# ISA Technical Report

## ISA TCS Position Statement on LED Full Life Cycle Assessment

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International Solid State Lighting Alliance

Technical Committee on Standardization

This statement is prepared by ISA Technical Committee on Standardization.

Working Group 1:

"Research Development of Cycle-LED Program: Progress Update LED Recycling and Full Life Cycle"

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# 1. Background

Climate change that has led to an increasing number of extreme weather events has become center of attention over the past few years. Our anthropogenic activities are believed to be the main cause behind it. The rapid advancement of economy inevitably brings excessive use of natural resources, causing serious environmental deterioration problems. Nowadays, a phase out regulation of banning the manufacture, importation or sale of incandescent light bulbs for general lighting has been widely executed all over the world. By upgrading the traditional light source to LED, an approximate €300billion in the global energy bill and 1,000 MT of $CO_2$ emissions is reduced every year, resulting in a great benefit to the environmental protection. However, the waste gases produced by a LED lighting product comes from not merely the electricity consumption during its operation, but also any part in its whole life cycle, such as its manufacturing process and material recycle process when it is discarded. Unfortunately, there have only a few researches considering the environment impact for a LED lighting product within its whole life cycle from raw materials to end-of-life, which is a key step to achieve the sustainable and green development for LED lighting industry. Thus, the purpose of this statement is to propose a life cycle assessment (LCA) methodology to analyze the environment impact for a LED lighting product by considering the greenhouse gases (GHG) emissions during its life-cycle, material recycle, replace and maintenance, end-of-life estimation and so on.

# 2. Advancement of the development of LED lighting products

Today, artificial lighting consumes around 19% of the world's total energy, which produces approximately 10% of all carbon emitted in the world [1][2]. In the long lighting history, traditional lighting sources (i.e. incandescent bulbs and fluorescent lamps) rely on thermal radiation or fluorescence to convert electricity to light, which are very inefficient. For example, an incandescent bulb converts only about 5% of electrical energy into visible light and its luminous efficacy is only ~10lm/W, while the luminous efficiency of fluorescent lamp is only 20% [3]. By contrast, Light-emitting diodes (LEDs) produce visible light via electroluminescence which converts electricity to light without relying on heat for radiation (luminous efficacy>200lm/W, luminous efficiency>30% [4]). Therefore, LED is much more efficient and it has become a comparatively low-energy consuming, long lasting and environmentally friendly alternative to traditional lighting sources. Now LED is primed to play a critical role in the future of TVs and commercial displays / backlighting, mobile communications, and medical applications [5]. Thus, the 2014 Nobel Prize in Physics was awarded for inventing of blue LEDs.

Since the early 1990s, invention of the first commercial blue LED chip makes LEDs feasible for white lighting applications through phosphor conversion or RGB technique [7]. Under 20 years of development, the LED products as light source and illuminants undergoes great improvements on luminous efficacy, color quality, lifetime, cost-effectiveness, etc [6]-[8]. In addition, LED lighting products gain continuous support from a large number of governments around the world via various policies and regulations. As a result, a rapid growth hits LED lighting market in recent years, leading to a market penetration rate approaching to 30% in 2017. During this process, a lot of splendid large scale internal and external lighting projects are emerged by using LED technique, for instance the “New LED Illumination for the Sistine Chapel”, “City of Los Angeles LED Conversion Project”, “Hong Kong subway lighting energy-saving renovation project”, etc[9].

# 3. Research progress on LCA of the LED lighting products

LCA is a way to quantitatively characterize the environmental impacts induced by an industrial product during its full life cycle, originating from the raw material extraction, through manufacture, distribution, operation, to disposal/recycle. The parameter of qualifying the impact extent of the product to environment is called functional unit, which must be clear defined and easily measured in a LCA analysis. In general, the functional unit could be different depending on the special goal and scope of the LCA analysis. For light sources, a variety of functional units such as “illuminance on 1 m distance on a 1 $m^2$ surface”, “lumen hour” or “hour” are found in literature [10]-[22]. However, these parameters are only convenient to be used in comparing the energy cost-efficiency amongst different lamps and luminaires during the use stage, but not for the other stages such as manufacturing and recycling.

By taking into account the energy consumption in all stages, parameters linked to electrical power consumption seems more suitable to be the functional unit in an overall qualification over the full life cycle. In this scenario, a research team from the Hong Kong Polytechnic University employed “carbon footprint of products (CFP)” as the functional unit in the LCA analysis of electrical products [23]. Detailed methodology of CFP extraction of products refers to calculations of greenhouse gas (GHG) emissions in ISO 14067 standard [24]. However, in their study, effect of power output of the product is not taken into account when using CFP to evaluate the environmental impact assessment. That means CFPs extracted from the LED lighting products with different rate powers are not comparable. Therefore, it is not applicable to be directly used as the functional unit in LCA analysis of LED lighting products.

# 4. Proposals

During the LCA analysis, the unit processes are grouped into five successive stages: raw material acquisition, manufacturing, transportation, use and end of use. The carbon footprint occurred at each stage is characterized by GHG emission in a carbon dioxide equivalent (with the unit of “kg $CO_2$ eq.”), and calculated by the following formula [24].

$$CF = \text{Activity Data} \times \text{GHG Emission Factor} \times \text{Global Warming Potential}$$

in which CF indicates the carbon footprint, “GHG Emission Factor” with the unit of “kg CO2 eq. /unit” indicates the mass of a GHG emitted relative to an input or output of a unit process or a combination of unit processes, “Global Warming Potential” describes the mass of carbon oxide that has the same accumulated radiative forcing over a given period of time as one mass unit of a given GHG.

Following the guidelines described in ISO 14067, carbon footprint over the entire life cycle of the LED lighting product is expressed by a summation of contribution at each stage, as shown in below.

$$CF_{total} = CF_{RM} + CF_{M} + CF_{D} + CF_{U} + CF_{EOL}$$

in which $CF_{RM}$ is the carbon footprint of the raw material stage (kg CO2 eq.); $CF_{M}$ is the carbon footprint of manufacturing stage (kg CO2 eq.); $CF_{D}$ is the carbon footprint of distribution stage (kg CO2 eq.); $CF_{U}$ is the carbon footprint of use stage (kg CO2 eq.); $CF_{EOL}$ is the carbon footprint of end of life stage (kg CO2 eq.).

For considering the functionality, environmental impact and cost as a whole, we propose a new parameter, i.e. CF/lumen-hour, as the function unit to carry out the full life cycle assessment of LED lighting products. This new function parameter is calculated by normalizing the carbon footprint by a product of luminous flux and lifetime.

$$CF/lumen\text{-}hour = CF/ (\Phi \times L)$$

in which Φ indicates the rated luminous flux of the LED lighting product, L indicates the lifetime of the LED lighting product, such as the $L_{70}$ (the period when lumen maintenance decays to 70% of its initial value) or the real operational life. Then the LCA study of the LED lighting product can be performed by four phases: a) goal and scope definition; b) life cycle inventory (LCI); c) life cycle impact assessment (LCIA); and d) life cycle interpretation, as described in ISO 14040 and ISO 14044[25][26].

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