**Hill Air Force Base Case Study**
**New Lighting Technology Installation**

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**Abstract**

Sulfur lighting is the first lighting technology breakthrough in recent history. The world's largest installation of sulfur lighting was implemented by CES/Way International, Inc. at Hill Air Force Base in Utah, where it is used in aircraft hangars dedicated to F16 and C130 aircraft maintenance and overhaul. This case study outlines the Department of Energy's pilot project criteria for the Hill application, discusses in detail how the technology was developed and applied at Hill, reports savings results and describes the benefits and new opportunities that this new lighting alternative brings to the industry and its clients.

**Hollow Light Guide and Sulfur Lamp Background**

In 1881, the first U.S. light pipe patent was proposed using a reflective coating inside a tube to reflect light from wall to wall and pipe it down the tube. Using conventional mirrors does not work well because mirrors are only about 95 percent reflective with the rest of the light lost by absorption.[2]

Optical fibers composed of certain glasses or plastics can transport light much more efficiently, but are impractical for transporting large quantities of light. Large solid fibers or fiber bundles would be required. These bundles are heavy, difficult to install in many applications and exceedingly expensive.[2] Fiber optics were successfully produced and patented in the 1970's.

The prism light guide was patented in 1981, 100 years after the first patent on piping light appeared[2] and after a student at the University of British Columbia, Lorne Whitehead, recognized that prismatic materials in a hollow light guide could efficiently transport large quantities of light.

The first guides were constructed as rigid rectangular acrylic pipes with molded prisms, and each side of the ¼ inch thick rigid panel was flat.[2]

In 1983, 3M recognized that the macro-prism structure, which existed in these first thick-walled rigid panels, could be made as continuous film incorporating microscopic prisms with the same 90° geometry.[2] This film, known as 3M™ Optical Lighting Film (OLF) was brought to market in 1989. With the typical losses due to absorption and transmission, the reflectance efficiency of OLF has been calculated as approaching 99 percent.[1]

Using OLF, circular hollow light guides can be produced in a variety of sizes depending on the specific application. Based on the amount of light to be delivered and the distance it must be transported, tube diameters up to 10 inches or larger are routinely produced.[2]

In 1970, Fusion Systems began development of an electrodeless, microwave-powered lamp for UV applications. Twenty years later, the sulfur lamp was invented.

By 1992, Fusion Lighting was incorporated with exclusive rights to all visible technology of the sulfur lamp. The first commercial sulfur lamp, Solar 1000®, was brought to market in 1994 and subsequently won several awards for technological innovation. The next generation sulfur lamp is today's Light Drive™ 1000, introduced in 1997.

Sulfur lamp development by Fusion Lighting was backed by the U.S. Department of Energy (DOE) and NASA, who were interested in attaining extreme technical data on the lamp relating to its potential for reduced energy use, color rendering quality, efficacy, lamp life and light delivery systems.

Each sulfur light bulb contains a small amount of sulfur and inert argon gas. When the sulfur is bombarded by focused microwave energy, it forms a plasma that glows very brightly, producing light containing all colors of the rainbow, closely matching that of the sun, but with very little heat or ultraviolet (UV) in the beam.

Each bulb, about the size of a golf ball, runs at 1425 watts producing approximately 135,000 lumens with a color rendering index of 79. Because there are no filaments or other metal components, it is possible that the bulb may never need replacement.
Sulfur lamps are an efficient, powerful, bright, full-spectral light source with many different indoor and outdoor uses.

The sulfur lamp can be used in a number of configurations. It can be used with reflectors for replacing high bay fixtures or with a hollow light guide commonly called a "light pipe", for illuminating large areas.

In any configuration, the light emitted can be filtered, tinted, dimmed and reflected to meet precise lighting needs.

Sulfur lamp technology is being utilized today in appropriate configurations across a wide range of applications in U.S. and Europe, including airport tarmac, aquarium, automobile assembly plant, cold storage facility, gas station, gymnasiums/sports facility, highway signage, museum, plant growth, postal sorting facility and a subway station.[a]

The first DOE-sponsored applications of sulfur lamps in the U.S. are at the Smithsonian National Air and Space Museum and on the outside front canopy of DOE's Forrestall Building, both in Washington, D.C.

**Case Study**

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[a] Lighting Research Center, Rensselaer Polytechnic Institute, Lighting Futures, Volume 1, Number 3

**Hill Air Force Base Application**

***Background***

In 1996, DOE was looking for an aircraft hangar site in which to install a sulfur lighting demonstration project to illustrate the technology in a different application and help move it into the mainstream. They approached Andrews Air Force Base in Virginia with the idea of making the installation in the Presidential hangar for Air Force One. Andrews could not fund such a project, but Hill Air Force Base in Utah could because they were already in the midst of the first basewide, fence-to-fence energy systems upgrade ever undertaken by the military. CES/Way International, Inc. of Houston, Texas was implementing Hill's Energy Savings Performance Contract (ESPC). The Air Force suggested the sulfur lighting project be installed at Hill and CES/Way volunteered to support the project by using their lighting expertise to apply the new technology in a demonstration project to solve the base's low light problem.

