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ACCELERATING THE DEPLOYMENT OF SOLID STATE LIGHTING (SSL) IN EUROPE*

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EXECUTIVE SUMMARY

Solid State Lighting, in particular the use of LEDs and OLEDs for general lighting, is a promising technology with high growth potential in Europe. The path for the development of SSL in Europe is sketched out in the Green Paper on SSL of the European Commission. The current study supports the direction taken in the green paper towards deployment of SSL.

Lighting represents 19% of global electricity use and 14% of electricity consumption in the EU. The energy savings potential is particularly high in the residential and tertiary sectors; however there is also a significant potential in outdoor and industry.

SSL has many applications. The sectors where the technology is mature are evolving rapidly. Specifically, mass adoption has shifted from niche markets such as traffic lights and signage to architectural lighting and automotive industry, whereas the next step will be mass usage in the general lighting sector. In terms of value, architectural applications represent the largest proportion with 45% of global revenues.

Europe still has a dominant position in the area of lighting. It hosts the two world largest lighting companies and many of the top-10 lighting fixtures companies. The challenge is to keep this position, even if most of the production takes place in Asia.

A distinction has to be made between replacement and retrofit market, expecting to have high growth by 2014-15, and the new lighting fixtures and luminaires, anticipated to take up rather by 2020.

European consumers are particularly keen to have dimmable LED products. So far outdoor applications of SSL have outperformed indoor applications in terms of market value but the trend is expected to be reversed by 2020.

Lighting uses mainly high-brightness LEDs, low-power LEDs are still in use for some niche lighting applications. Today, architectural, decorative and scenic lighting represent the highest penetration rate for LEDs. In the domain of general lighting, LEDs start penetrating the outdoor lighting sector; however the part for indoor applications is rapidly increasing. Concerning indoor lighting, LED penetration in the residential sector is low and the growth rate is still slow.

The LED industry is rather fragmented. It is usually divided into five segments: materials, equipment, finished lamps and components, luminaires and systems, and finally lighting services and solutions. In the medium and long run, the latter is expected to become important as consumers could be provided with lighting services instead of lamps and fixtures.

LEDs are made from a variety of semiconductor materials, including various rare earth elements (REE). China is the main producer but also consumer of REE, which can bring some risks to Europe due to its strong dependence on China. Solutions to limit this dependence include opening new mines or recycling REE.

As LED chip production is a profitable activity, many companies have been created on the segment of LED chips, many of them being in China.

The European manufacturing base is strong in the downstream segments of the value chain close to the application (40%) but it is weaker in the upstream segments (LED packaging, chips, wafers). MOCVD (metal organic chemical vapour deposition) equipment is still mainly produced in Europe.

The big three in the SSL industry are the traditional lighting players Philips, Osram and GE. The manufacturing structure consists of a) product design, b) product manufacturing and c) marketing and sales. In Asia, companies are active in a) and b) often for non-Asian firms who are in charge of marketing and sales. European companies are active in market design and marketing and sales and often outsource manufacturing in Asia (sometimes through a subsidiary).

R&D takes place mainly in Japan, the US and Europe. Through patent cross-licensing however the research base becomes broader, including China, Taiwan and South Korea. Europe is suffering from fragmented funding. Taiwan has the largest investment worldwide, estimated at $600 million, 70% being private. Korea's R&D is also mainly privately financed, whereas in China, the government is investing heavily in research.

LED commercialisation channels might face a reshuffle, in particular when the industry will be moving to lighting services. For LEDs to penetrate the market more, end-user information and training, as well as training for installers, would be necessary.

LED is still a costly product, in particular in the general lighting segment where alternatives remain cheaper. The price needed for mass adoption has not yet been reached. It is estimated that a price of $8 would allow a 25% market share for LEDs. In Europe, a price of €10 would allow to reach, after some time, a 50% market share for LEDs versus 50% for CFLs in the residential sector. It is to be noted that the price for LED bulbs differs from one continent (and one country) to another, e.g. LED bulbs are cheaper in Japan than they are in the US or Europe.

Despite the potential of SSL for energy efficiency and also better lighting, many obstacles to its development remain.

Cost and consequently payback time are not yet in the advantage of LED-based general illumination, compared to conventional lighting technologies. Quality is an issue, particularly in the absence of standards, both for testing and for final products. Luminous efficacy and lifetime (by luminaire design) can still be improved. Last but not least, educational barriers remain, that could be overcome by training of all players in the market, from the designer to the user.

Europe is also suffering from a lack of market-oriented public-private partnerships and programmes, a lack of incentives from the government compared to other parts of the world, from a fragmented luminaire market and inadequate supply chain, to quote a few.

Various initiatives are taking place in terms of standards and the first results are coming, such as interoperability standards from Zhaga.

As far as the environment is concerned, LEDs do not contain mercury. Life cycle analysis seems to be quite favourable for SSL but further research into environment and health benefits will be required to confirm this.

Europe has a dominant position in lighting, but is faced with challenges to keep its advantage and to keep the pace in a quickly changing market.

Some of the obstacles to mass adoption in the general lighting segment will disappear as technology evolves to cheaper products with better light quality. But price and energy efficiency might not be the only selling elements for LEDs. Innovation might be an important asset when designing new lighting products.

Further legislation and policy initiatives addressing SSL will need to be designed in such a way to reinforce Europe's strategic strengths in the lighting sector, as proposed in the Green paper on SSL of the European Commission.

Accelerating the deployment of Solid State Lighting (SSL) in Europe

1. Introduction

The Joint Research Centre of the European Commission has been contracted a study on the current and future prospects of the Solid State Lighting (SSL) in Europe. This study will be an input to the Digital Agenda for Europe (DG INFSO of the European Commission), which will give policy options to foster the SSL markets in Europe.

1.1. *Scope and Objectives of the work*

The scope of the present study is Solid State Lighting, i.e. the use of LEDs and OLEDs for general lighting (indoor and outdoor, including street lighting), but not the other uses of LED (displays, such as TV and mobile phones, seven-segment displays[1], signalling, such as advertisements, car lights, etc.).

The study's principal goal is to assess the current situation and conditions for a wide deployment of Solid State Lighting (SSL) in Europe with a view to support and follow-up on planned activities on general lighting addressed in the Digital Agenda for Europe (DAE), particularly:

(1) the preparation by the Commission of a Green Paper on SSL, which was published on 15 December 2011;

(2) an action aiming to encourage EU Member States to include, by 2012, specifications for total lifetime costs for all public procurement of lighting installations.

More specifically, the study aims to analyse the current situation of SSL in Europe, identify the barriers to its wider deployment and explore mechanisms for overcoming such barriers and accelerating SSL adoption. This is for the benefit of users in saving energy and in having better quality lighting. The study aims also to explore related supporting issues including public procurement, the creation of lead markets, as well as standardisation and certification aspects.

The study of the practices in public procurement in EU Member States for the particular case of lighting is the subject of a separate report, as well as the analysis of test cases for LEDs[2].

As regards public procurement, the study aims to examine and report on the practices in public procurement in EU Member States for the particular case of lighting and to propose approaches which could be applied in specifying total lifetime costs for public tenders for new lighting installations.

1.2. *Electricity consumption for lighting in Europe and in the World*

The global consumption of electricity has been increasing faster than the overall energy consumption because of the versatile nature of its production and consumption, as well as the relatively high

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[1] A seven-segment display (SSD), or seven-segment indicator, is a form of electronic display device for displaying decimal numerals that is an alternative to the more complex dot-matrix displays. Seven-segment displays are widely used in digital clocks, electronic meters, and other electronic devices for displaying numerical information.

[2] Michaela Valentová, Michel Quicheron and Paolo Bertoldi. 2011. *LED Projects and Economic Test Cases in Europe*. Available at http://ec.europa.eu/information_society/digital-agenda/actions/ssl-consultation/docs/led_report_test_cases.pdf

efficiency and cleanliness at the point of use. Lighting is an essential form of goods, or even services, for which usage has increased and will keep increasing.

Lighting was the first service offered by electric utilities and still continues to be one of the largest electrical end-uses. Globally it accounts for 650 Mtoe of primary energy consumption and results in emissions of almost 1 900 million tonnes (Mt) of CO_2. This is 70% of the emissions of the world's passenger vehicles and three times more than emissions from aviation (IEA, 2006).

Energy efficiency is one of the most effective means to tackle these problems. It can both save energy and reduce greenhouse gas emissions. The EU committed itself in its new energy policy to reduce energy consumption by 20% by 2020 and is taking new measures for that purpose. These measures include minimum efficiency requirements for energy-using equipment in buildings, industry, transport and energy generation.

The savings potential of lighting energy is very high with the current technology, and is even larger with the new energy-efficient lighting technologies coming onto the market. Currently, more than 33 billion lamps operate worldwide, consuming more than 2650 TWh of energy annually, which is 19% (Figure 1) of the global electricity consumption. Lighting uses a quite smaller fraction in the European Union (14%), as can be seen in Figure 2.

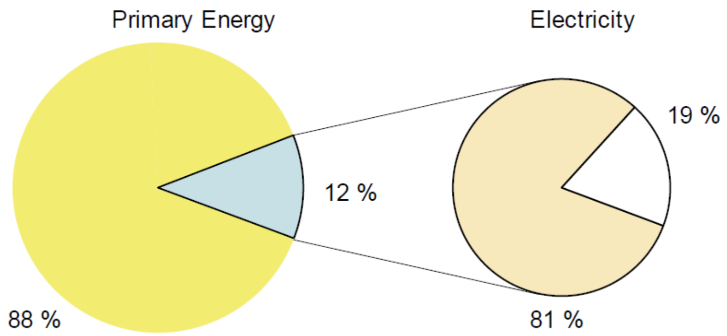


Figure 1 - Global Lighting Energy Use [IEA, 2006]

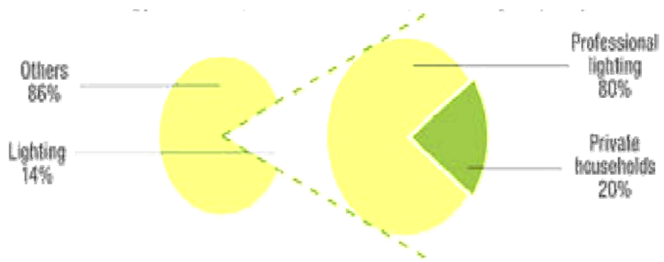


Figure 2 - Lighting Electricity Consumption in the EU [CELMA & ELC, 2011]

Globally, almost one-fifth of the total amount of electricity generated is consumed by the lighting sector. Almost half of the global lighting electricity is consumed by the commercial/tertiary sector, estimated at 1 133 TWh, representing 43% of lighting consumption. The rest is distributed between the residential sector with an estimated consumption of 811 TWh, representing 31% of lighting consumption, the industrial sector with an estimated 490 TWh, representing 18%, and the outdoor stationary sector with an estimated 218 TWh representing 8% of total lighting electricity consumption (IEA, 2006), as illustrated in Figure 3.

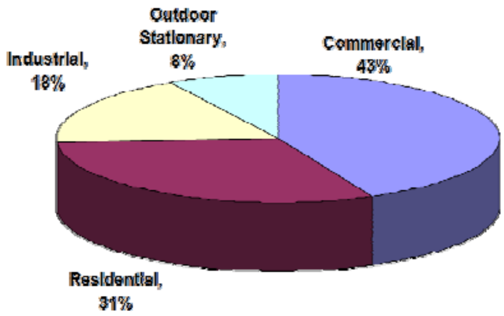


Figure 3 - World Lighting Consumption Shares by Sector in 2005 [IEA, 2006]

In the EU, lighting represents 14% of electricity consumption. The largest part of the lighting electricity is consumed by the tertiary sector estimated at 164 TWh, representing 40.2% of lighting consumption. The rest is distributed between the residential sector with an estimated consumption of 84 TWh representing 20.6% of lighting consumption, the industrial sector with an estimated 100 TWh, representing 24.5%, and the outdoor stationary (mostly street lighting) sector with an estimated 60 TWh representing 14.7% of total lighting electricity consumption, as can be seen in Figure 4.

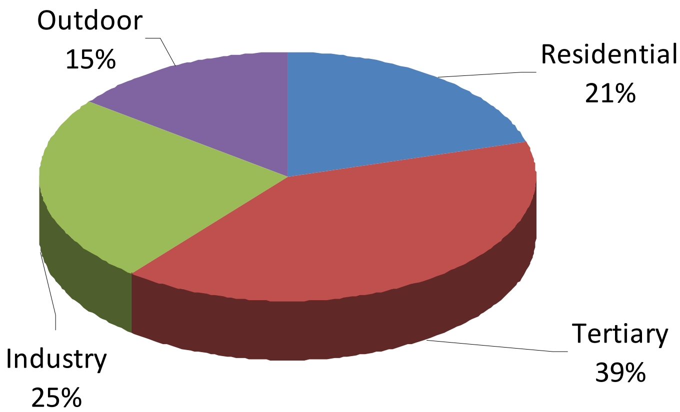


Figure 4 - European Lighting Consumption Shares by Sector in 2007 [ISR-University of Coimbra]

Artificial light sources play an indispensable role in the daily life of any human being. Electrical light sources are responsible for an energy consumption of around 2 650 TWh per annum for producing 133 Plm.h (peta-lumen-hour) of artificial light for the same period [Waide P, Tanishima S. Light's labour's lost: policies for energy-efficient lighting. IEA/OECD: Paris; 2006]. Line losses due to electricity transport have to be added to the above figure, then the global consolidated energy use reaches 3 418 TWh [Brown LR. Plan B 4.0: Mobilizing to Save Civilization, WW Norton & Co; 2009]. This represents almost 19% of worldwide electricity production or nearly 3% of world annual use of primary energy resources[3].

Increasing global awareness of environmental protection and energy conservation has brought about the rise of the energy-efficient lighting solutions. In addition, the OECD's incandescent lamp ban policy educates consumers on the concept of saving energy on lighting and using high-efficiency light sources. Both facts constitute a positive step forward promoting the development of the Solid-State Lighting market.

[3] In EU-27 this figure is estimated to be 10% in average of the final electricity consumption [Bertoldi P., CELMA / ELC LED Forum, Frankfurt 14 April 2010]

In fact, the lighting industry is facing the next revolution at this very moment: In the short/medium term SSL, inorganic and organic light emitting diodes, will become the next generation light sources. Today, LEDs, with a continuous growth of their *luminous efficiencies* (expressed in lm/W) and overall *energetic efficacies* (in %), establish themselves as breakthrough solutions for achieving substantial energy savings in the domain of lighting. Roughly a LED is an encapsulated semi-conductor crystal that has a p-n junction in it and emits light when unidirectional electric current is applied. Theoretically, an ideal semiconductor junction can transform 100% of the injected electrical power into incoherent and almost monochromatic light, this not of course possible in real life.

For several years, LED efficacy, reliability and light quality have been constantly increasing with amazing speed. In May 2011, Cree announced a breakthrough on the record of 231 lumens per watt (lm/W) for a white power LED laboratory prototype[4]. With a single-die component at a correlated colour temperature of 4 500 K and standard room temperature 350 mA testing, 231 lumens per watt for a white power LED have been demonstrated. In March 2011, Osram announced a warm white laboratory LED of 142 lm/W[5]. Moreover, it is possible today to procure commercially available High Brightness LEDs with efficacy going up to 135 lm/W at 1 A, as claimed by Nichia (September 2010)[6]. Concerning the efficacy to transform electricity into white light, the limit of 30-35% is now on reached.

1.3. LIGHT SOURCES

The largest amount of light, 64% of the total is delivered by fluorescent lamps, which have efficacies in the range 40–100 lm/W. Fluorescent lamps are used mostly to provide general-purpose indoor lighting in tertiary and industrial buildings. However, in some countries (such as Japan) fluorescent lighting is also the main source of household lighting. Cultural traditions and preferences appear to play a large role in determining the choice of residential lighting systems, with significant implications for energy consumption. Fluorescent lamps account for 20% of global lamp sales and 45% of electric-lighting energy consumption. The next major group of lighting technologies is high-intensity discharge (HID) lamps, including mercury vapour lamps, high- and low-pressure sodium lamps and metal halide lamps. These high-power lamps provide large amounts of light at medium to high efficacy levels (35–150 lm/W) and are used primarily for outdoor lighting (including street lighting), and for indoor lighting in spaces with high ceilings, such as in some industries. HID lamps account for 1% of global lamp sales, use 25% of global electric-lighting energy and provide 29% of the delivered light. Among HID lamps, mercury vapour lamps constitute an old and inefficient technology which, despite having low cost-effectiveness compared with the alternatives, still accounts for a significant share of total HID lighting applications. Both HID and fluorescent lamps are discharge lamps which require ballasts to regulate input voltages, frequencies and currents to enable the ignition and subsequent operation of the lamp. Ballasts need power in order to function, ranging from a few percent to as much as 40% of the total lighting system consumption, depending on the efficiency of the ballast adopted. Because the efficacy of these various lighting sources varies so profoundly, their relative level of use has a large impact on overall lighting energy consumption.

[4] http://article.wn.com/view/2011/05/09/Cree_231_Lumen_Per_Watt_LED_Shatters_LED_Efficacy_Records/

[5] http://www.led-professional.com/technology/light-generation/from-the-osram-laboratory-efficiency-record-for-warm-white

[6] http://www.ledsmagazine.com/news/7/9/4

1.4. DEFINITIONS[7]

LED refers to a light-emitting diode that is a semiconductor light source. LEDs are used as indicator lamps in many devices and are increasingly used for other lighting. Introduced as a practical electronic component in 1962, early LEDs emitted low-intensity red light, but modern versions are available across the visible, ultraviolet and infrared wavelengths, with very high brightness.

LEDs are used mainly for signage, displays and lighting (indoor, outdoor and automotive).

Solid-state lighting (SSL) refers to a type of lighting that uses semiconductor light-emitting diodes (LEDs), and organic light-emitting diodes (OLED) – also known as polymer light-emitting diodes (PLED) – as sources of illumination, rather than electrical filaments, plasma (used in arc lamps such as fluorescent lamps), or gas.

The term "solid state" refers commonly to light emitted by solid-state electroluminescence, as opposed to incandescent bulbs (which use thermal radiation) or fluorescent tubes. Compared to incandescent lighting, SSL creates visible light with reduced heat generation or parasitic energy dissipation. Most common "white" LEDs convert blue light from a solid-state device to an (approximate) white-light spectrum using photoluminescence, the same principle used in conventional fluorescent tubes.

Nowadays, there are three main LED product families (conventional or regular LEDs[8], High and Ultra-High Brightness LEDs). The following table gives some indication on that issue.

