent lamps are often inferior to what is now available in state-of-art white LEDs.

Area light source: LEDs do not approximate a “point source” of light, but rather a lambertian distribution. So LEDs are difficult to use in applications requiring a spherical light field. LEDs are not capable of providing divergence below a few degrees. This is contrasted with lasers, which can produce beams with divergences of 0.2 degrees or less.[44]

Blue Hazard: There is increasing concern that blue LEDs and cool-white LEDs are now capable of exceeding safe limits of the so-called blue-light hazard as defined in eye safety specifications such as ANSI/IESNA RP-27.1-05: Recommended Practice for Photobiological Safety for Lamp and Lamp Systems.[45][46]

Blue pollution: Because cool-white LEDs (i.e., LEDs with high color temperature) emit much more blue light than conventional outdoor light sources such as high-pressure sodium lamps, the strong wavelength dependence of Rayleigh scattering means that cool-white LEDs can cause more light pollution than other light sources. It is therefore very important that cool-white LEDs are fully shielded when used outdoors. Compared to low-pressure sodium lamps, which emit at 589.3 nm, the 460 nm emission spike of cool-white and blue LEDs is scattered about 2.7 times more by the Earth's atmosphere. Cool-white LEDs should not be used for outdoor lighting near astronomical observatories.

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## 7.0 History of Street Lighting

Before incandescent lamps, gas lighting was employed in cities. The earliest lamps required that a lamplighter tour the town at dusk, lighting each of the lamps, but later designs employed ignition devices that would automatically strike the flame when the gas supply was activated. The earliest of such street lamps were built in the Arab Empire,[1] especially in Córdoba, Spain.[2]

The first electric street lighting employed arc lamps, initially the 'Electric candle', 'Jablohoff candle' or 'Yablochkov candle' developed by the Russian Pavel Yablochkov in 1875. This was a carbon arc lamp employing alternating current, which ensured that the electrodes burnt down at the same rate. Yablochkov candles were first used to light the Grands Magasins du Louvre, Paris where 80 were deployed. Soon after, experimental arrays of arc lamps were used to light Holborn Viaduct and the Thames Embankment in London - the first electric street lighting in Britain. More than 4,000 were in use by 1881, though by then an improved differential arc lamp had been developed by Friederich von Hefner- Alteneck of Siemens & Halske. The United States was swift in adopting arc lighting, and by 1890 over 130,000 were in operation in the US, commonly installed in exceptionally tall moonlight towers.

The first street in the UK to be lit by electric light was Mosley Street, in Newcastle-upon-Tyne. The street was lit by Joseph Swan's incandescent lamp in February, 1879.[3] Wabash, Indiana holds the title of being the second electrically-lit city in the world, which took place on February 2, 1880. Four 3,000 candlepower Brush arc lamps suspended over the courthouse rendered the town square "as light as midday." [4] Kimberley, a city in the centre of South Africa, was the first city in Africa to have electric street lights - first lit on 1 September 1882. Timișoara, in present-day Romania, was the first city in mainland Europe to have electric public lighting on the 12th of November 1884. 731 lamps were used.

Arc lights had two major disadvantages. First, they emit an intense and harsh light which, although useful at industrial sites like dockyards, was discomforting in ordinary city streets. Second, they are maintenance-intensive, as carbon electrodes burn away swiftly. With the development of cheap, reliable and bright incandescent light bulbs at the end of the 19th century, they passed out of use for street lighting, but remained in industrial use longer.

Incandescent lamps used for street lighting until the advent of high-intensity discharge lamps, were often operated as high-voltage series circuits. To avoid having the entire street go dark if a single lamp burned out, each street lamp was equipped with a film cutout, a small disk of insulating film that separated two contacts connected to the two wires leading to the lamp. If the lamp failed (an open circuit), the current through the string became zero, causing the entire voltage of the circuit (thousands of volts) to be imposed across the insulating film, penetrating it (see Ohm's law). In this way, the failed lamp was bypassed and illumination restored to the rest of the street. (This is the same principle used in Christmas tree lights.) The circuit usually contained an automatic device to regulate the voltage in the circuit, preventing the current from increasing as additional lamps burned out, preserving the life of the remaining lamps. When the failed lamp was replaced, a new piece of film was installed, once again separating the contacts in the cutout. This style of street lighting was recognizable by the large porcelain insulator that separated the lamp and reflector from the light's mounting arm. The insulator was necessary because the two contacts in the lamp's base may have operated at several thousands of volts above ground/earth.

Today, street lighting commonly uses high-intensity discharge lamps, often HPS high pressure sodium lamps. Such lamps provide the greatest amount of photopic illumination for the least consumption of electricity. However when scotopic/photopic light calculations are used, it can be seen how inappropriate HPS lamps are for night lighting. White light sources have been shown to double driver peripheral vision and increase driver brake reaction time at least 25%. When S/P light calculations are used, HPS lamp performance needs to be reduced by a minimum value of 75%. This is now a standard design criteria for Australian roads.

## ***7.1 Dangers of street lights***

There are two optical phenomena that need to be recognized in street light installations.

