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Comparative Life Cycle Assessment (LCA) of streetlight technologies for minor roads in United Arab Emirates

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ABSTRACT

In this work, the Life Cycle Assessment (LCA) method is used to investigate the environmental impacts of two recent energy efficient streetlight technologies, Ceramic Metal Halide (CMH) and Light Emitting Diode (LED), with the aim of assessing their application in Abu Dhabi — United Arab Emirates (UAE). The cradle to grave analysis for CMH and LED streetlights includes raw material extraction, production of streetlight fixture, use and end of life scenario, all modeled using the SimaPro software package. The results show that LED lights have larger environmental impact during the production stage, but this is offset during the operational life of the lamp, due to the lower energy consumption of LEDs. For both types of lamps, the production stage has significantly less overall impact when compared to the impact during their operational life. The analysis in this paper also covers a scenario where stand-alone light fixtures are powered by photovoltaic (PV) panels, with and without battery recycling, in addition to a scenario where the energy used for operation comes from a solar power plant. In all the cases analyzed, the LED lamp has a lower overall environmental impact. Furthermore, our analysis shows that most environmental impacts come from battery production, consumption of fossil fuels for energy, and transportation of parts.

Introduction

The need for street lighting has existed for a long time. On January 28, 1807, Pall Mall in London witnessed the first street lighting powered by gas. About 70 years later, the first electric street lighting was developed by Russian Pavel Yablochkov (Pohl, 2006).

Many different lighting technologies have been developed and used for outdoor illumination, with energy efficiency and lighting quality increasing continuously over the years. Electric street lighting has varied from using incandescent bulbs, to the use of more energy efficient technologies, such as high pressure sodium (HPS), metal halide (MH), Ceramic Metal Halide (CMH), Light Emitting Diode (LED) and induction lamps. With increasing world population and urbanization, the amount of energy used for lighting of public areas is also increasing, so energy savings in this field would have significant positive impact on the environment.

When choosing the appropriate lighting technology for roadway lighting, care has to be taken to ensure that the level of illumination satisfies road safety standards. In order to have safe roads at night, luminous flux (lm) and illuminance (lumen/m^2 = lux) should be sufficiently high to provide adequate illumination of the road and quality of colors perceived by human eye should preferably be as high as possible. Acceptable standards for illuminance on roads, parking areas and highways can range between 5 to 30 lx, with higher lux levels at cross sections and places with more pedestrians (Schreder, 2012). The color rendering index (CRI) is a factor that indicates the comparison of lamp light to daylight, where CRI is considered to be 100 if colors are perceived similarly to daylight conditions (Descottes and Ramos, 2011).

This project aims to compare two types of lamps from the latest streetlight technologies, dedicated Light Emitting Diode (LED) and Ceramic Metal Halide (CMH) bulb, in order to determine which lamp is more efficient and could be installed on the internal (minor) roads of the Emirate of Abu Dhabi, UAE. The lamps are chosen based on the same range of luminescence and CRI, according to standards for safe road lighting. While high pressure sodium (HPS) lamps are currently most widely used in street lighting since they are very efficient, with lumen efficacy greater than 100 lm/W, their color temperature of 2000 K and low CRI in the range of 20–30 (OSRAM, 2013) do not compare favorably with the state of the art streetlight technologies. The main motivation for choosing road lighting in Abu Dhabi as a study subject is that most of the roads in UAE are very well illuminated, consuming a significant amount of energy. The total length of Abu Dhabi internal roads is 8379 km (Statistics Centre — Abu Dhabi, 2011) with an average distance of 20–50 m between two light poles on junctions and internal roads. If it is assumed that 70% of internal roads are lit and that the distance between the light poles is fixed at 50 m, then it can be calculated that there are about 117,000 high intensity lamps working 12 h a day, throughout the year. Having even a minor added environmental improvement per light pole will result in a significant decrease in greenhouse gas emissions. Moreover, Abu Dhabi has committed itself to sustainable