	Conventional LED	High Brightness LED	Ultra-high brightness white LED
Specifications	• 350x350 μm die • 30 mA, 3.5 V supply • < 200 mW power • External QE~20% • 20 lm/W • 1 to 3 lm generated • Typical epoxy housing	• Up to 1x1 mm² die • 350 mA, 3.5 V supply • Up to 1 Watt power • External QE > 30% • > 30 lm/W • 5 to 30 lm generated • Specific packaging	• Up to 2x2 mm² die • > 50A/cm² • up to 5 watt power • External QE > 30% • > 50 lm/W • > 100 lm generated • CRI ~ 80 • Specific packaging

Table 1 – Types of LEDs [Roussel, 2007]

When speaking about LED for Lighting, it is necessary to distinguish between the following items:

LED chip or die: The LED chip is a semiconductor device that emits incoherent optical radiation that may be in the ultraviolet, visible, or infrared wavelength regions. There is not a standardised process to make LED chips that takes the substrate and grows a layer of crystals with a complex combination of gases at a particular temperature. The uniformity of growing the crystals is critical to producing high-quality chips. The process is complex, capital-intensive and requires high-calibre human resource capacity.

LED control circuitry: Electronic components located between the power source and the LED array designed to limit voltage and current, to dim, to switch, or otherwise control the electrical energy to the LED array. The circuitry does not include a power source.

LED driver: A power source with integral LED control circuitry designed to meet the specific requirements of a LED lamp or a LED array.

[7] From Wikipedia: http://en.wikipedia.org/wiki/Light-emitting_diode and http://en.wikipedia.org/wiki/Solid-state_lighting
[8] Called also “low power LEDs” or “5mm LEDs”

LED package: LED packages refer to the assembly of one or more LEDs, including the mounting substrate, encapsulant, phosphor if applicable, electrical connections, and possibly optical components, along with thermal and mechanical interfaces.

LED Array or Module: This refers to an assembly of LED packages (components), or dies on a printed circuit board or substrate, possibly with optical elements and additional thermal, mechanical, and electrical interfaces that are intended to connect to the load side of a LED driver. Power source and ANSI standard base are not incorporated into the device. The device cannot be connected directly to the branch circuit.

LED lamp or bulb: There are two general categories of LED lamps: an integrated LED lamp, which refers to an assembly that is integrated with a LED driver and has a standardised base to connect it directly to an electrical circuit; and a non-integrated LED lamp, which refers to an assembly with an ANSI10 standardised base, but without a built-in LED driver. Non-integrated LED lamps are designed for connection to LED luminaires.

LED light engine: A subsystem of a LED luminaire that includes one or more LED packages, or a LED array, or LED module; and LED driver; electrical and mechanical interfaces; and an integral heat sink to provide thermal dissipation. A LED light engine may be designed to accept additional components that provide aesthetic, optical, and environmental control (other than thermal dissipation). A LED light engine is designed to connect to the branch circuit. A LED light engine with standardised base is an integrated LED lamp.

LED luminaire or fixture: This is the complete lighting unit that integrates LED components and is directly connected to an electrical branch circuit. It consists of a light source and driver, along with parts to distribute the light, and to connect, position, and protect the light source [Bardsley Consulting et al., 2010]. Luminaires can contain from one up to several hundred LED packages.

A luminaire typically includes the following components, besides the high-brightness (HB) LEDs:

-The **power conversion sub-system** includes the AC-DC converter and the LED driver. Its performance is critical for high-efficiency, high-current drivers and power management solutions at reasonable cost. The power conversion is a very fragmented market. The relatively low volumes in LED lighting have been a disincentive for companies to invest in this area;

-**Thermal materials and heat-sinks** provide thermal management, ensuring low operating temperature of the LED, an essential condition for long life;

-**Optical elements** are used to distribute spatially the light. Because of the directional nature of LEDs, the optical elements can be simpler than with other lamps (in some cases reflectors may be avoided);

-**Mechanical and Electrical** components serve for structural support, decoration and interconnections.

The above-mentioned components are produced by a large number of small- and medium-size companies.

1.5. APPLICATIONS OF LEDS - FROM MOBILE APPLICATIONS TO LIGHTING

As mentioned in the definitions, LEDs have been used for various applications.

Figure 5 shows the general trend in the application of LEDs (mostly High Brightness) spreading in three large areas:

- Phase I - mobile appliances, such as laptops and mobile phones in which their higher component cost is justified by the longer battery autonomy, as well as better display quality.

- Phase II - large displays, such as TVs and computer monitors, which by 2010 have transformed the market from CRT to flat screen technologies (Plasma, LCD with fluorescent backlighting and LCD with LED backlighting).
- Phase III – LED for lighting, that is SSL and in particular general illumination covering a wide variety of applications, as shown in Figure 6 and Figure 7, which also shows a time scale of product availability, as well as the timing of broad product acceptance.

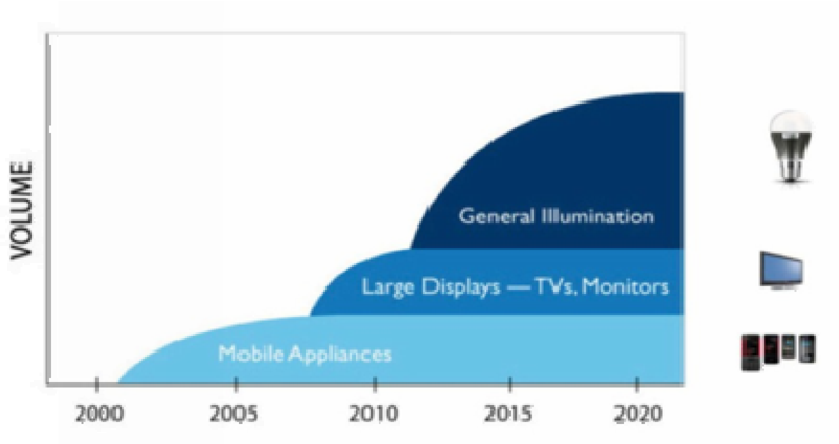


Figure 5 - LED application trends [CELMA; ELCFED, 2011]

The range of LED applications is much wider and is presented in Figure 6.

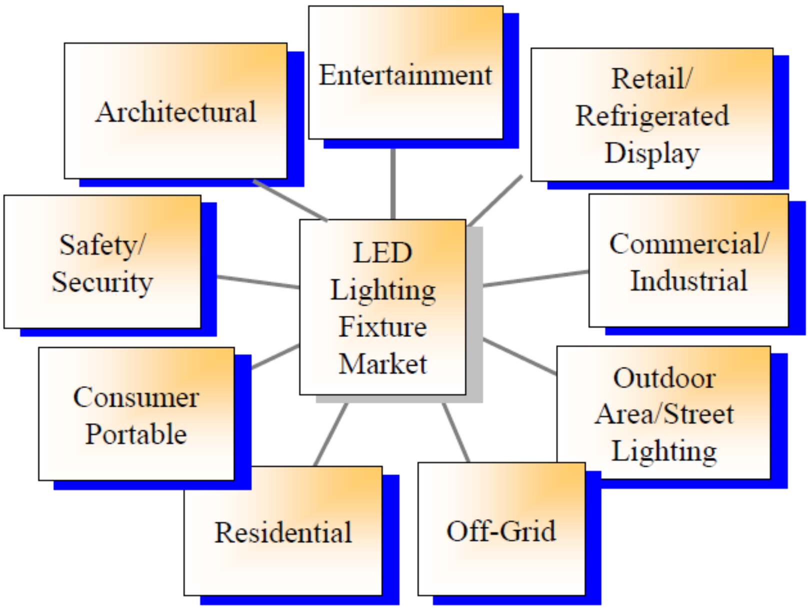


Figure 6 - LED Lighting Market Segmentation [Bhandarkar, 2009]

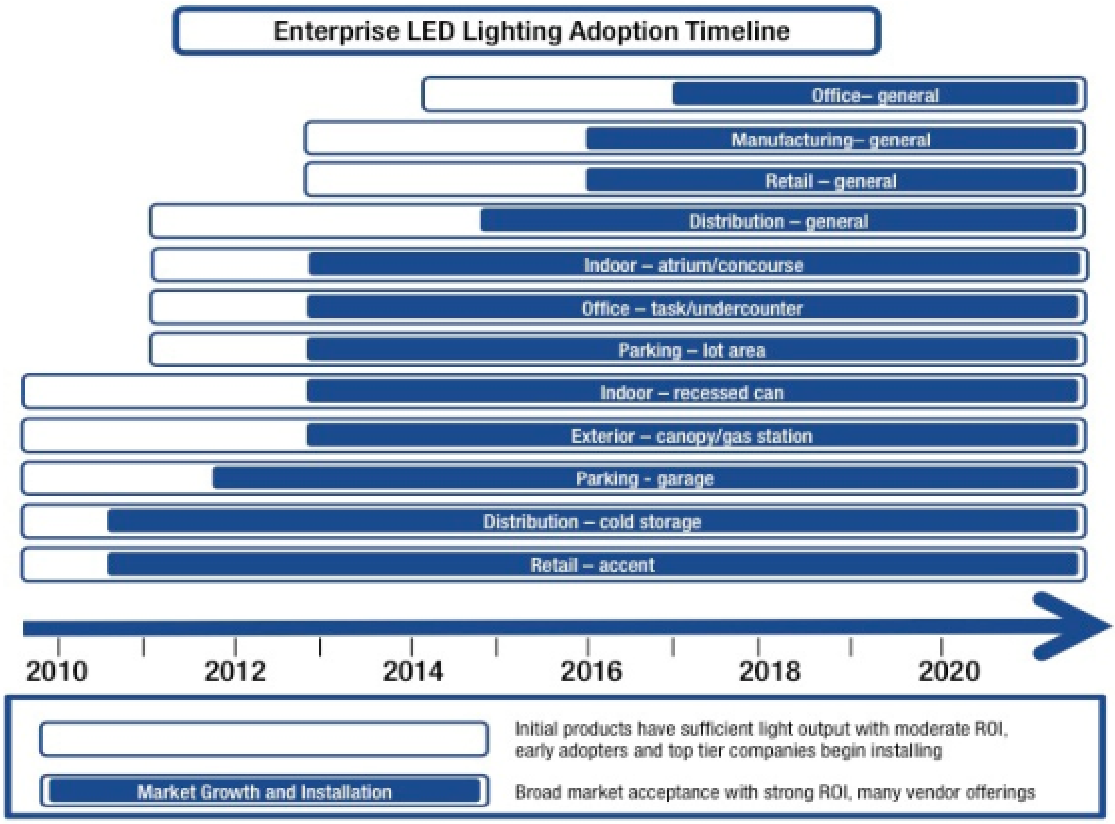


Figure 7 - Enterprise LED Lighting Adoption Timeline [GTM Research, 2010]

Figure 8 shows an overview of the evolution of applications of SSL in the last forty years. Initially, the market was dominated by signalling and display applications. Mobile automotive and entertainment applications followed, with lighting applications becoming more and more diversified in the last decade.

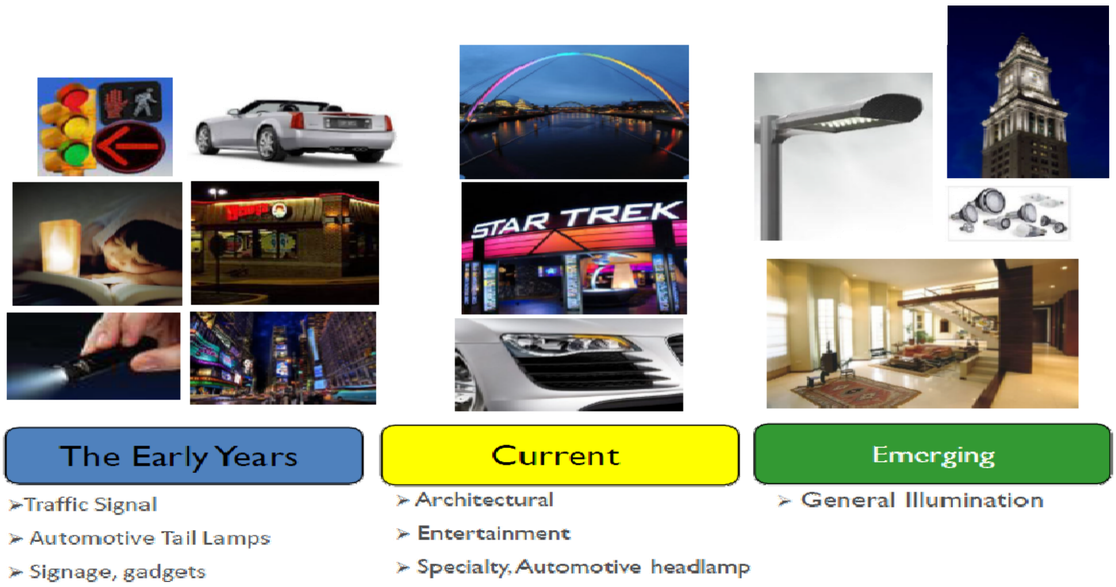


Figure 8 - Applications for Solid-State Lighting [Anderson, 2010]

New possibilities in Decorative and Architectural Lighting were opened by SSL, due to their superior colour and special distribution capabilities, as well as lower maintenance costs and improved design possibilities.

The use of LEDs is also becoming more common in Tertiary Buildings, to replace tubular fluorescent, CFL and halogen incandescent lamps. Energy savings vary over a wide range. In the replacement of halogen incandescent lamps, high efficiency LEDs slash the energy consumption by a factor of up to 10.

2. The Lighting and SSL markets

In the present chapter, the first focus will be given on the global SSL market and trends, followed by detailed presentation of the applications of SSL. More particularly, the market will be analysed by application and by region. The present paper will further analyse the outdoor and domestic lighting sector. This chapter will end with some conclusions.

Let us examine the global lighting market.

2.1. Global lighting market

In March 2011, the US Department of Energy (DoE) estimated the global world market for lighting to be approximately $110 billion[9] [Report on Solid-State Lighting Research and Development Multi-Year Program Plan, DoE, March 2011]. Another analyst gave the value of $96 billion for the same year, these values are comparable [Archenhold G., Integrated System Technologies, 2010]. Figure 9 gives the global lighting market growth since 1997 and the trend till 2019. In fact, by 2019 the market size will be expected to reach $165 billion.

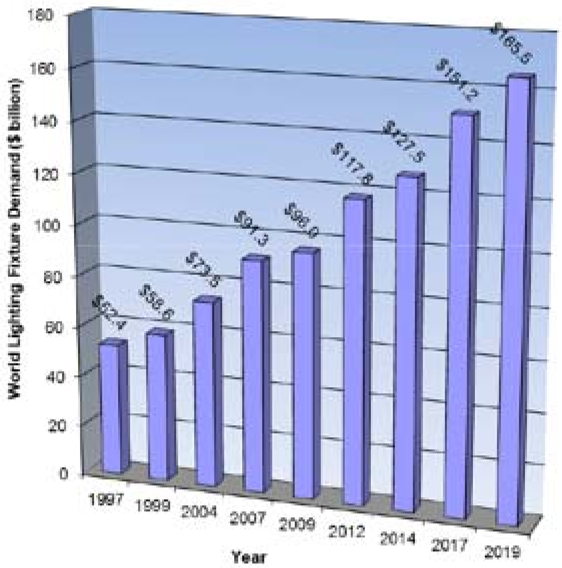


Figure 9 - Global lighting market growth [Archenhold G., Integrated System Technologies, 2010]

The observed growth is mainly driven by (a) global population growth (b) the developing nations demand for more lighting and (c) electrical grid development. Growth demand is seen mostly in:

- China (19.6%)
- Eastern Europe (8.1%)
- Other Asia (6.3%)
- Africa/Middle East (6.8%)
- Latin America (9.5%)
- Canada & Mexico (4.4%)

As shown in Figure 10, the lighting market is traditionally divided into two major segments: Light sources and Ballast/fixtures.

[9] The US market share is estimate to be approximately 25%, or $27 billion.

Figure 10 - Global lighting market segmentation (2009 values)

Taking for granted that the dominating technologies in 2009 were incandescent and fluorescent lamps, it is possible to split the $110 billion as follows: 62.2% for incandescent technology and 34.5% for fluorescent segment.

Figure 11 shows the market segmentation between consumer and professional applications.

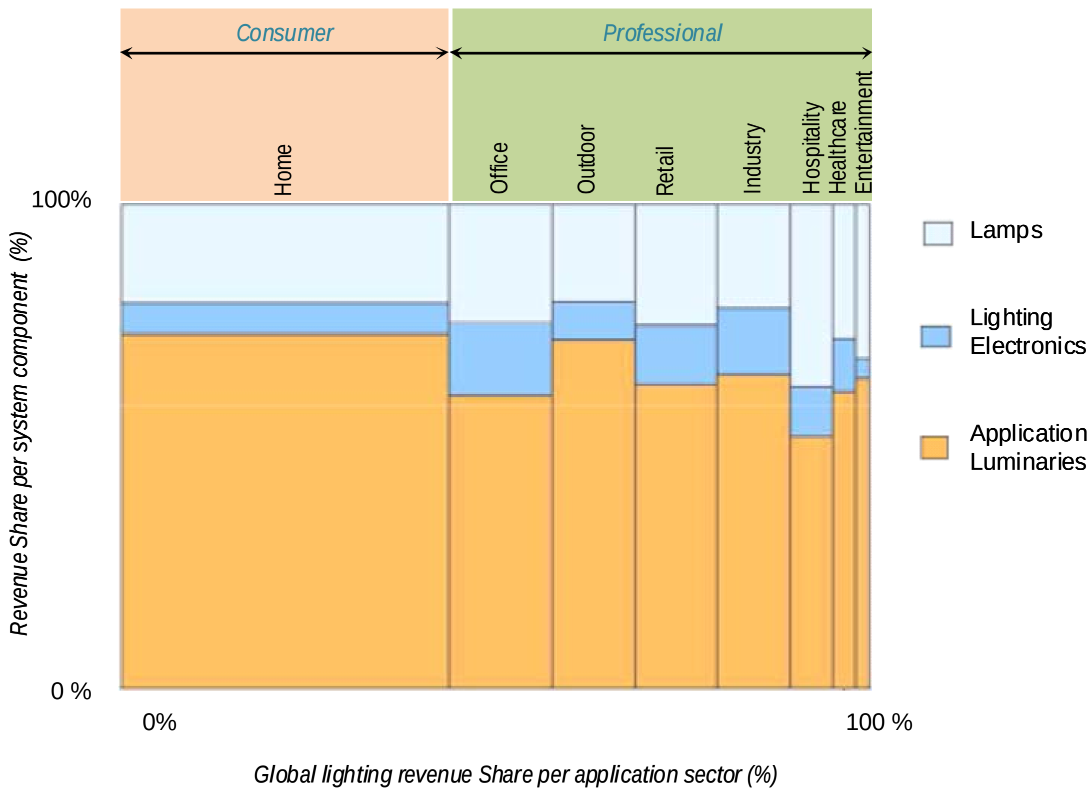


Figure 11 - Market segmentation in 2010 between consumer and professional applications [Philips Lighting Analysts Day, Boston, 2010, updated 2011]i

Furthermore, the lighting industry can be categorised into several domains as Figure 12 shows.