The loss of night vision because of the accommodation reflex of drivers' eyes is the greatest danger. As drivers emerge from an unlighted area into a pool of light from a

street light their pupils quickly constrict to adjust to the brighter light, but as they leave the pool of light the dilation of their pupils to adjust to the dimmer light is much slower, so they are driving with impaired vision. As a person gets older the eye's recovery speed gets slower, so driving time and distance under impaired vision increases.

Oncoming headlights are more visible against a black background than a grey one. The contrast creates greater awareness of the oncoming vehicle.

Stray voltage is also a concern in many cities. Stray voltage can accidentally electrify light poles and has the potential to injure or kill anyone who comes into contact with the pole.[5] Some cities have employed the Electrified Cover Safeguard technology which sounds an alarm and flashes a light, to warn the public, when a pole becomes dangerously electrified.

There are also physical dangers. Street light stanchions (poles) pose a collision risk to motorists. This can be reduced by designing them to break away when hit (frangible or collapsible supports), protecting them by guardrails, or both. High winds or accumulated metal fatigue also occasionally topple street lights.

## **7.2 Light pollution**

In urban areas light pollution can hide the stars and interfere with astronomy. In settings near astronomical telescopes and observatories, low pressure sodium lamps may be used. These lamps are advantageous over other lamps such as mercury and metal halide lamps because low pressure sodium lamps emit lower intensity, monochromatic light. Observatories can filter the sodium wavelength out of their observations and virtually eliminate the interference from nearby urban lighting.

The light pollution also disrupts the natural growing cycle of plants.

## **7.3 Safety**

A misconception is that installing street lights will automatically make streets safer and reduce crime, so political pressure can be a major factor in installation of street lights. Untrained officials often assume that if some is good, more must be better, and install the brightest lights possible. Misuse of street lights can cause accidents, and crime lighting is an entirely different type of lighting than used for automobile navigation.[citation needed]

## **7.4 Purposes of street lights**

There are three distinct main uses of street lights, each requiring different types of lights and placement. Misuse of the different types of lights can make the situation worse by compromising visibility or safety.

## **7.5 Beacon lights**

A modest steady light at the intersection of two roads is an aid to navigation because it helps a driver see the location of a side road as he comes closer to it and he can adjust his braking and know exactly where to turn if he intends to leave the main road or see if someone is at the intersection. A beacon light's function is to say "here I am" and even a dim light provides enough contrast against the dark night to serve the purpose. To

prevent the dangers caused by a car driving through a pool of light, a beacon light must never shine onto the main road, and not brightly onto the side road. In residential areas, this is usually the only appropriate lighting, and it has the bonus side effect of providing spill lighting onto any sidewalk there for the benefit of pedestrians. On Interstate highways this purpose is commonly served by simply placing reflectors at the sides of the road to reflect the light coming from people's headlights.

## **7.6 Roadway lights**

Street lights are not normally intended to illuminate the driving route (headlights are preferred), but to reveal signs and hazards outside of the headlights' beam[citation needed]. Because of the dangers discussed above, roadway lights are properly used sparingly and only when a particular situation justifies increasing the risk. This usually involves an intersection with several turning movements and much signage, situations where drivers must take in much information quickly that is not in the headlights' beam. In these situations (A freeway junction or exit ramp) the intersection may be lit so that drivers can quickly see all hazards, and a well designed plan will have gradually increasing lighting for approximately a quarter of a minute before the intersection and gradually decreasing lighting after it. The main stretches of highways remain unlighted to preserve the driver's night vision and increase the visibility of oncoming headlights. If there is a sharp curve where headlights will not illuminate the road, a light on the outside of the curve is often justified.

If it is desired to light a roadway (perhaps due to heavy and fast multilane traffic), to avoid the dangers of casual placement of street lights it should not be lit intermittently, as this requires repeated eye readjustment which implies eyestrain and temporary blindness when entering and leaving light pools. In this case the system is designed to eliminate the need for headlights. This is usually achieved with bright lights placed on high poles at close regular intervals so that there is consistent light along the route. The lighting goes from curb to curb.

Research a few years ago suggested that by comparison to other countries, more pedestrians are hit by motor vehicles at night in Britain. The theory behind this was that Britain almost exclusively, used low pressure sodium street lighting, (LPS); unlike the rest of the world that use mercury vapour gas discharge lighting. This was most noticeable when flying in from Europe at night and seeing a warm orange glow when approaching Britain. LPS lighting, being monochromatic, shows pedestrians as shadowy forms, unlike other forms of street lighting. In recognition of this, pedestrian crossings are now lit by additional "white" lighting, and sodium lighting is being replaced by modern types.[citation needed]

## **7.7 Security lighting**

A sodium vapor light. This type is often used as security lighting. Security lighting is similar to high-intensity lighting on a busy major street, with no pools of light and dark, but with the lighted area extending onto people's property, at least to their front door. This requires a different type of fixture and lens. The increased glare experienced by drivers going through the area might be considered a trade-off for increased security. This is what would normally be used along sidewalks in dense areas of cities. Often unappreciated is that the light from a full moon is brighter than most security lighting.

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