Hill's original plan was to improve the quality of lighting in the low bay and hangar areas by doubling the number of lighting fixtures to reach the desired standard of 70 foot candles. Prior to the sulfur fusion lighting installation at HAFB, the existing mercury vapor and metal halide light fixtures produced very low light levels for the tasks performed in the hangars and low bays. For instance, in the low bays, fixtures mounted at 26 feet produced only 40-45 foot candles of light. In the high bays, 28-30 foot candles were produced by fixtures mounted at 45 feet. Needless to say, tremendous amount of task lighting was used to augment these poor light levels.

The DOE set criteria that had to be met by the pilot project. These were:

1. Must pay from savings
2. Must increase existing light levels
3. Must increase quality of light

What resulted at Hill AFB is the world's largest installation of the new sulfur lighting technology where it is used in aircraft hangars dedicated to F16 fighter and C130 cargo aircraft maintenance and overhaul.

*Installation Overview and Challenges*

Prior to beginning installation, a design team consisting of personnel from DOE, Fusion Lighting, Cooper Lighting, Ply-Light, 3M and CES/Way was assembled to develop the basic lighting concept.

It was agreed that light guides using Light Drive™ 1000 lamps would be used in the low bay area due to a mounting height requirement of 26 feet. Additional consideration had to be given to the task being performed, aircraft configuration and accessibility of the light sources for maintenance purposes.

Tightly spaced F-16 fighter aircraft are overhauled in the low bay area, so work occurred over and around the planes. Aircraft are parked in an overhaul dock for anywhere from 30 days to a full year and cannot be moved during that time period. The lighting system also had to be flexible enough to accommodate a change in aircraft should the mission change in the hangar.

All these considerations were met by installing light pipes and Light Drive™ 1000 lamps across the space. For maintenance, light sources were located over walk ways and drive ways so that no maintenance had to occur over aircraft. Should any change be made in the location or orientation of the docking station, the pattern of the light pipes would not have to be changed.

The light guides employed are ten-inch diameter tubes fabricated of multiple layers of plastic materials, with varying reflective and transmissive properties. Each ten-foot section of hollow light guide weighs approximately 30 pounds and are mounted on 16 foot centers. Forty-four (44) light pipes are installed, each being 105 feet long with a Fusion lamp module coupled to each pipe end.

In the large high bay hangars, a minimum mounting height of 45 feet was required by the Air Force to allow for work over and around three C-130 and two F-16 aircraft. Another consideration was to try to keep the same mounting points as the existing high bays to keep installation costs down.
Cooper Lighting designed a high bay fixture of metal refractor globes lined with glass to accommodate the Light Drive™ 1000 lamp. The new fixtures were installed in the same location as the old fixtures, so all design criteria were met.

In two of the four high bay hangars, replacement of the rigid conduit pendants up to 40 feet in length was necessary. This was accomplished by reaching over the docked aircraft to a height of 90 feet above the floor to make the installation.

Hill Air Force Base's sulfur fusion lighting retrofit reduced the number of fixtures in the low bay areas while increasing light levels to 70 foot candles using 88 sulfur lamps and 44 light pipes. In the hangars, the number of fixtures was maintained, but the lighting level was tripled. A total of 288 sulfur lamps were used.

***Projected Savings***

| | | Hill Air Force Base | | |
|---|---|---|---|---|
| | | Building 225<br>TOTAL SAVINGS | | MATERIAL COST<br>$997,462.40 |
| EXISTING KW | NEW KW | SAVED KW/MO | KW SAVINGS | ENERGY SAVING |
| 1123.84 | 410.4 | 713.4 | $48,542.46 | $140,176.69 |
| EXISTING KWH | NEW KWH | SAVED KWH/YR | KWH SAVINGS | SIMPLE PAYBACK |
| 5,843,968.0 | 2,134,080.0 | 3,709,888.0 | $91,634.23 | 7.12 |

*Re-Lamping Results*

Pacific Northwest National Laboratory undertook to assess the efficiency and performance of the system with the following findings:

Lighting Level [4]

Compared to the high-intensity discharge systems they replaced, the sulfur lamps produces lighting levels that were 39%-47% higher in the low bay area and 130%-160% higher in the high bay area.