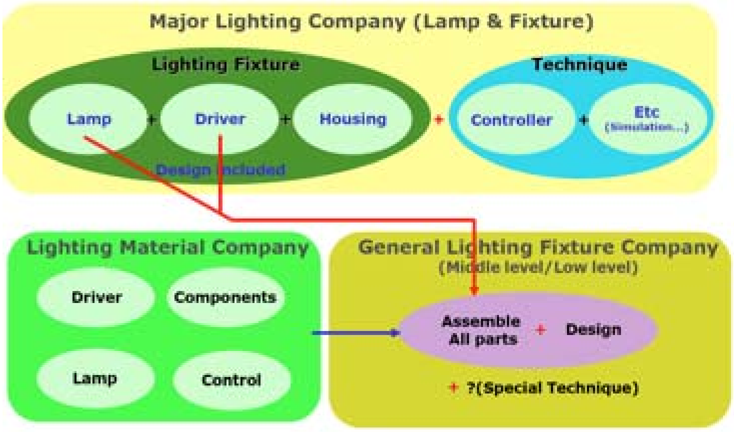


Figure 12 - Categorisation of Lighting industry [Archenhold G., Integrated System Technologies, 2010]

World production of lighting fixtures (top 60 countries) is worth about US$ 64.4 billion for the year 2008, with 8.9% increase in comparison with the previous year. The ten major countries, in order of lighting fixtures production, are China, the United States, Japan, Germany, Italy, Mexico, the United Kingdom, India, Spain and Brazil, which together produce 75% in value of the world total production. The world trade of lighting fixtures can be estimated at $26.5 billion of exports and $27.3 billion of imports (the difference is mostly due to transport costs, included in the accounting from the import side). According to CSIL, 40% of the world trade of lighting fixtures is made by residential lighting, 60% by technical lighting. [Volpe A. CSIL, Lighting Fixture Worldwide, June 2010]

Concerning the Light Sources market, it is dominated by three majors: Philips (NL) with 44% of the world market revenues, Osram (D) with 27% and General Electric (US) with 10% [Philips, 3rd Quarter 2011 report, 2011]. Large lighting companies control the access to sales and distribution channels and customer.

2.2. European lighting market

Expanding LED lighting is a 'no-brainer'. It means more money in your pocket, and a healthier planet. Please give us your ideas on how to speed up its deployment and maximise the number of jobs and savings Europe can gain from expanding the use of LED lighting.

Statement of European Commission Vice President Neelie Kroes on 15th December 2011, day of adoption of the EU Green Paper on Solid State Lighting].

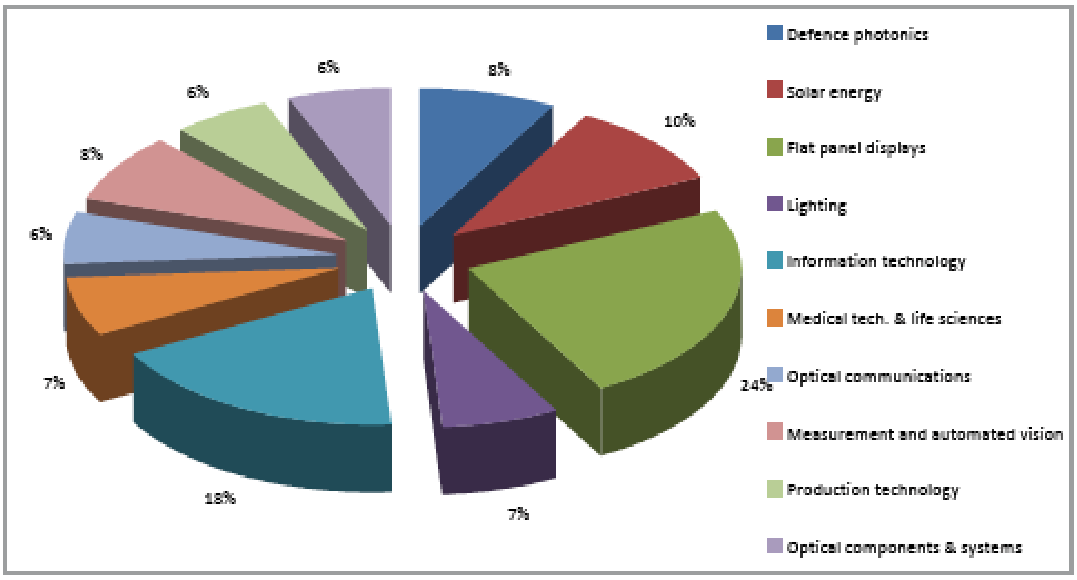


Figure 13 - World photonics production by sector (2008). Total: €277B, redrawn with modifications from [Optech Consulting, April 2010]

Although consistent updated information for the EU is not generally available, the world market as given in [Southern European Cluster in Photonics and Optics, 2010] can be compared for 2008 with the information from 2005 in [Optech Consulting, 2007] to extract some indicative trends. Most sectors have roughly the same proportion of world production. The world market for civil photonics products in 2008 was worth €256 billion, the defence market adding an additional €21bn - leading to an overall total of €277 billion [Optech Consulting, April 2010]. Figure 13 shows world photonics production by sector.

The best estimate of the size of EU photonics production in 2008 is €58.5 billion. Today, Europe's position is dominant in the area of lighting. The two largest worldwide lighting companies (Philips and Osram) are based in Europe. Furthermore, Germany, Italy, UK and Spain are ballooning to the top-10 of lighting fixture producers.

Referring to the production volume, the total market share of European companies (including overseas production plants) is estimated at about 50% for lamps (excluding LEDs).

Today already 1 000 SMEs dominate the EU lighting & luminaire market with an annual turnover of over €20 billion. Existing and new enterprises, including start-ups and new SMEs, will create new platforms for growth and further contribution to the EU's GDP. Exporting our leadership to developing and emerging countries will facilitate even further growth, including business in adjacent areas. Thereby further strengthening a global role for the EU. [Jürgen Sturm, ELC, Photonics 21, Feb. 2011]

The lighting industry in Europe currently employs an estimated 150 000 people. Leadership in SSL will not only maintain employment at this level but will create even more high quality jobs in adjacent areas like the communications industry, R&D centres, constructions sector etc. [Jürgen Sturm, ELC, Photonics 21, Feb. 2011].

Eastern European demand for lighting is rapidly growing with almost 8% per year. In 2010, the combined rebound of the main European economies after the 2008-2009 crisis, and the impact of new lighting technologies, allowed a recovery of the lighting fixtures demand: a 7% increase was achieved mostly through imports, while European production remained pretty stable [CSIL, The European market for lighting fixtures, June 2011].

As explained in the previous section of this document, growth of LED market resumed in 2010. Actual tendencies show that lighting will be from 2013 the 2nd largest HB LED application after backlights. Furthermore, Strategies Unlimited estimates that the global market for HB LEDs for lighting applications will increase from $1.7 billion in 2013 to $4.5 billion by 2015. Furthermore, LED-based products may become mainstream by 2015 [Morgan JP., Osram, 2010].

In 2008, about 50% of applications were using RGB LEDs, but white will increase to more than 70% of the market by 2013. Furthermore, white HB-LEDs accounted for 65% of the HB-LED market in lighting applications in 2009 and 76% in 2010. Figure 14(a) shows a snapshot for 2010 and (b) the projected growth during the next years for these two technologies.

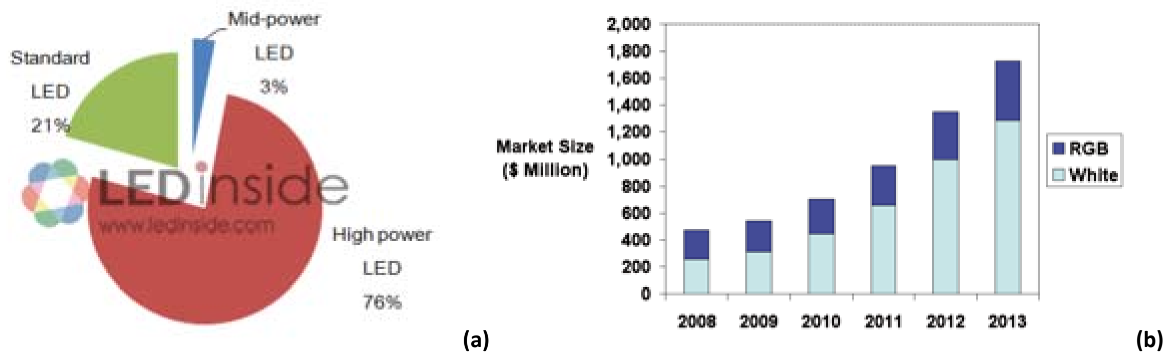


Figure 14 (a) LED technology market shares for lighting in 2010 [Chu R. LEDInside, November 2010] (b) HB white LEDs market share evolution between RGB and white LED technologies for lighting applications [Steele R, Strategies Unlimited, July 2009]

ElectroniCast Consultants reported that in 2010 the worldwide consumption value of packaged component-level LEDs, which are used in SSL General Lighting, reached $500 million. They forecast that the consumption value will reach $2.1 billion in the year 2015 and it will be nearly $13.4 billion in 2020 (Figure 15). This corresponds to an average annual increase of 33.2% (2010-2015) and ElectroniCast predicts faster overall growth in the second-half of the forecast period (2015-2020), at 44.9 % per year [ElectroniCast, News Release, May 19, 2011].

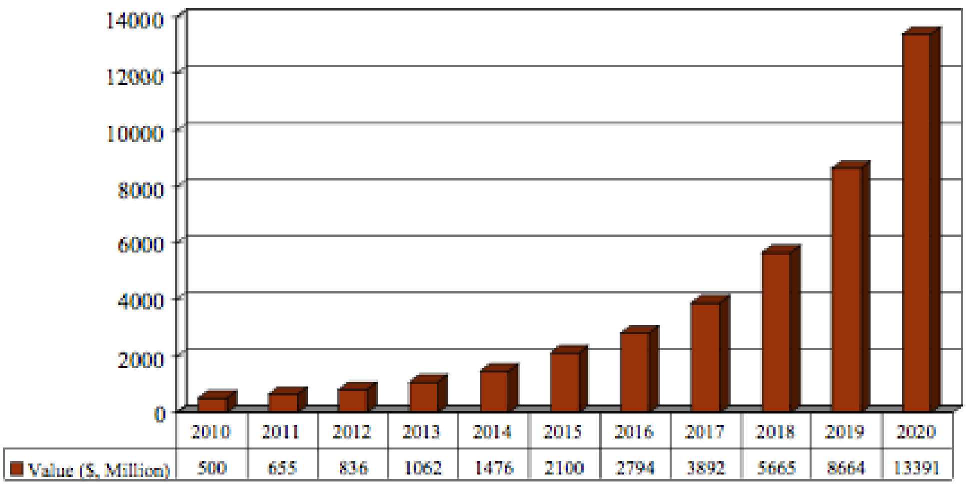


Figure 15 - Global Market Forecast of LEDs used for General Lighting (Value Basis, US$ million) [ElectroniCast, News Release, May 19, 2011]

Situation in Europe

In 2009, the SSL market share in Europe was 0.3% and this increased to 6.2% in 2010 (2011 DAE scoreboard[10]). Unfortunately Europe is far behind Asia and the USA, and it will be a challenge to bridge the gap in the next years.

2.3. LED Benefits and application for street lighting

LEDs in buildings can offer, besides higher efficiency:

- Less radiated heat (very relevant for display lighting of most items);
- Lower maintenance costs;
- Improved design possibilities.

Street lighting is one of the fast growing applications sectors for LED technology. The potential advantages include:

- Reduced energy costs (about 50% compared with HPSV-High Pressure Sodium Vapour lamps);
- Lower maintenance costs (lifetime of well-designed LED luminaires can be three to six times longer than that of HPSV;
- Improved colour rendition, leading to increased visual acuity and safety;
- Less light spillage (leading to higher system efficiency) and less light pollution due to the more directional light output of LEDs.

Figure 16 and Figure 17 show the spatial distribution of LED vs HPSV-High Pressure Sodium Vapour luminaires, illustrating the differences.

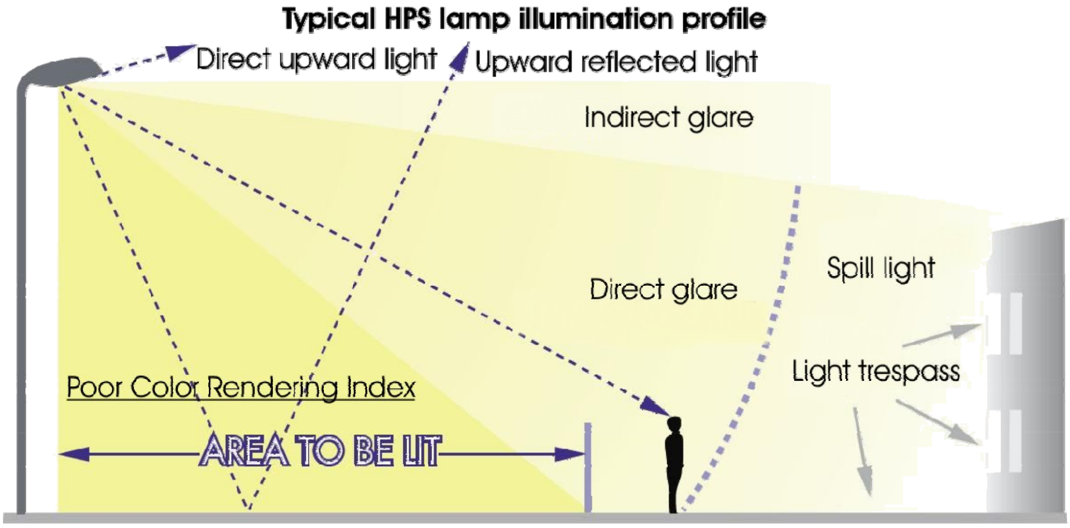


Figure 16 - Street Lighting Quality - HPSV lamps [DaTran Lighting, 2009]

[10] http://ec.europa.eu/information_society/digital-agenda/scoreboard/docs/scoreboard.pdf

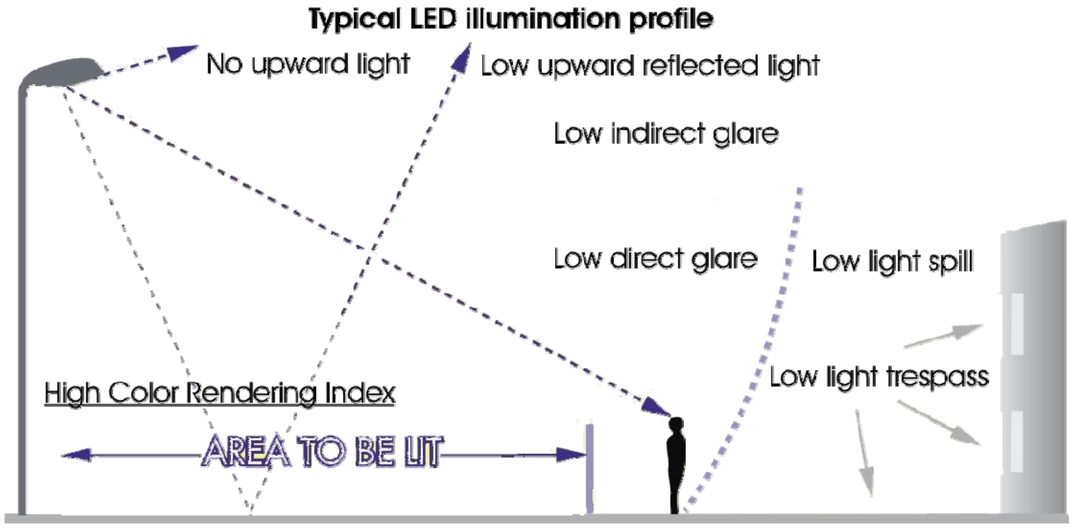


Figure 17 - Street Lighting Quality with LED lamps [DaTran Lighting, 2009]

In general LED technology is already available mostly for small roads in urban and pedestrian areas. The replacement of existing street lamps with LED lamps is limited by the large initial cost, as well as the limited number (but increasing) of manufacturers offering LED modules**.** Currently, most manufacturers only sell complete systems. Manufacturers and LED experts are convinced that replacement modules will be available soon as appropriate research is already being carried out. These replacement modules will facilitate the exchange of discharge lamp technology with LED technology and furthermore ensure that replacement of these LED modules will also be possible after 10 years of utilisation. Some manufacturers combine LED technology with solar PV and wind technology, associated with battery storage, for street lights, avoiding the costs of connection with the grid. This combination of both technologies presents another advantage for further energy and cost savings.

The estimation of the energy saving potential of LED technology for street lighting strongly depends on the existing system technology in a community or in a city. Street lights in Europe can be equipped with high pressure sodium lamps, mercury vapour lamps, or compact fluorescent lamps.

Figure 18 shows a wide street in which one side is illuminated with High Pressure sodium vapour lamps luminaires (70 W lamps, plus 13 W ballasts). The other side is illuminated with LED luminaires (32x1W Lamps, and 6 W drivers).

An important challenge in this application is the improvement of radiation characteristics. Currently, LED street lights are not suitable for large streets as the current characteristics lead to unpleasant blinding effects which influence the road safety (Möller, et al., 2009).

Figure 18 - Street Lighting Efficiency - LED vs. High HPSV Pressure Sodium Vapour lamps [ISR-University of Coimbra 2011]

2.4. *LED LIGHTING – MARKET BY APPLICATION*

Until 2007, LED Lighting applications included mainly niche markets. This segment is growing thanks to technical advances which have enabled LEDs to make significant strides toward cost competitiveness for several sizable applications in outdoor and interior lighting. Furthermore, multiple retailers around the world are actively promoting LED lights for indoor and outdoor decorative illumination applications. Meanwhile, LED lights with the Edison sockets, used for replacing conventional light bulbs, are starting to appear on the shelves of many of these same stores. Still today (2011), the LED lighting market is highly fragmented, encompassing many niche applications. General illumination applications are starting to emerge. It is very difficult, using existing studies to dissociate LED fixture, or LED luminaire market from single LED industry revenues. Fixture volumes are small and costs are high, independent of the high cost of LEDs. Thanks to improved technology, LEDs may be ready to take off.