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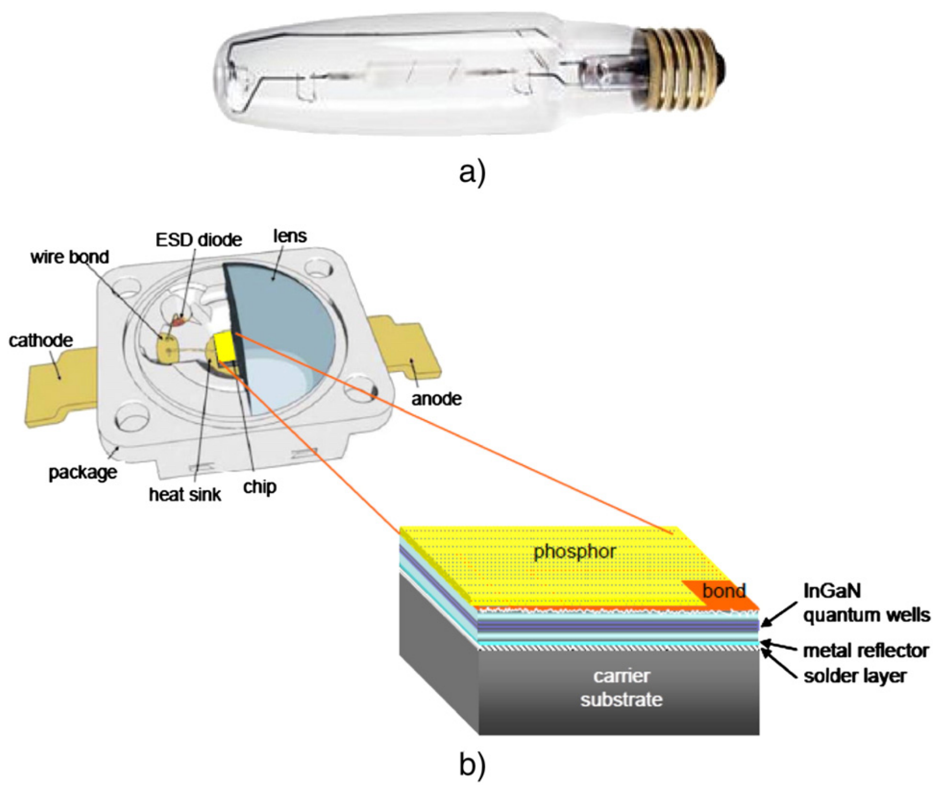

Fig. 1. (a) MasterColor HPS — retro fit CMH bulb by Phillips (Philips Lighting Solutions, 2012), (b) Schematic drawing of OSRAM's LED and the cross section of an LED chip (OSRAM, 2009).

development (Abu Dhabi Sustainable Group, 2012). The results of comparative LCA analysis for CMH and LED streetlight technologies could help the government of Abu Dhabi in choosing the most efficient and environment friendly option while accommodating the increasing energy needs of the constantly growing population. However, the methodology developed in this work is equally applicable to other cities around the world.

Ceramic Metal Halide (CMH) lamps

Metal halide (MH) lamps belong to the group of high pressure discharge lamps, similar to high pressure sodium lamps, where light is generated by a gas discharge of particles created between two hermetically sealed electrodes in an arc tube (OSRAM AG, 2012). Each MH lamp contains approximately 5 mg of mercury, and an arc tube filled with a gaseous mix of metal halides that are used to produce bright white color (Navigant Consulting Europe, Ltd., 2009). The first generation of MH lamps were made with high purity quartz arc tubes (OSRAM AG, 2012) but are susceptible to color shift during the operational life, due to loss of the arc material and mitigation of halides (GE Lighting, 2005). Ceramic Metal Halide (CMH) lamps use ceramic arc tubes as opposed to quartz tubes. Ceramic arc tubes can withstand higher temperatures than quartz, allowing more efficient use of chemicals, providing improved luminous efficacy and color rendering index. While quartz MH lamps operate at ~80 lm/W (GE Lighting, 2013), CMH lamps are as efficient as HPS lamps with 100 lm/W lumen efficacy (GE Lighting, 2005; OSRAM, 2013). Furthermore, CMH lamps have constant color throughout the lamp's operational life and CRI > 90, providing almost daylight conditions (GE Lighting, 2005), unlike quartz MH or HPS lamps, with CRI ~70 and ~20, respectively (GE Lighting, 2013; OSRAM, 2013). CMH lamps combine the bright white light properties of MH technology, such as high CRI and color temperature above 3000 K (GE Lighting, 2013), with lumen efficacy of HPS technology. With these properties, CMH lamps provide very efficient street illumination. A big advantage of CMH bulbs is that they can be used as retro-fit to HPS light fixtures,

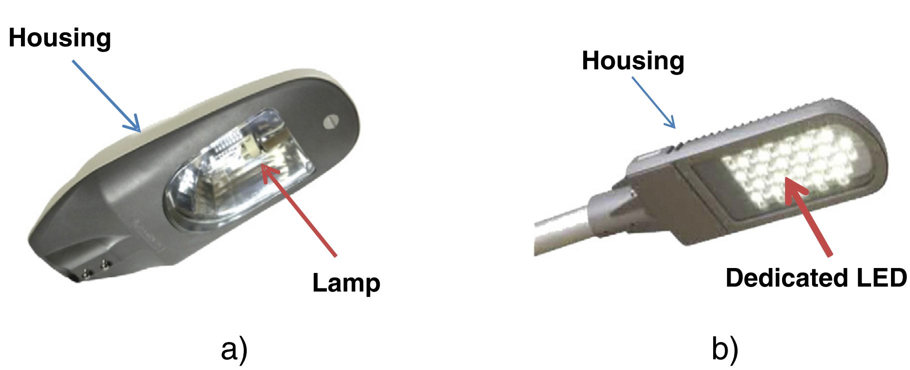

Fig. 2. CMH (a) and LED (b) streetlight fixtures (CMH Street Light, n.d; LED Street Light, n.d).