Energy Consumption [4]

In comparison to an appropriately designed lighting system to achieve comparable lighting levels with metal halide lamps, sulfur lamps would consume 17% less energy in the low bay area and 37% less energy in the high bay area. But due to inadequate pre-retrofit lighting, requirement to use pre-existing fixture locations which were closer than optimally placed and the addition of 32 more sulfur lamps to illuminate side and storage areas not previously lighted, energy consumption increase by 63% in the high bay area.

However, if all pre-retrofit lighting had been working and additional side lights had not been installed, high bay energy consumption would have increased by only 26% and still provide at least twice the light level. Where sulfur light guides replace inefficient fixtures in the low bay area, energy consumption decreased by 42%. The sulfur lamp retrofit must be viewed as a total package, not each section as a stand-alone.

Lighting Quality [4]

Workers in the building reported being able to read samples of small type more easily after the sulfur lamp installation. They are better able to make out lettering on control panels as well as the colors of wiring – due not only to higher light levels, but also to excellent color rendering. Some workers were bothered by computer screen reflection, probably due to increased light levels.

Hill AFB Pilot Project Results Recap

- The new lighting has been uniformly accepted by the aircraft workers.
- Light levels and general distribution of light in the low-bay areas (light pipe installation) is much more uniform than the previous lighting system.
- Light levels and general distribution of light in the high bay areas, traditional down-light fixture using the Fusion light source, has been dramatically improved. Light level readings have been increased from an average of 30 foot candles to 80+ foot candles.
- Low bay area number of fixtures reduced while light levels increased
- High bay number of fixtures retained but lighting level doubled
- With a project of this nature, you cannot do too much planning!

The Hill Air Force Base sulfur fusion lighting retrofit is the first of its kind in a federal ESPC project. Its use and its implications for energy savings and lighting efficacy has far-reaching significance to lighting designers and engineers, public and private utilities, the military, government and private sector industries such as automobile manufacturing and aviation.

**Benefits of the Technology**

Sulfur lighting offers the following advantages:

- Improved visual performance with full color sun-like spectrum
- Low operating costs due to energy efficiency
- Lower cost of ownership over the lifetime of the lighting system
- Minimal heat in light beam enabling wider choice of materials for use in optics
- Minimal degradation of materials exposed to light - no UV filters needed for most applications
- Improved control of light and greater light distribution efficiency
- Much more light emitted over the life of the lighting system – 100% at 60,000 hours
- No observable color shifts over life of lamp - no need to match lamps or to relamp for color consistency
- No drop-off in performance due to burning in an off-vertical position
- More light faster with full light output in 20 seconds
- Less lighting down time with hot restrike time of 5 minutes
- Longer life due to no filaments or electrodes
- Environmentally friendly due to no mercury - no risk of exposure to toxins in event of bulb failure and no additional disposal cost for spent lamps
- Reduces energy and gives more control of lighting by dimming capability to 30%
- Broad range of application across numerous markets

**References**


1. S.G. Saxe, L. Whitehead and S. Cobb, Jr., *Materials and Optics for Solar Energy Conversion and Advanced Lighting Technology*, SPIE Volume 692, 1986, p.235.
2. K.G. Kniepp, Remote Lighting Applications, *Energy Engineering*, Volume 93, Number 4, 1996, p.29, 30, 31, 32, 33.
3. Fusion Lighting, Light Drive™ 1000 Product Sheet, 1997.
4. E. E. Richman, J. H. Heerwagen, J. B. Hollomon, *Demonstration and Assessment of Sulfur Lamp Retrofit Lighting System at Hill Air Force Base, Utah*, Pacific Northwest National Laboratory Report #PNL-11976, September 1998.

**LIGHT DRIVE™ 1000 SPECIFICATIONS** [3]

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|---|---|
| **ELECTRICAL INPUTS** | |
| 1425 Watts Input Power | |
| 200-240V, 50/60 Hz 1ϕ | |
| 277V, 60 Hz 1ϕ | |
| **PHYSICAL** | |
| Lamp Mass With Integral Electronic Power Supply | 15.4 lbs. |
| **OUTPUT** | |
| Total Luminous Flux | 135,000 lumens |
| Correlated Color Temperature | 6000 K |
| Color Rendering Index ($R_3$) | 79 |
| Average Luminance | 19 Candela/Mm$^2$ |
| Flicker (Max-Min)/Max | 0* |
| X, Y Chromaticity Coordinate | 0.3171, 0.397 |
| S/P Ration | 2.4 |
| *As perceived by human vision | |
| **DESIGN LIFETIME** | |
| Lamp System Excluding Magnetron | 60,000 Hours |
| Magnetron** | 20,000 Hours |
| **Two magnetron replacement kits provided with each Light Drive™ 1000 | |