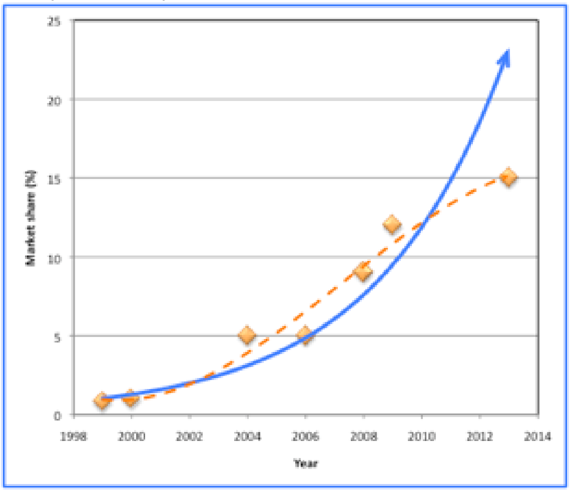


Figure 19 - HB-LED for lighting share evolution. The blue curve is an exponential least squares fit expressed by y=a.exp(b.x); dashed line corresponds to 3rd order polynomial model [data compiled from various sources for this report]

The HB LED for lighting market size rose from approximately 1% in 2000 to 5% of shares in 2004, reached 9% in 2009, followed by a 12% in 2010 (Figure 19). In absolute value, in 2008, $470 million of HB LED revenues were attributable to lighting applications when LED fixtures accounted for a total of $1.87 billion.

When the global financial storm broke out in 2009, the income of consumers reduced substantially, the environmental consumption trend was repressed, and the demand for LED lighting products with a high unit price reduced. Also, as the price of substitute products, such as energy-saving bulbs and T5 fluorescent lamps, also went down, the market for LED lighting fixtures did not grow as significantly as was expected. As a result, the market increased in 2009 by only 14% to USD 2.14 billion[11] when compared to 2008. Figure 20 illustrates the global and European luminaires market.

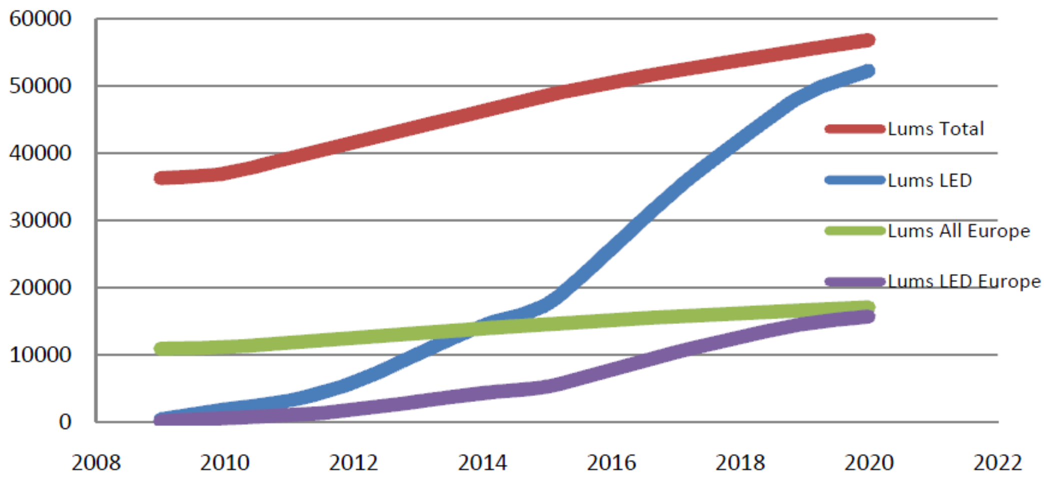


Figure 20 - Luminaires Market World & Europe in Million EUR [CELMA; ELCFED, 2011]

In 2009, LED-based lighting, with 12% market share of HB LED, forms a medium-size but rapidly growing segment of the LED market. It is behind LEDs for mobile appliances (44%), signs and displays (17%), and comparable to automotive uses (11%). Within the global lighting market, estimated at an annual $110 billion—roughly one-fourth of which consists of light bulbs—LED-based lighting represents an even smaller portion: an estimated 0.01% [Gereffi G., Center on Globalization, Governance & Competitiveness, Duke University, USA, November 2008].

The “lighting” market segments can be split into applications. Figure 21 shows the revenue distribution among these applications for 2009; it should be noticed that the global value of $2,848 billion is 25% higher than the one mentioned in the above paragraphs, the reason is this value accounts also for low power LEDs still used for some lighting applications. As can be seen, the largest application continued to be Architectural at 29% of the market, followed by Commercial/Industrial at 19%. Architectural lighting includes various systems: Wall washers, Floodlights, Strip-lights, Accent lights, Cove lights, Spotlights, Path lights, In-ground lights, Step-lights, Pool and spa lights, Flexible rope lights or festoon lights.

[11] Notice that these values account for the LED fixture market revenue and not only for the LEDs

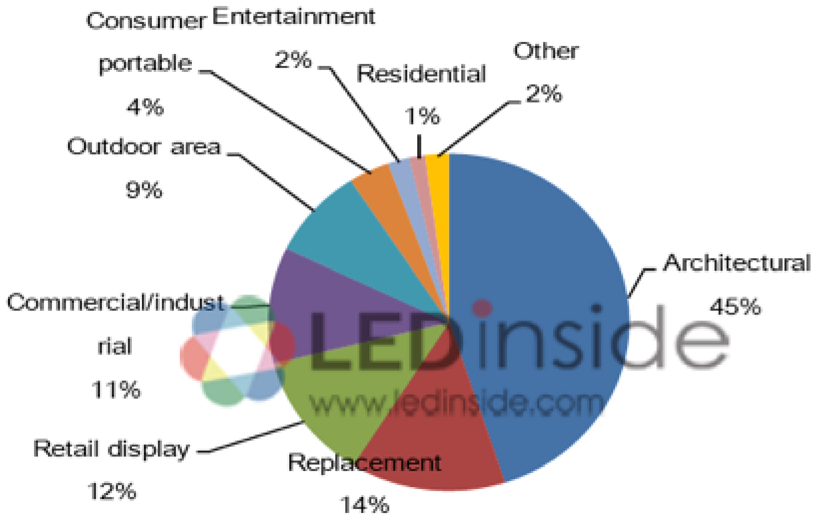


Figure 21 - Application market segments and associated shares for LED for lighting in 2010. The global market size is addressing LED fixtures [Chu R. LEDInside, November 2010]

As LED penetrated various lighting applications following the need for overall luminous flux, the maturity for each product is different. Figure 22 illustrates schematically as an S-curve this maturity level based on market shares for the different applications.

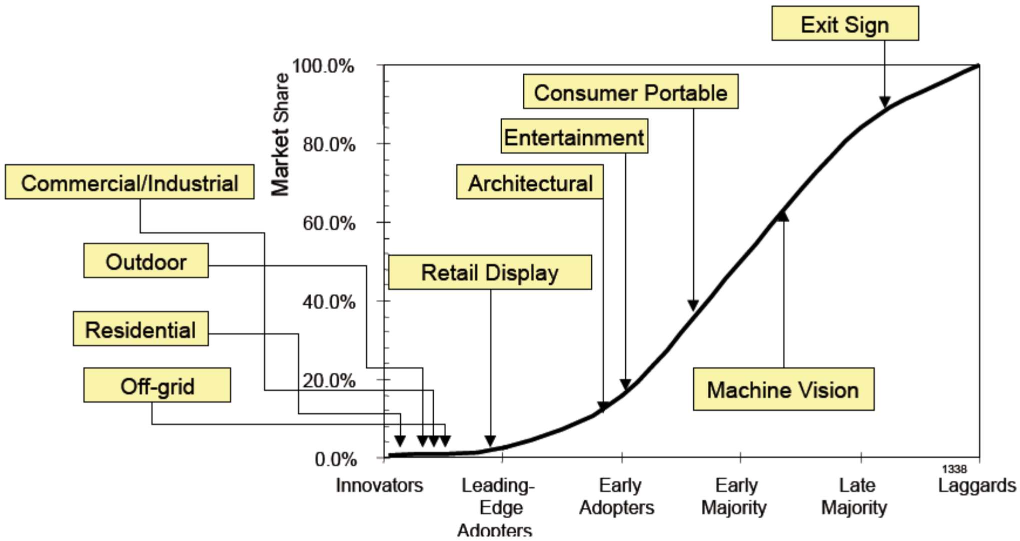


Figure 22 - Maturity level S-curve for various LED lighting applications (2009 snapshot) [Steele R., Strategies Unlimited, July 2009]

Following Strategies Unlimited, Figure 23 shows the short-term LED-lighting market evolution for each application. Highest growth applications in 2009 were: (1) Outdoor (2) Replacement Lamps (3) Entertainment (4) Residential (from a very small base). It can be noticed also that this year started to see major commercial retrofit adoptions, e.g. Wal-Mart, Starbucks, etc. But in the near future replacement lamps and commercial/Industrial applications will be the leading segments. In fact, in 2014, the highest growth rate will be coming from the replacement lamp, at CAGR of 92%, and smooth adoption in Japan market is expected in the next few years.

Figure 23 - LED-Lighting market shares (US$ billion) short-term evolution by application [Chu R. LEDInside, Nov. 2010]

Figure 24 shows the LED Lighting market dynamics by application as observed in 2009.

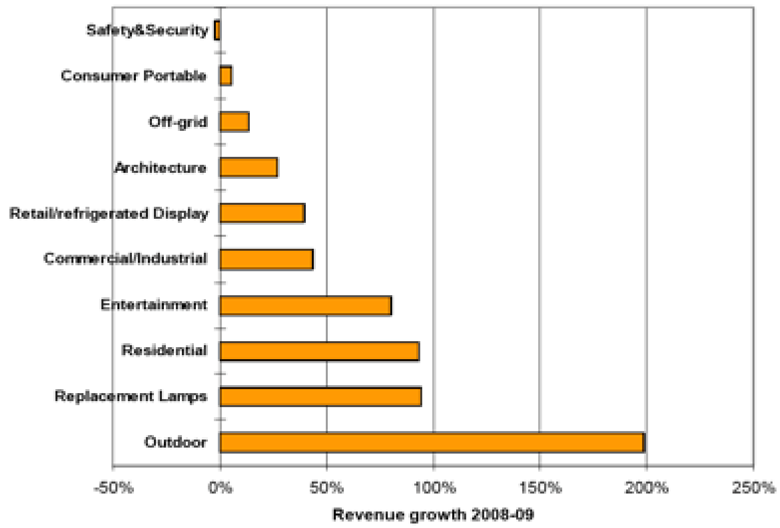


Figure 24 - LED Lighting Market Dynamics in 2009 [Bhandarkar V., Strategies Unlimited, July 2010]

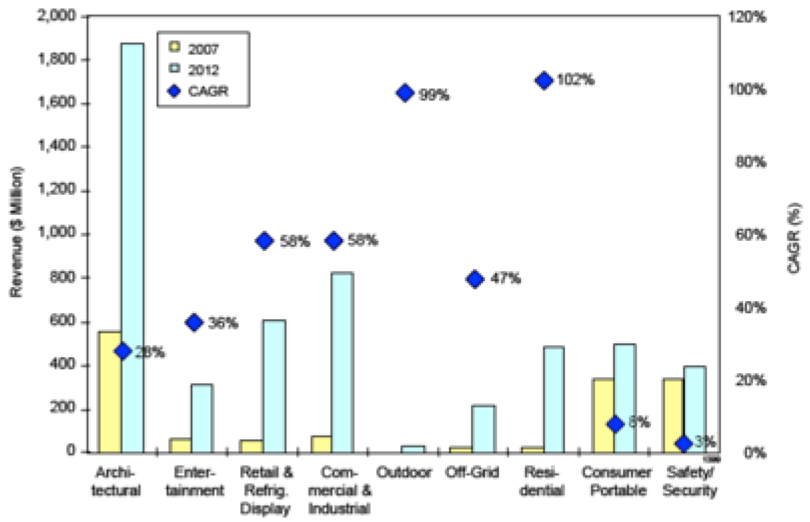


Figure 25 - Revenues variation by lighting application for 2007 and forecast for 2012, as expected by Seoul Semiconductor (2010) and associated CAGR for the same period [Bhandarkar V., Strategies Unlimited, July 2010]

Applying the above indications for growth rates, Seoul Semiconductor predicted in 2010 the evolution shown in Figure 25 for the various application segments in 2012 (compared to 2007 situation).

As indicated in 2010 by D. Lin (editor of BeLight magazine) the penetration rate of LED-based products is expected to reach a considerable level in the next two years However, widespread adoption of LED lighting is only expected to take place in the next five years due to technological issues involved in the lighting design of commercial and public spaces. Philips estimates that LED penetration in lighting will reach 80% by 2020. Figure 26 illustrates this.

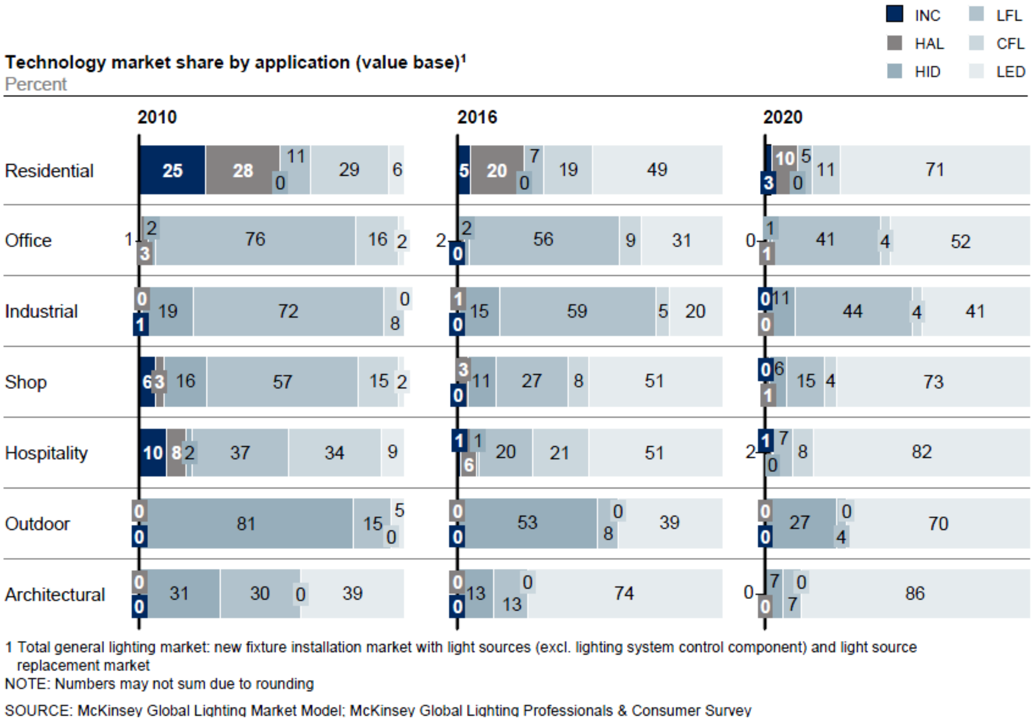


Figure 26 - Technology market share differs by application [McKinsey & Company, Inc., 2011].

However, it is not possible to make a unique scenario for LED penetration in the lighting market. Figure 27 (a) & (b) show three possible penetration scenarios. Whatever the hypothesis, demand for LEDs for general illumination will range between 0.6 to 1 billion units after 2020 [YOLE Développement, 2007].

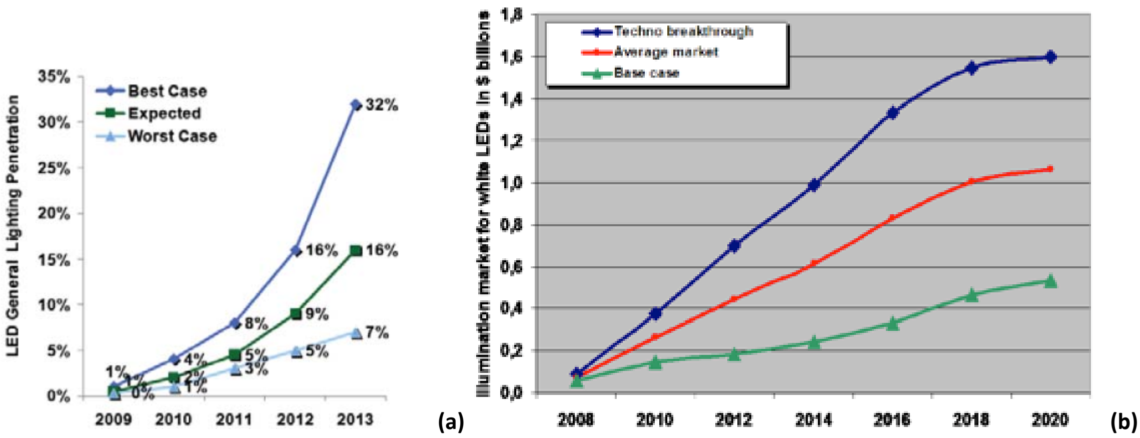


Figure 27 - (a) Possible scenarios for LED penetration in the global lighting market [Settler J., News Street Research, March 2010 and Irick J, President & CEO GE Lighting Solutions, 2010] and (b) forecasted market size [YOLE Développement, 2007].

Concerning LED luminaires, in 2007, they represented about 1.9% of the world lighting fixture market. In 2008 the growth rate was in the order of 28%. Thousands of companies worldwide are participating at the luminaire or fixture level. The size of these companies ranges from start-ups to the world's largest lighting companies.

2.5. LED market by region

Figure 28 shows the LED fixture revenue by world region in 2007. As can be seen, a very large percentage of all LED lamps and luminaires are manufactured in China. Figure 29 shows the regional market evolution for the next years.

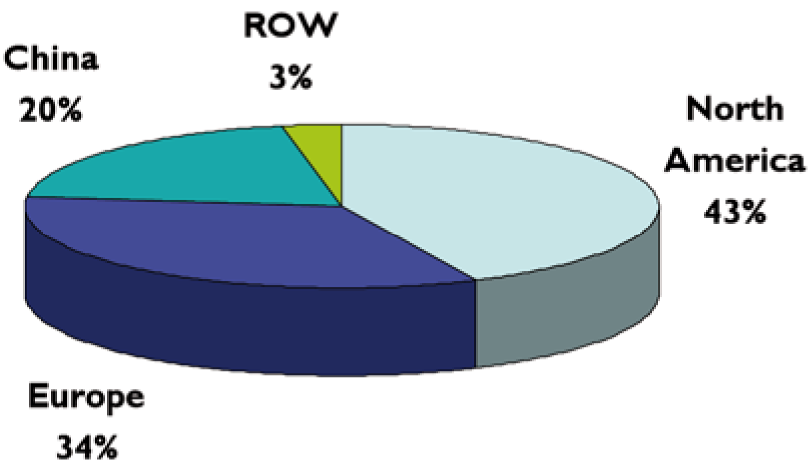


Figure 28 - LED fixture revenue distribution among world regions (2007 snapshot, ROW: rest of the world) [Steele R., July 2009]

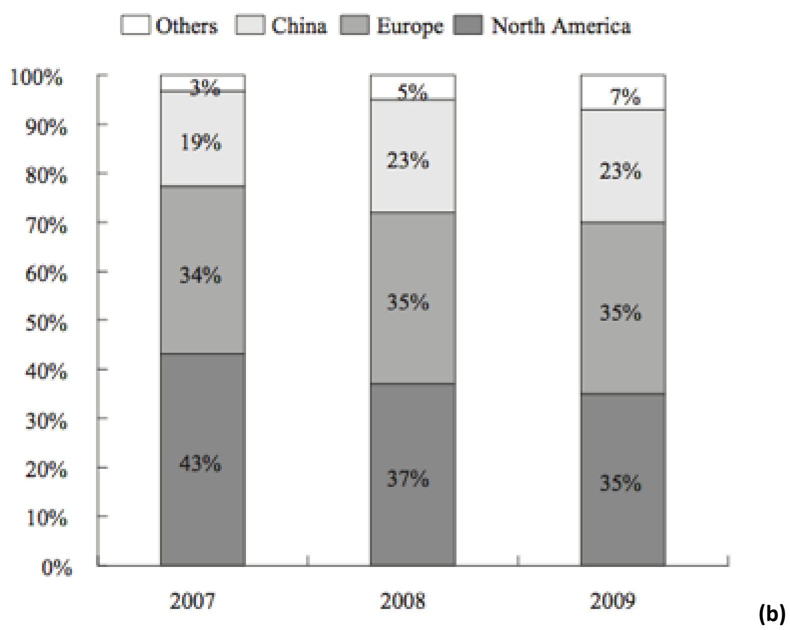


Figure 29 - Regional market share evolution from 2007 to 2009 [ITIS Programme, IEK/ITRI (2009/12); Strategies Unlimited (2009)]

By looking closer into the national lighting markets the following facts and projections come out:

- Demand for both AC and DC dimmable LED products is far higher in European and US markets than in Asian markets [Lin D., BeLight magazine, 2010]. In fact dimmers are widely used to provide soft, relaxing lighting in spaces such as hotels, commercial buildings and even homes in the United States and Europe. Japan's lighting culture differs from that of the West, and dimmer demand did not increase as fast as expected. For example, Lutron, one of the major dimmer manufacturers, has a market share of almost 70% in the United States and approximately 50% in Europe, whereas all other world regions remain under 20% [Using Light and Shade to Accent Interior Space Dimmer Switch Maker from America Introduces New Concepts in Lighting, Japan External Trade Organization, 2004].

- In Asia, the market for LEDs is rapidly expanding. Based on 2008 information, the current market size in Asia for LEDs can be assumed to be about US $7 to $8 billion in 2010, of which lighting constitutes about US $500 to $600 million and growing [Ton MK., EEDAL, 2011]. The Chinese objective is that LED-based lighting products should account for 30% of the national lighting market by 2015 [Hashmi K., EEDAL, 2011].
- In India, the LED light market is expected to witness a 41.5% CAGR to reach INR 18.5 billion (€295 million) by 2015 from 2.3 billion in 2009 [Frost & Sullivan, 2008].
- The business environment in China has become competitive, and cities are trying to attract new business as well as tourism. Tourism in China spiked around the 2008 Olympic Games in Beijing, and the country invested in the 2010 World Exposition in Shanghai. Many buildings are decorated with LED lighting with a joint agreement between the city and private parties. The decoration is very often using monochrome (red, orange, yellow, blue, green) lighting, although often in combinations of single colours, using domestically-manufactured LED packages. This market continues to grow, although very few international players participate in this market, more than 36% of the total market for architectural lighting could be attributed to China’s building decoration market. The Chinese building decoration boom contributed approximately $282 million to LED fixture revenues in the architectural lighting segment in 2009. Between 2008 and 2010 the growth of LED markets was sustained by various international events hosted by China, where LEDs were used in the major attractions: 2008 Olympics – Beijing; 2010 World Fair – Shanghai; 2010 China’s 60th National Day celebration – Beijing. It can be noted here that in the sole area of the World Fair in Shanghai 1.3 million LEDs have been installed.
- In the US, the share of LEDs is projected to grow to approximately 1/3 of the market on a unit basis and around 3/4 on a revenue basis. This is based on the fact that the North American lamp market is expected to remain flat in units, but to grow at a 25% CAGR from $3.6 billion in 2010 to over $11 billion in 2015. Figure 30 illustrates this tendency.

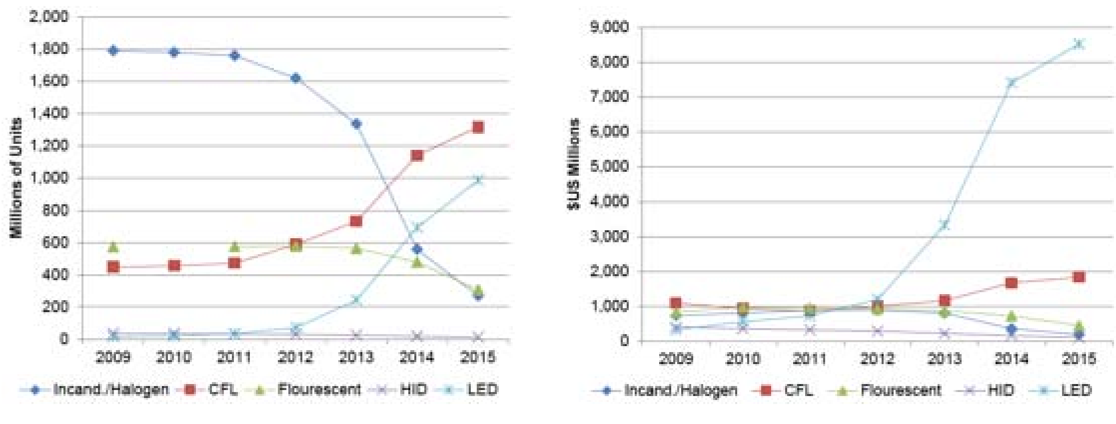


Figure 30 - USA market shares yield for different lighting technologies in terms of million units and revenue [Young R., IMS Research, 2011]

It is also expected that LED luminaire design will evolve. As Figure 31 shows, integrated luminaires (for indoors and outdoors) dominate the market today but during the next five to ten years light engines, modules and finally LED lamps will take the major part of the market.

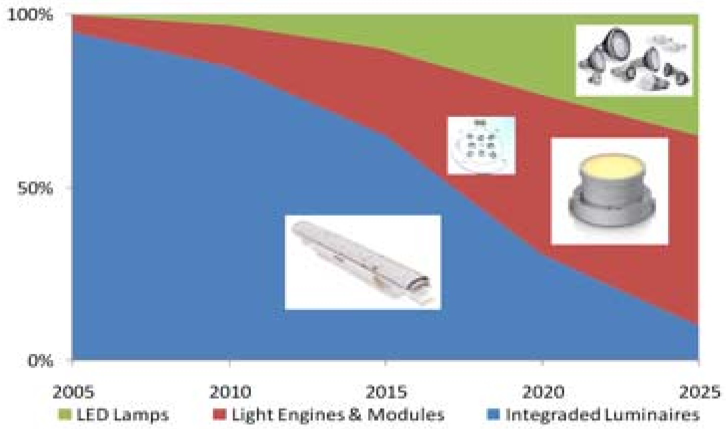


Figure 31 - LED luminaire design evolution [Cook K, Chairman, Next Generation Lighting Industry Alliance, 2010]

2.5.1. Outdoor lighting sector

Concerning outdoor lighting, today this application attracts the attention of many companies, but essentially SMEs. Figure 32 shows the global shipments of LED street lights and the forecast for 2011-2012.

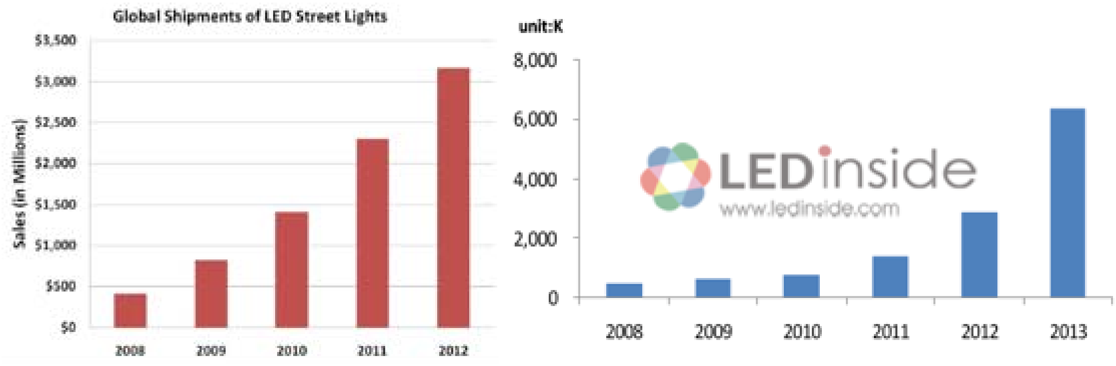
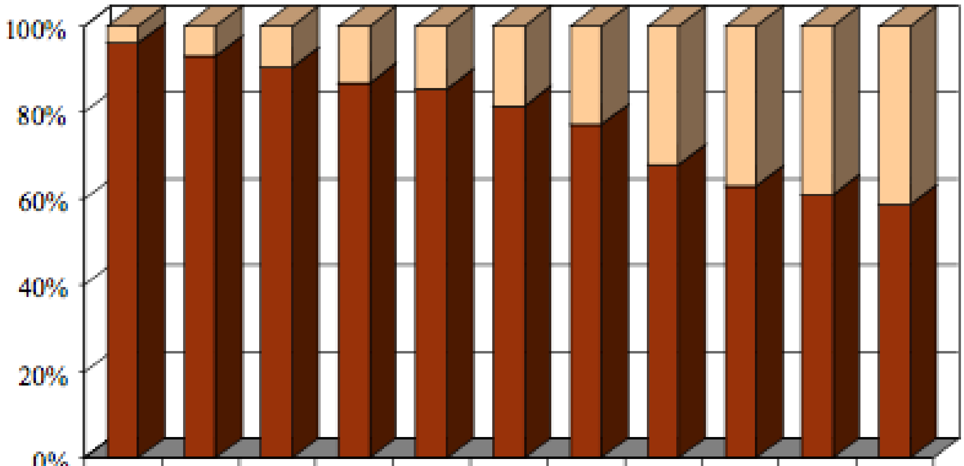


Figure 32 - Global shipments of LED street lights in (left hand) sales volume [Photonics Industry and Technology Development Association, 2009] and (right hand) number of thousand units [Chu R. LEDInside, Nov. 2010]

Outdoor lighting will evolve regularly as technology advances. There are some promising expectations; the projected CAGR is 43% [Chu R. LEDInside, Nov. 2010]. Following ElectroniCast market opportunity analysis (MOA) published in 2010, LEDs in exterior General Lighting lamp applications (street, parking-lots, roadway-tunnels, bridges, landscaping, pool/fountain, buildings, architectural and other general lighting) represent nearly 93% share of worldwide consumption in 2010. In 2019, the relative market share of component-level LEDs used in exterior lamps is forecast to decrease significantly to nearly 59% (Figure 33), but will increase in value to $5.4 billion [ElectroniCast, News Release, November 24, 2010].



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
INTERIOR	14	35	61	104	145	266	477	1249	2080	2748	3796
EXTERIOR	334	462	574	688	842	1164	1620	2625	3516	4286	5409

Figure 33 - LEDs used in SSLs - Indoor versus Outdoor Applications (Value Basis, US$ million) [ElectroniCast, News Release, November 24, 2010].

In China, the street lamp market size is about 28-30 million units, and about 1.5-2 million new street lamps are installed every year, mainly using mercury and sodium lighting sources. China began using LED street lamps in 2007, which is later than the USA and Japan. As the Chinese government has a strong policy dominance and execution ability, the small scale product demonstration and testing stages were skipped, and LED street lamps were directly installed in larger areas, pushing the development of the LED lighting industry a big step forward. Thus, in China the total LED streetlight installation volume in 2009 was around 250 000 and 287 000 in 2010. Meanwhile, the Chinese outdoor market is expected to grow even more rapidly with LED general lighting expected to become more widespread after 2015. Taiwan's Photonics Industry Technology & Development Association (PIDA) estimates that the global market scale for LED street lamps will total $1 billion in 2008, with the China market accounting for about $486 million. Most manufacturers are more optimistic when estimating the LED street lamp market size in China because the Chinese government has recently announced relevant government contracts and programmes. Also, after the Chinese government replaced conventional street lamps with LED street lamps, many negative opinions about the product characteristics arose, such as the high failure rate, shorter life than expected, and the glare problem. These suggest that there is still much space for improvement in the product characteristics of the LED street lamps, because the product at present is not completely satisfactory.

In the US, the city of Los Angeles decided in 2010 to install 7 000 new LED based streetlights. Furthermore, it is noted that in the US, LEDs have achieved in 2010 an estimated 4.3% market penetration in outdoor parking lighting. For flood lighting, LED penetration is of about 0.72%.

Globally, penetration of LED lights is estimated to be less than 1% of street lighting. Indeed, of the estimated 1 300 million street lighting poles installed globally, LED street lights account for only 870 000 units.

2.5.2. Domestic lighting sector

Focussing now on **domestic lighting**, all analysts agree that this segment will be the most difficult to penetrate during the next five years (an analysis of the barriers to the market expansion in this segment will be discussed in the following sections of this report). In fact, LED lamps are still at the early phase of their lifecycle, as a result of which their penetration is much lower than other types of lamps.

- In Japan the penetration rate of LED retrofit lamps increased to a significant amount from March 2010 (Figure 34). In April 2010, LED lighting penetration reached 18%, according to GfK (9% month-on-month growth) in term of units and 56% in term of revenues. Also, the same year, the Average Sale Price (ASP) of a LED bulb is under 3 000 JPY (29 €).

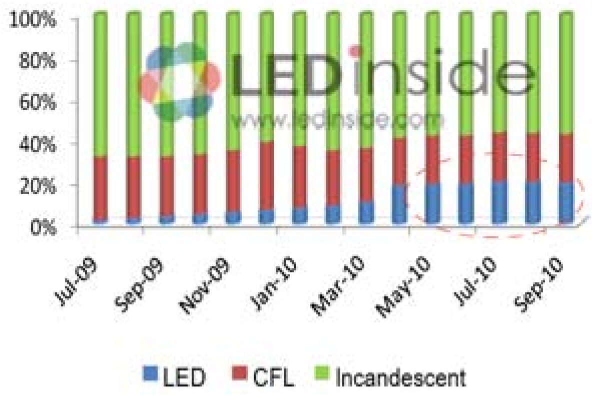


Figure 34 - LED retrofit lamp penetration in Japan [Chu R. LEDInside, Nov. 2010]

- In Switzerland 2 million domestic luminaires are sold annually. The total market without light sources is 100 million Euro [Geilinger E., EEDAL, 2011]. The professional market, in comparison, amounts to 300 million Euro per year, at a guess this is 2 million units sold as well. Figure 35 shows that in this country, in 2010, 12% of lighting systems sold by retailers were LED-based.

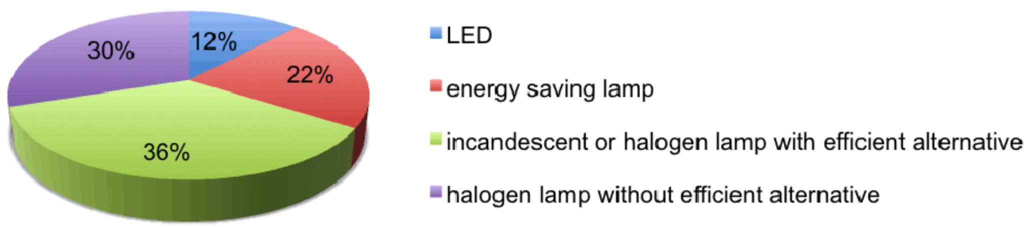
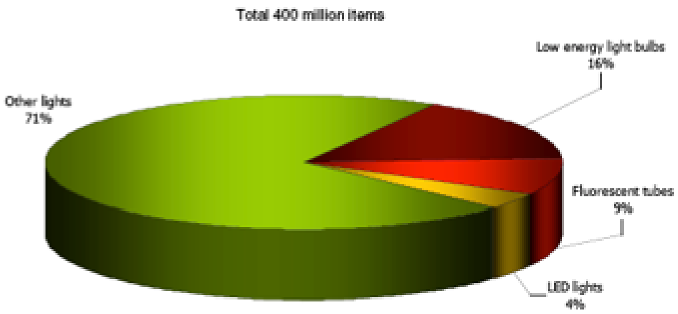
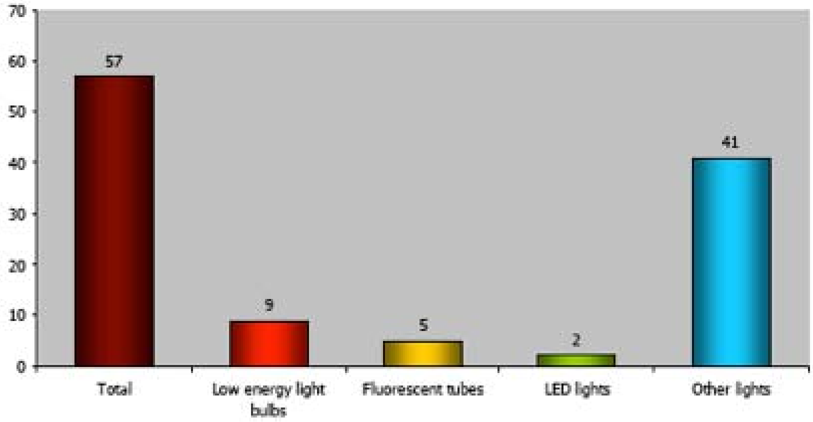


Figure 35 - Domestic luminaires of a big Swiss retailer by light sources (assortment 2010) [Geilinger E., EEDAL, 2011]

- In the Netherlands, as reported by Theo Hendriksen [Possession, disposal and purchasing of discharge lamps in Dutch households, GfK, May 2009], less than one in four households possesses LED lamps, whereas nearly nine out of ten households possess (at least) one low-energy light bulb. This limited group of households that have discovered LED lights, possess no less than nine LED lights on average. In addition to the Do-It-Yourself (DIY) market, specialist shops and household goods stores are mentioned as frequent purchase locations. The total quantity of lights in Dutch households amounts to over 400 million. This is consisting of around 65 million low-energy light bulbs, almost 40 million fluorescent tubes and almost 15 million LED lights. In Figure 36 below the total population is set at 100% and the lights are shown in percentages.



(a)



(b)

Figure 36 - (a) Lighting technologies used in the Dutch residential sector (2008 snapshot) and (b) average number of technology type owned [Hendriksen T., GfK, May 2009]

- In Sweden, as reported by Mats Bladh [Bladh M., EEDAL, 2011], it is estimated that the incandescent bulbs phase-out will boost LED market shares. Figure 37 shows this projection.

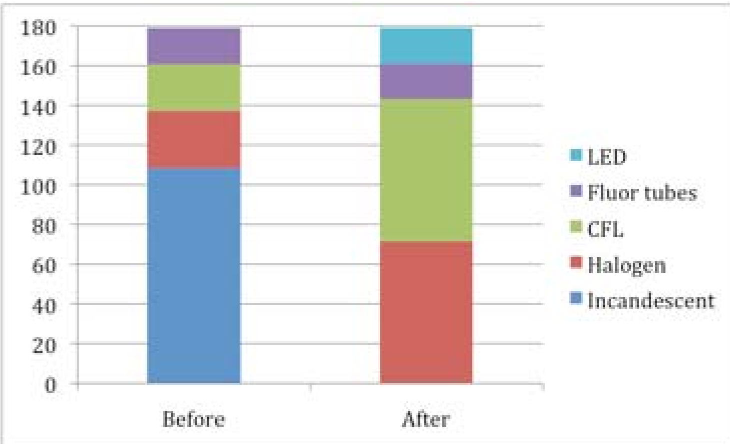


Figure 37 - Projected evolution of Swedish domestic lighting market boosted by incandescent lamp phase-out [Bladh M., EEDAL, 2011]

- In Denmark, some indicative data show (Figure 38) that LED sales for domestic use declined during the last years, but the average luminous efficacy[12] of the LED sold increased. Clearly customers are looking for high quality products.

[12] The average luminous efficacy is defined as the ratio of the average lamp lumens sold over the average lamp wattage sold.

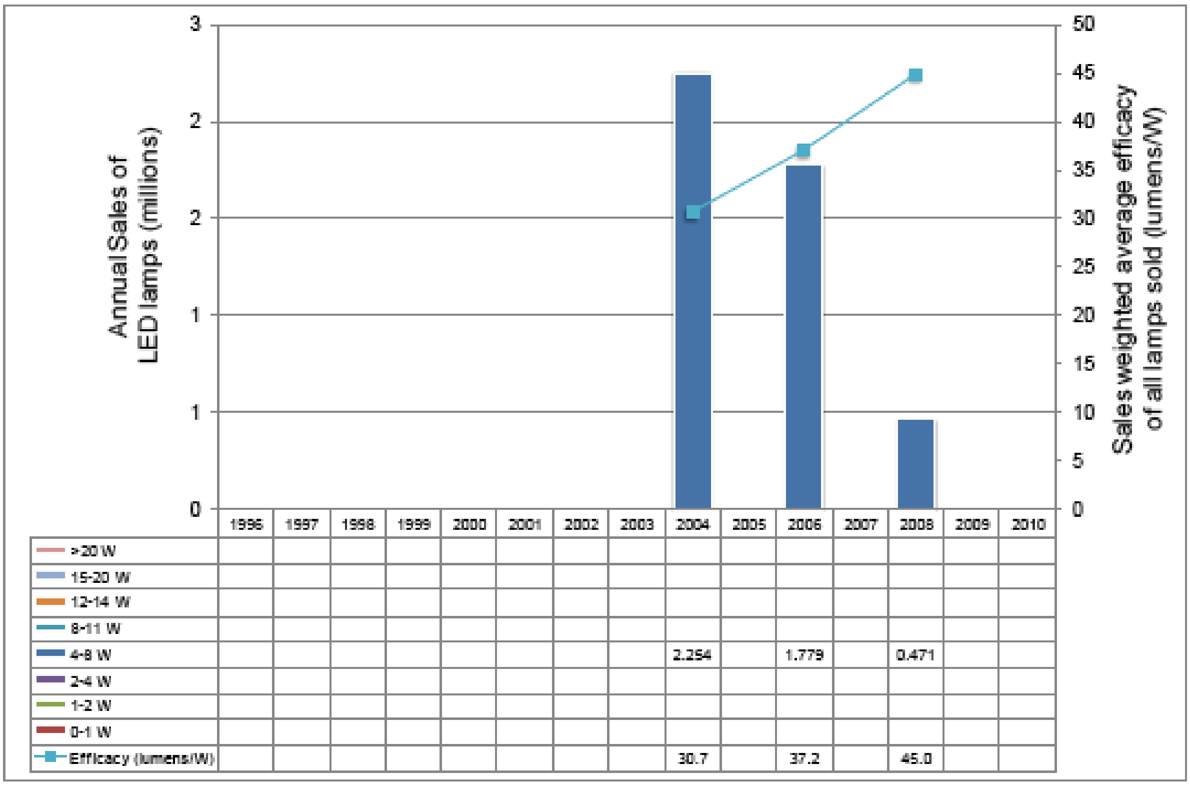


Figure 38 - Annual LED sales for domestic sector use in Denmark and associated average luminous efficacy of the products [IEA-4E Mapping & Benchmarking Annex, June 2011]

2.6. Conclusions

As described in the above paragraphs, the LED industry has been growing fast for several years now. Today the main LED applications are still mobile appliances and displays. The lighting segment has been having the fastest growth since a few years; consequently lighting will become the dominant market segment before 2020. The main part of LED revenues is coming from Asian countries (growth in Taiwan and Korea is increasing, whereas in Japan it is slowing down). However, looking at revenue coming from LED-based fixtures, Europe is well positioned (1/3 of the market size today, with China as a serious challenger). Lighting is mainly using high-brightness LEDs, low-power LEDs are still in use for some lighting niche applications. Today, architectural, decorative and scenic lighting represent the highest penetration rate for LEDs. In the domain of general lighting, LEDs start penetrating the outdoor lighting sector; however the part for indoor applications is rapidly increasing. Concerning indoor lighting, LED penetration in the residential sector is low and the growth rate is still slow.

For consumers, the initial large exposure to LED for general lighting applications will come in the form of LED bulb replacement that can be used in existing sockets. As the initial perception of the technology by consumers will come from this first exposure to bulb replacement, their quality and performance will be critical to the future of the industry. Standards and regulations are therefore needed to ensure simplicity of operation and a reasonable level of quality.

Dedicated LED modules and luminaires will come in a second wave and deliver the full benefit of the technology. Additional standardisation efforts are however needed to ensure a minimum level of upgradability and interoperability.

Situation in Europe

Europe accounts for 34% of LED fixture revenue [Steele R., July 2009] and this share has been almost stable during the last three years ITIS Programme, IEK/ITRI (2009/12); Strategies Unlimited (2009)].

Demand for dimmable LED products and complex intelligent lighting systems is far higher in European markets than that in Asian markets.

Concerning outdoor lighting and the tertiary building sector, many examples exist in European countries. However, it is difficult to get reliable data.

Very few data are available for LED use in the residential sector. In the Netherlands, one in four households possesses LED lamps; In Switzerland 12% of lighting systems sold by retailers are LED based; In Denmark, LED sales for residential use declined, but the average luminous efficacy[13] of the LED sold increased.

[13] The average luminous efficacy is defined as the ratio of the average lamp lumens sold over the average lamp wattage sold

3. The industrial value chain

As can be seen in the next sections, the LED industry is quite fragmented. Analysing the value chain is therefore rather interesting.

Usually the LED value chain is divided into five segments: materials, equipment, finished lamp and components, luminaires and systems, and finally lighting services and solutions. Figure 39 shows the distribution of revenues among these segments in 2010 and estimation for 2020 [Challenges to Solutions", by Prof. G.Q. (Kouchi) Zhang and Dr. Henk van Zeijl, Delft University of Technology].

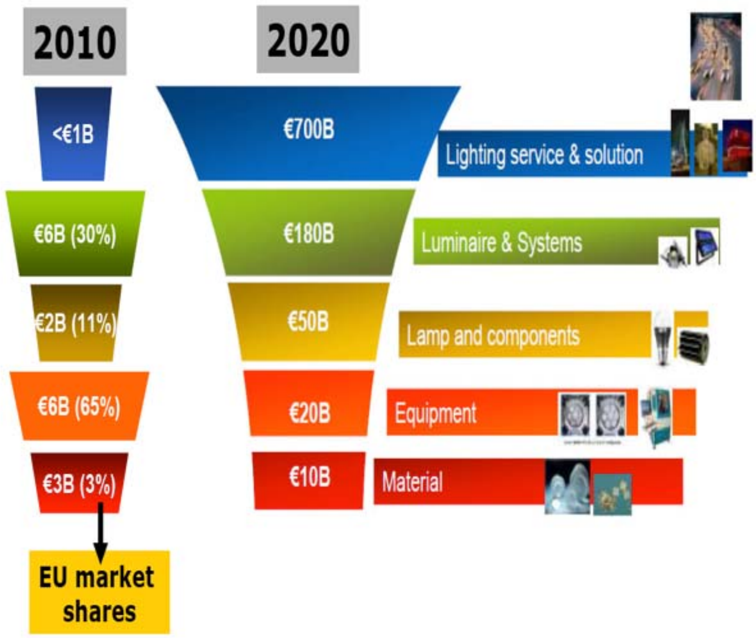


Figure 39 - LED Lighting value chain and associated revenues for 2010 and 2020 - Percentages in parenthesis correspond to EU market shares [Challenges to Solutions", by Prof. G.Q. (Kouchi) Zhang and Dr. Henk van Zeijl, Delft University of Technology].

Gereffi, G, et al. from the Center on Globalization Governance and Competitiveness proposed a slightly different structure for the value chain that includes distribution and final sales circuits (Figure 40).

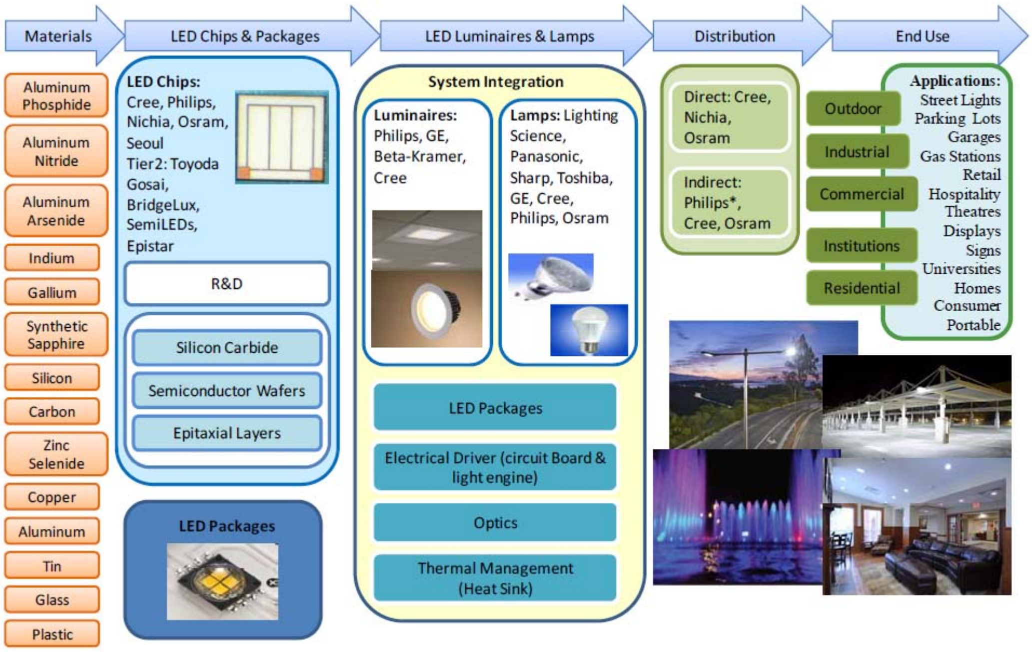


Figure 40 - Detailed Lighting LED Industry Value Chain [Gereffi, et al., 2010]

Philips, for its part proposes a "level scheme" for the value chain as shown in the following table:

Light sources

- **Level 1: LED chip manufacturing** is by far the most capital intensive. Cree, for example plans to spend 30% of sales on capex this year. According to a May 2009 report by IMS Research, Nichia held 24%, Osram Opto 10.5% and Philips Lumileds 6.5% of the packaged LED market. Seoul Semiconductors, one of the most aggressive companies in this area, ranked 4th. IMS' January 2010 report on the top HB LED companies by US$-based sales indicates a 2009 market share of 42% for Nichia, 11% for Cree, 8% for Showa Denko, 7% for Epistar and 2% for Epivalley.
- **Level 2**: **Electronics and controls** is mainly an assembly business.
- **Level 3: Retrofit LED lamps** – this business is similar to the traditional lamp business, involving assembly and sale through similar distribution channels.

Applications/solutions

- **Level 4: Applications**
- **Level 5: Solutions and services**

Table 2 - Value chain level scheme

3.1. *RAW MATERIALS*

Concerning the very first level of the value chain, raw materials, the following remark can be made: LEDs are made from a variety of semiconductor materials, including different combinations of gallium, indium, arsenic, antimony, nitrogen, and phosphors.

AVAILABILITY OF RARE EARTH MATERIALS USED IN SSL PRODUCTION

The 17 rare-earth elements (REE) shown in Table 16 comprise the lanthanide series in the periodic table (elements 57 through 71), plus scandium (Sc) and yttrium (Y). Rare earth elements are widely used in the production and operation of a wide range of products (such as wind turbines, electric cars, optical fibres, computer chips and solar cells (Figure 86)), and are also used in the phosphors that create light in a number of different light bulb types, including fluorescent, LED, and mercury vapour lamps.

Table 3 - The Rare Earths and some of their end uses [Hard Assets Investor, 2011]

Name	***Symbol***	***Some End Uses***
Cerium	Ce	Catalysts, Ceramics, Glasses, Misch Metal*, Phosphors and Polishing Powders
Dysprosium‡	Dy	Ceramics, Phosphors and Nuclear Applications
Erbium‡	Er	Ceramics, Glass Dyes, Optical Fibres, Lasers and Nuclear Applications
Europium‡	Eu	Phosphors
Gadolinium‡	Gd	Ceramics, Glasses, Optical and Magnetic Detection and Medical Image Visualisation
Holmium‡	Ho	Ceramics, Lasers and Nuclear Applications
Lanthanum	La	Automotive Catalysts, Ceramics, Glasses, Phosphors and Pigments
Lutetium‡	Lu	Single Crystal Scintillators
Neodymium	Nd	Catalysts, IR Filters, Lasers, Permanent Magnets and Pigments
Praseodymium	Pr	Ceramics, Glasses and Pigments
Promethium	Pm	Phosphors and Miniature Nuclear Batteries and Measuring Devices
Samarium	Sm	Microwave Filtres, Nuclear Applications and Permanent Magnets
Scandium	Sc	Aerospace, Baseball Bats, Nuclear Applications, Lighting and Semiconductors
Terbium‡	Tb	Phosphors
Thulium‡	Tm	Electron Beam Tubes and Medical Image Visualisation
Ytterbium‡	Yb	Chemical Industry and Metallurgy
Yttrium‡	Y	Capacitors, Phosphors (CRT and Lamp), Radars and Superconductors

Groups: yttrium and lanthanide (scandium falls into neither category)

‡ *Heavy REM*

* *Misch Metal is an alloy of rare-earth metals used not only for lighter flints, but also, probably more importantly, in purifying steel by removing oxygen and sulphur.*

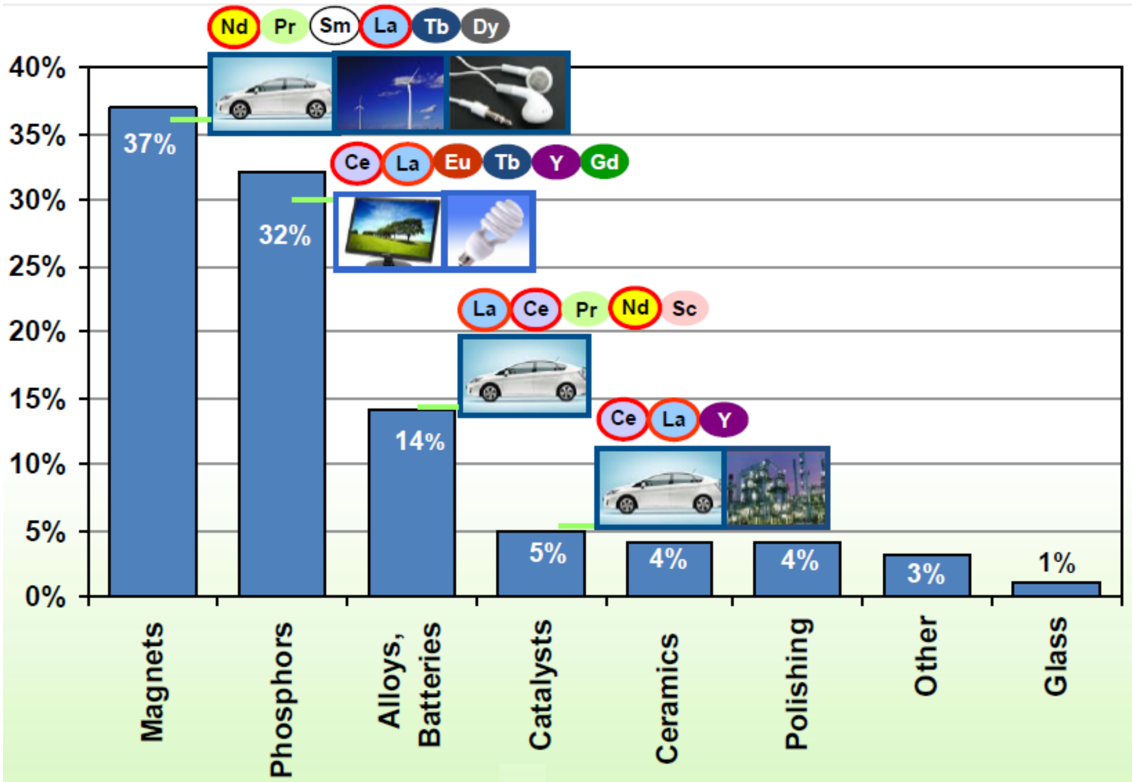


Figure 41 - Global Demand of Rare Earths by Value in 2008. Energy-efficient lighting is a major application of REE compounds used to make phosphor materials [Spencer, et al., 2011]

The oxides of the rare-earth elements Cerium (Ce), Europium (Eu), Lanthanum (La), Terbium (Tb) and Yttrium (Y) are the most important for the lighting industry. This is because they are used to produce the phosphor mix contained in fluorescent and LED lamps. In fluorescent lamps phosphor is the white powder coating the inside of the lamp that converts ultraviolet light into visible light. In fact, the oxides of the above-mentioned rare-earth elements are responsible for the creation of red, green and blue light. As Figure 42 illustrates, the combination in the right proportion of these lights makes it possible to generate a natural and pleasant white light, with a good colour rendition index (Osram, 2011).

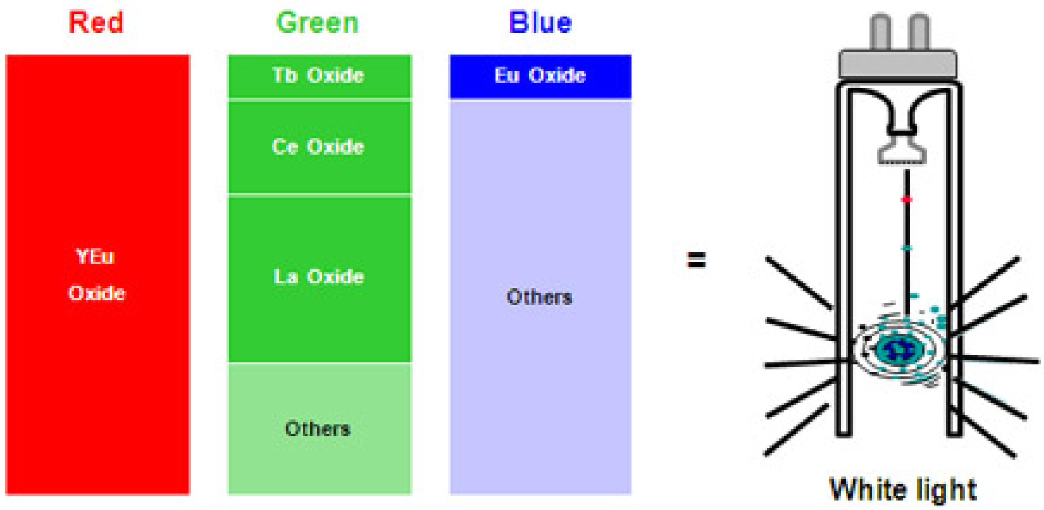


Figure 42 - Important rare earth oxides for the lighting industry [Osram, 2011]

The LED industry also uses a wide and growing range of phosphor materials to convert the light emission from the LED chips into different wavelengths in the visible spectrum. LED makers rely on their supply of phosphor materials as a crucial aspect of the production process. The most common LED phosphor is yttrium aluminium garnet (YAG) doped with cerium (Ce), another rare earth. Other phosphors which use REE include:

- Terbium aluminium garnet (TAG) containing terbium (Tb).
- Silicate phosphors such as BOSE and nitride phosphors commonly doped with cerium (Ce) or europium (Eu) (Walker, 2011).

The supply restrictions of these REE have increased the production costs of traditional light sources, impacting on the end user, which has meant a hidden benefit for LED lighting. The benefits of using LED lighting now include an additional point (Industry News, 2011) of using much less Rare Earths than traditional lamps. Total rare earth content in LEDs is estimated at one to two orders of magnitude lower than fluorescent lights of equivalent light output (DoE, December 2011).

For more information on REE production and supply, as well as strategies to improve their availability, see Annex IV.

LEDs, like many other energy efficient and renewable energy technologies, make extensive use of some raw materials classified as ‘green minor metals’, which are the basis for cleaner technology innovation[14]. Although raw materials are essential for the EU economy, their availability is increasingly under pressure. Within the framework of the EU Raw Materials Initiative, it was decided to identify a list of critical raw materials at EU level, in close cooperation with Member States and stakeholders. A report analysing a selection of 41 minerals and metals has been published[15]. In line with other studies the report puts forward a relative concept of criticality. This means that a raw material is labelled “critical” when the risks of supply shortage and their impacts on the economy are higher compared with most of the other raw materials. Two types of risks are considered: a) the "supply risk" taking into account the political-economic stability of the producing countries, the level of concentration of production, the potential for substitution and the recycling rate; and b) the "environmental country risk" assessing the risks that measures might be taken by countries with weak environmental performance in order to protect the environment and, in doing so, endanger the supply of raw materials to the EU. Building on existing approaches, this report sets out an innovative and pragmatic approach to determining criticality. The following figure shows the main drawbacks from this report: 14 raw materials falling within the top right cluster of the above diagram are critical. As noted, this is due to their high relative economic importance and to high relative supply risk.

[14] Green minor metals include: indium (In), germanium (Ge), tantalum (Ta), PGM [platinum group metals, such as ruthenium (Ru), platinum (Pt) and palladium (Pd)], tellurium (Te), cobalt (Co), lithium (Li), gallium (Ga) and RE (rare earths)

[15] Critical raw materials for the EU, Report of the Ad-hoc Working Group on defining critical raw materials, Version of 30 July 2010; The full report will be available on the Enterprise and Industry Directorate General website http://ec.europa.eu/enterprise/policies/rawmaterials/documents/index_en.htm

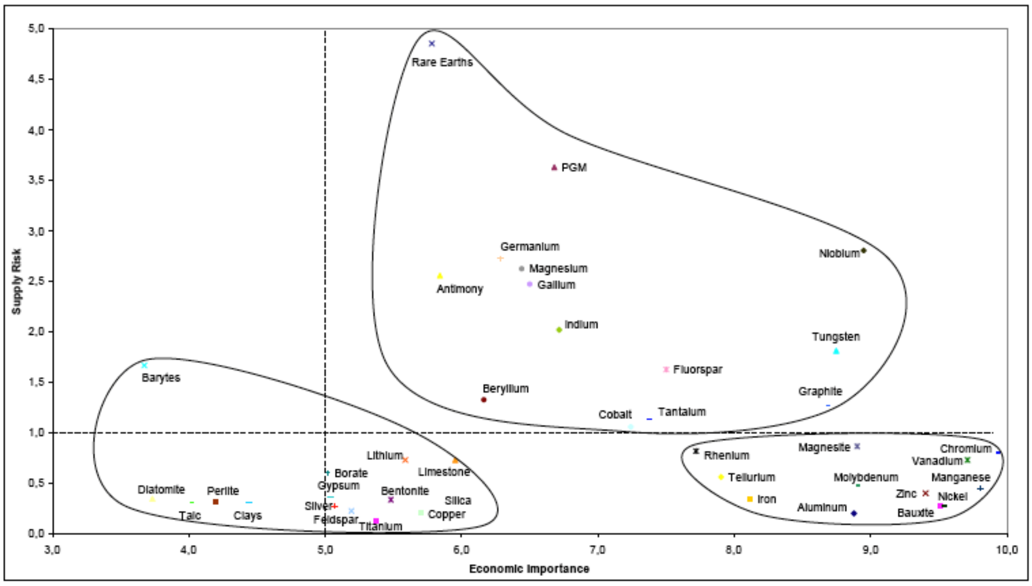


Figure 43 - Classification of various raw materials concerning their strategic importance for Europe [Critical raw materials for the EU, Report of the Ad-hoc Working Group on defining critical raw materials, Version of 30 July 2010]

Gallium is one of the most critical. Gallium occurs in very small concentrations in ores of other metals. Most gallium is produced as a by-product of treating bauxite, and the remainder is produced from zinc processing residues. Only part of the gallium present in bauxite and zinc ores is recoverable, and the factors controlling the recovery are proprietary. Therefore, an estimate of current reserves that is comparable to the definition of reserves of other minerals cannot be made. The world bauxite reserve base is so large that much of it will not be mined for many decades; hence, most of the gallium in the bauxite reserve base cannot be considered to be available in the short term. In 2009, world primary production was estimated to be 78 metric tons, 30% lower than the revised 2008 world primary production of 111 tons. China, Germany, Kazakhstan, and Ukraine were the leading producers; countries with smaller output were Hungary, Japan, Russia, and Slovakia. Refined gallium production was estimated to be about 118 tons; this figure includes some scrap refining. China, Japan, and the United States were the principal producers of refined gallium. Gallium was recycled from new scrap in Germany, Japan, the United Kingdom and the United States. Going forward, the gross consumption of gallium is expected to more than double by 2015 (270 MT) and increase substantially further again to reach close to 400 MT by 2020 (370 MT) of which about 45% will be for the PV sector (Umicore, 2010). LEDs, and generally speaking optoelectronics, are responsible for 11-18% of this use.

On a material level, indium, one of the key elements for many of the existing LEDs, is a rare material: 61th rank in terms of quantity found on earth (0.24 ppm in weight). Indium is widely spread, generally in low concentrations. Most quantities are recovered from sphalerite, a lead-zinc-sulphide mineral. Therefore indium production is connected to lead-zinc production. In 2007, indium reserves were estimated at only 6 000 tonnes, a figure which contributed to significant price increases. Since then, new deposits have been identified or have become economical, so that the range of reserves is not that critical today and prices dropped about 50%. Indeed, Indium Corporation has determined that indium reserves (proven and probable, measured and indicated, and inferred) in identified base metal mines in the world amounted to close to 50,000 millions of tonnes (MTn) of Indium (26 000 MTn in the Western world, 23 000 in the rest of world i.e. mostly China and former Soviet Union). Nevertheless indium is still quite expensive. Although a LED junction only uses a very small amount of this element, it has so far been impossible to recycle indium after use.

A partial list of the common compounds used includes resins, plastics, and metals associated with the other major components in a LED package. LEDs do not contain mercury but their production phase uses harmful substances. Among the major LED materials, gallium (a mainstay of the electronics industry) is the most heavily used, especially for blue LEDs. Aluminium is the most cost-effective material to recycle, suitable to be used again and again without loss of quality. However, so far there is no specific recycling procedure targeting LEDs and more especially the recovery of gallium and indium at the junction level. In addition, today even phosphors are not recovered. These are important setbacks for LED lighting and add to the abiotic material depletion impact of the sector.

LEDs are made from a variety of semiconductor materials, including different combinations of gallium, indium, arsenic, nitrogen, and phosphors. Various Rare Earth Elements (REE) are used in the manufacturing process of LEDs. China is the main producer of REE, but also the main consumer. It has therefore restricted exports, therefore prices have increased dramatically. The EU has published a report on critical raw materials, in terms of supply risk and environmental country risk, and gallium is one of them. Consumption is expected to more than double by 2015 and China is among the main producers. The EU has a strong dependence on imported REE from China. By opening new mines or recycling REE, it could be possible to limit this dependence.

3.2. LED Industry

The LED industry is on the threshold of a new expansion phase—a phase that will be characterised by growth rates in the high double digits during the next three years. This growth will be driven by the increased adoption of High Brightness (HB) and high flux—also referred to as high power or Ultra High brightness, UHB LEDs, into a new range of next generation lighting applications.

Looking closer at the beginning of the value chain, at LED component level (that will be integrated later in lighting systems), several sub-segments (often called also "levels") of the value chain can be distinguished. Figure 44 shows these levels.

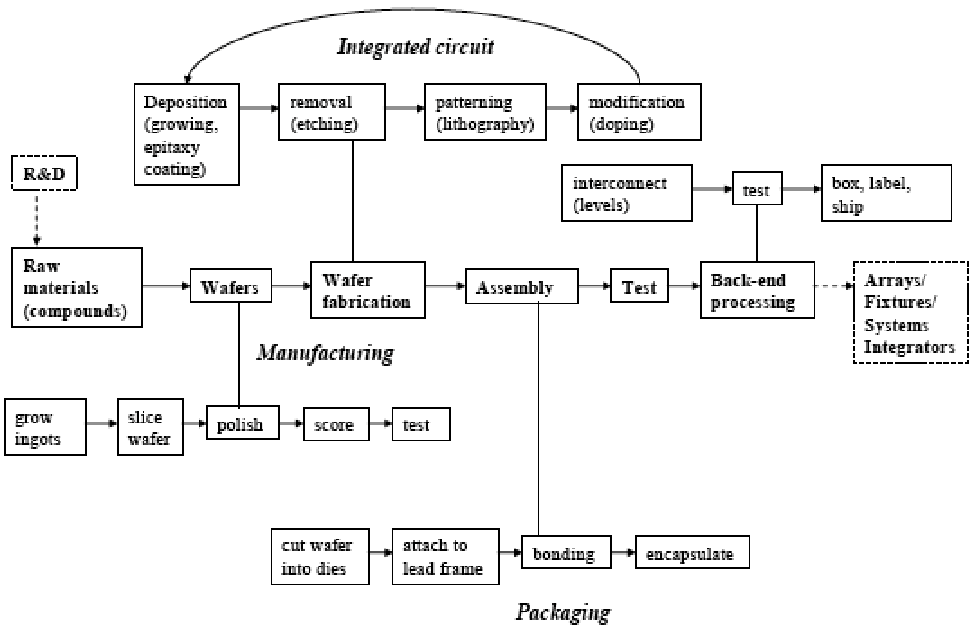


Figure 44 - LED component for lighting fabrication value-chain

Figure 45 shows a 2009 snapshot of the "top-10" companies producing dies (epi-wafers) and packaged LEDs. It shows that the gravity centre for this industry is clearly in Asia (Epistar is a Taiwanese and Nichia a Japanese company). Furthermore, the same snapshot two years before (2007) shows that Epistar was at rank 5 with $319 million and to the side of packaged LED Citizen was rank 1 with $375 million. These significant changes indicate that the LED-manufacturing world is moving rapidly. It should be mentioned that in 2010, the gross output of the LED chip industry in China was, for 62 players in the area, more than RMB 2.3 billion (245 million €).

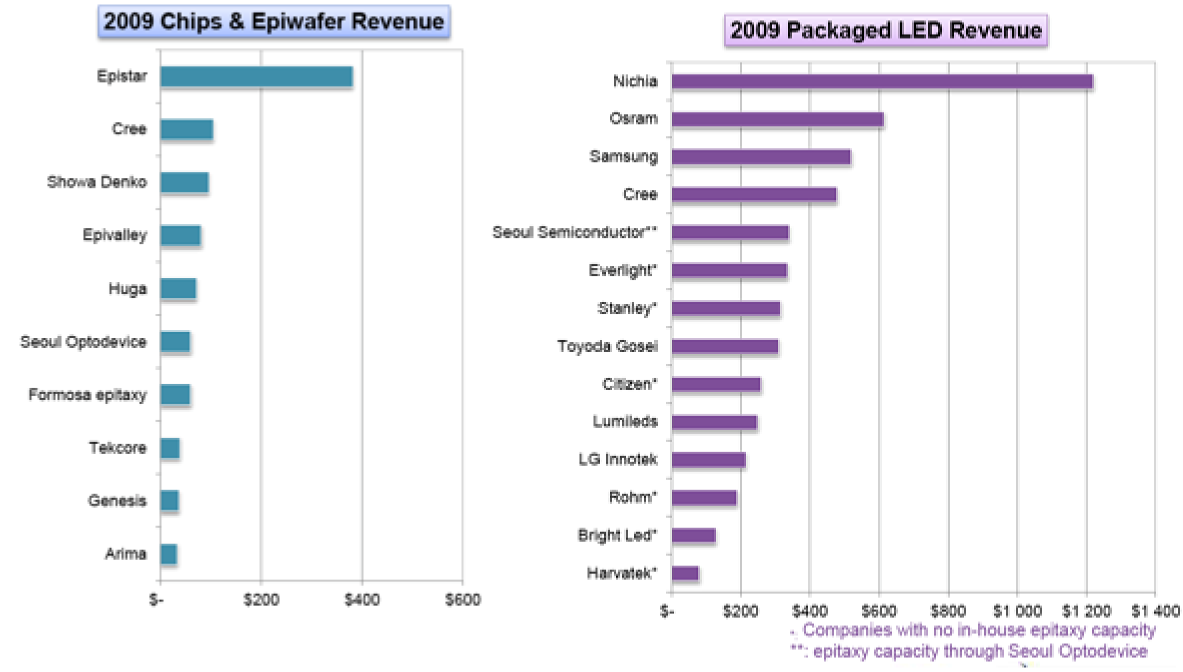


Figure 45 - High Brightness LED Companies Revenue Ranking (InGaN + InGaAlP based) [Yole Développement, 2010]

Figure 46(a) shows the GaN chip production capacity split among world's regions estimated at mid-2010. Figure 46(b) illustrates MOCVD capacity growth from 2009 to 2011. European capacity is rather small (3%) but it is expected to increase in the few next years.

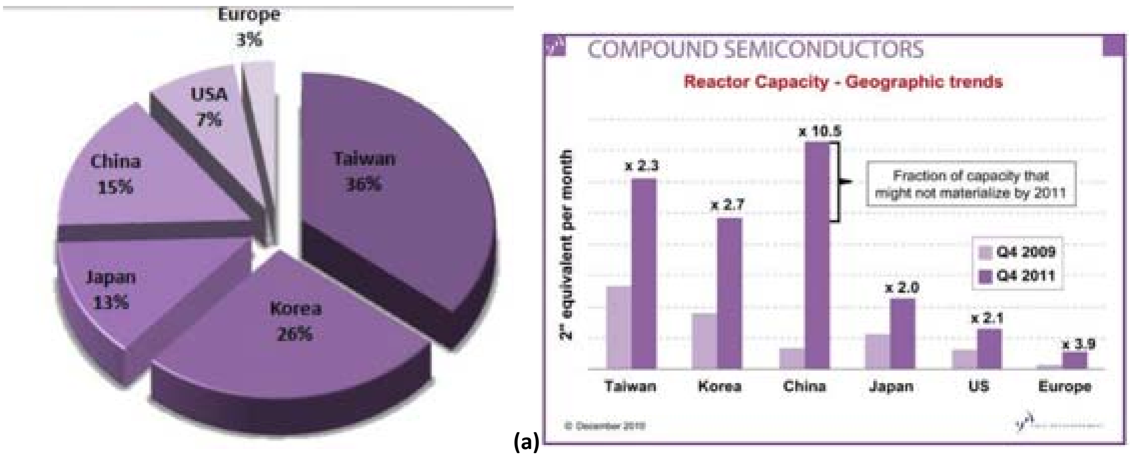


Figure 46 - (a) World capacity for GaN-chip production (mid-2010) [LED Fab Database, Yole Développement & EPIC, 2010].
(b) MOCVD capacity growth by world regions [Compound Semiconductors, Dec. 2010]

Following an analysis proposed by YOLE Développement in 2009, the "back-end" level 1 represents more than 54% of the packaged regular LED, where the phosphor represents 32% of the value. Figure 47 illustrates the fabrication cost breakdown on the final value of the regular LED and HB-LED component.

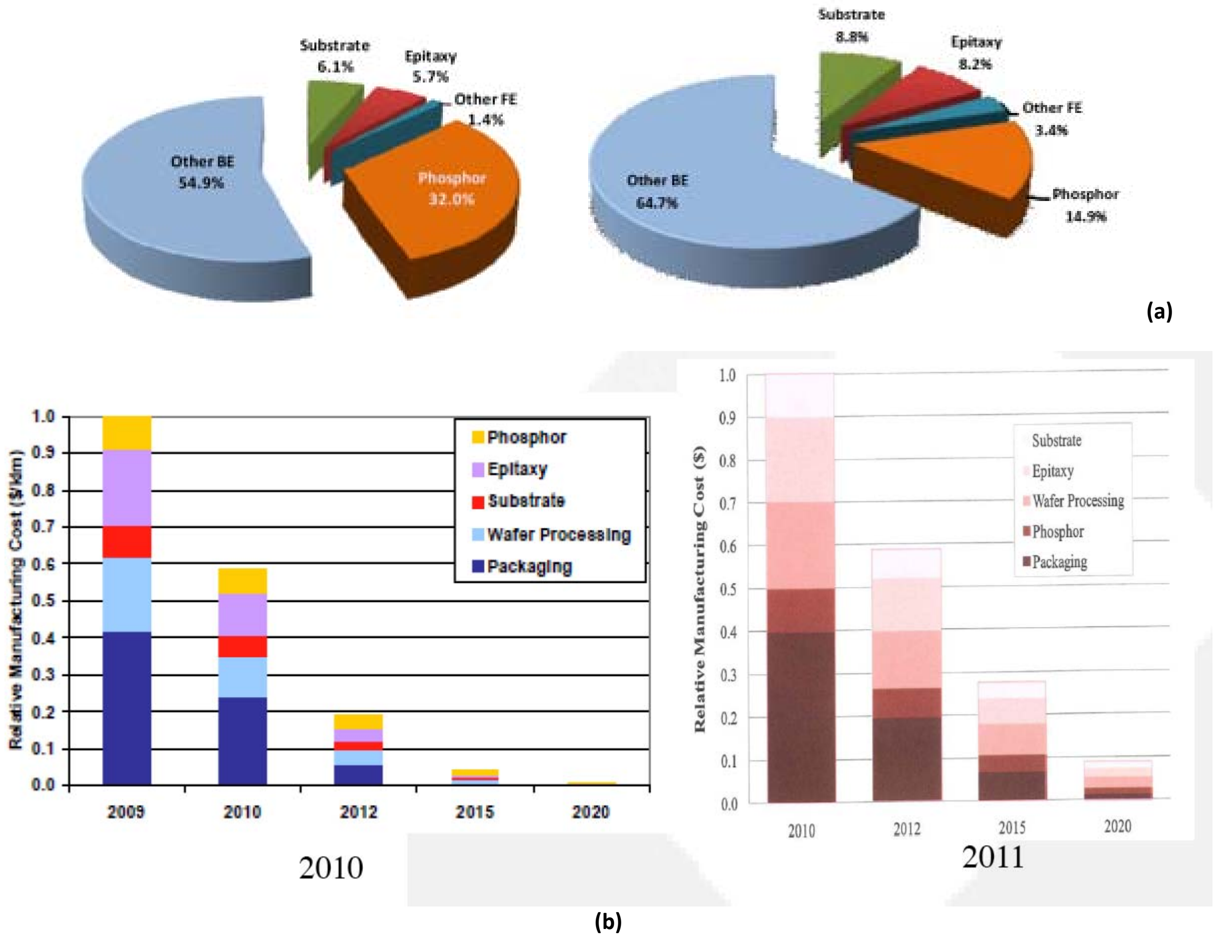


Figure 47 - (a) Cost breakdown of the final value of regular LED component (left hand) and HB-LED (right hand) and (b) Projected Packaged LED Cost Track. [DoE Manufacturing Workshop consensus, 2011]

LED chip production generally accounts for 70% of profits, and LED chip packaging accounts for about 30%. [Ton MK, EEDAL, 2011]. For this reason, many new enterprises are created every year on the segment of LED-chip. Many of them are Chinese. Figure 48 shows the number of new companies created in this segment every year.

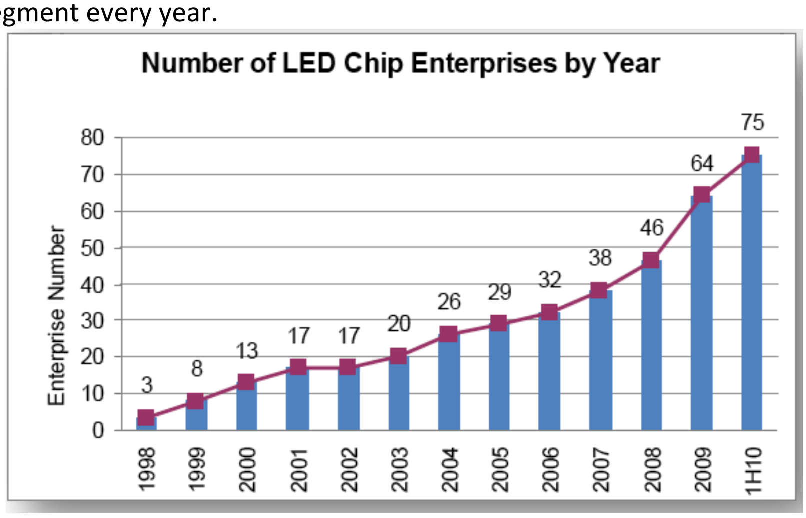


Figure 48 - New companies created each year on the LED Chip business [Chu R, LedInside, November 2010]

For process wafers, it is necessary to own specific heavy tools like Metal Organic Chemical Vapour Deposition (MOCVD units). MOCVD systems worldwide were estimated to have reached 662 units in 2010. 2011 may maintain or even exceed this number[16].The unit selling price of an MOCVD system is $1–2m, and the Chinese Government, in particular, offers a subsidy of up to 50%[17], so there is currently an upsurge of LED-related investments and a boom in MOCVD purchases in China. In 2010, the number of MOCVD systems registered with the National Development and Reform Commission (NDRC) alone is nearly 700, and some manufacturers purchase directly rather than wait for the NDRC subsidy. US-based Veeco and German-based Aixtron are the major two suppliers of MOCVD equipment, alongside Nippon Sanso and Thomas Swan.

On the production side, analysts foresee an over-supply of LED dies that could be effective within the next 5 years. As a consequence prices will decrease dramatically and revenue of semiconductor industry will slow down. This may have a positive effect for LED lighting products, but constitutes a threat for the lower levels of the value chain.

The gravity centre for the LED manufacturing industry has clearly moved to Asia, in terms of revenues, in particular for chips and epiwafers, but also for packaged LEDs. Because of the profits it can bring, many new companies have been created in the last years in the LED chip manufacturing segment, many of them being Chinese.

3.3. The major players

Before the SSL uptake, three large players traditionally dominated the general lighting market: Philips (the Netherlands), Osram (Germany), and General Electric (United States). Each of these has developed a strong presence in LED lighting through joint ventures with, and acquisitions of, specialised firms. Philips, for instance, has a large facility in California, Lumileds, and is a major manufacturer of LED chips for use in the company’s own packaged LED lighting products; it also sells packaged chips to other firms. Osram is a top manufacturer of LED components, as is General Electric, under its Ohio-based subsidiary Lumination (formerly Gelcore). While these traditional lighting giants have so far played a leading role in the LED general lighting industry, they face competition from new LED lighting firms, especially in Japan, Taiwan, Korea, and other Asian countries. A special focus has to be put on China, for which LED-Lighting industry growth becomes an important stake for the coming years.

In the general lighting value chain, the capital expenditure is much higher for upstream players, and associated margins are higher for this segment of the value chain as well. The major worldwide firms involved in the LED lighting industry span, to varying degrees, the manufacture of LED chips, LED lamps, and LED luminaires. Figure 49 shows the geographical distribution of the LED-Lighting industry and Figure 50 shows the geographical implantation of the main LED-Lighting players.

[16] Most forecasts were made before the debt crisis, these forecasts will have to be verified in practice.

[17] In 2009 the Chinese government was subsidising MOCVD equipment purchases by RMB 8–10 million each

Figure 49 - Geographical distribution of LED-Lighting industry [Gereffi, G., et al. Center on Globalization Governance and Competitiveness].

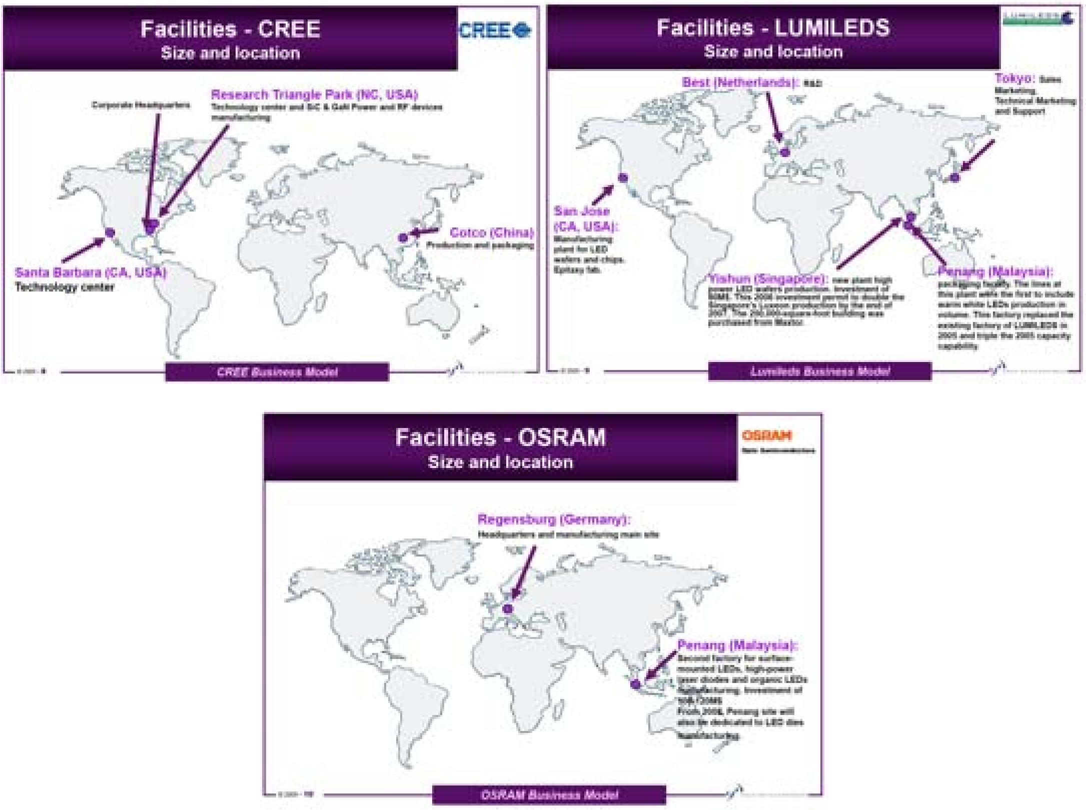


Figure 50 - Geographical distribution of facilities of three LED-Lighting majors [Yole Développement, 2009].

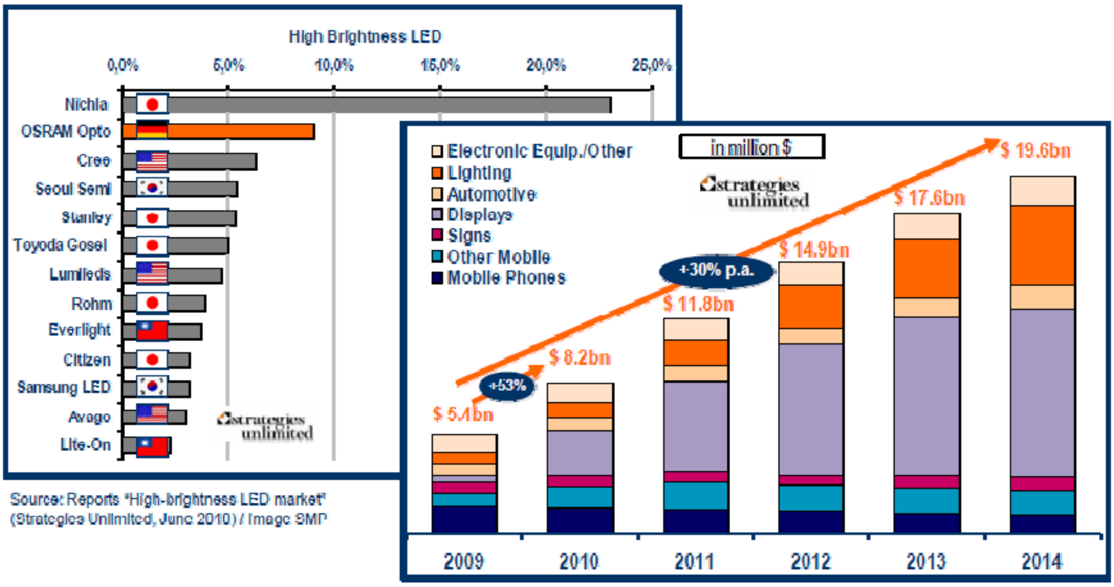


Figure 51 - High Brightness LED Main Manufacturers and Market Projections [Stapp, 2011]

Figure 51 shows the major HB-LED manufacturers, as well as market projections.

Solid-state lighting manufacture encompasses product design, product manufacturing, as well as marketing and sales. Many Asian firms do the product design and manufacturing for the original equipment manufacturer (OEM) companies that market and sell the product under their own brand. Companies in North America and Europe, in contrast, tend to do product design, marketing and selling, but—with the notable exceptions of Cree, Philips Lumileds, and a number of smaller firms—many outsource the manufacturing to Asian subcontractors [Gereffi, G., et al. Center on Globalization Governance and Competitiveness]. It should be noticed that many Asian and US firms are established also in Europe and have important stakes in the EU market. For example 10% of Cree’s sales and 5% of Nichia's revenue stems from Europe.

The LED Lighting business is rather complex and there are several links, cross licences, supply relations between the main actors, as shown in Figure 52. In fact, in 2007 five major companies were controlling 80% of LED sales: Cree, Nichia, Osram, Philips, and Toyoda Gosei and since 2000, licensing has been the rule. As an example, Figure 53 illustrates Cree's strategy in this direction.

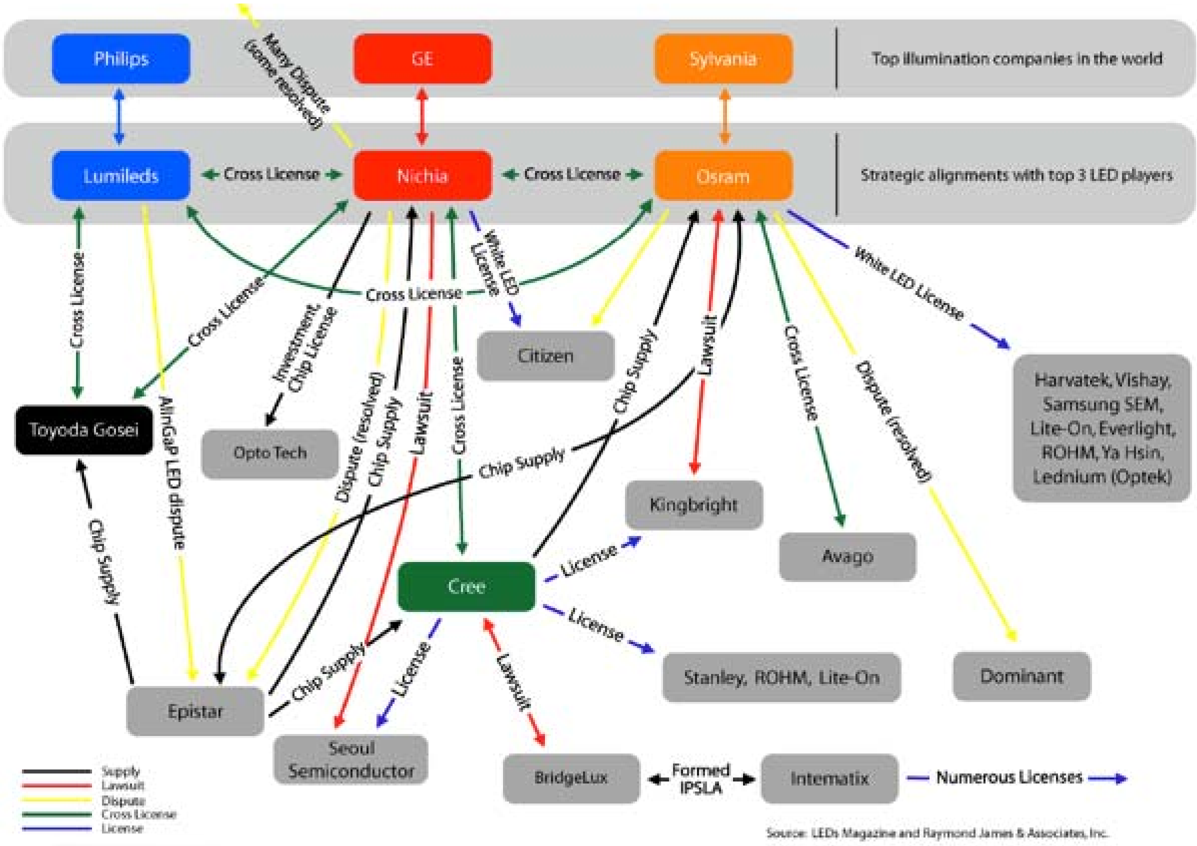


Figure 52 - LED-Lighting business eco-system and relations between actors [LED Magazine, 2008]

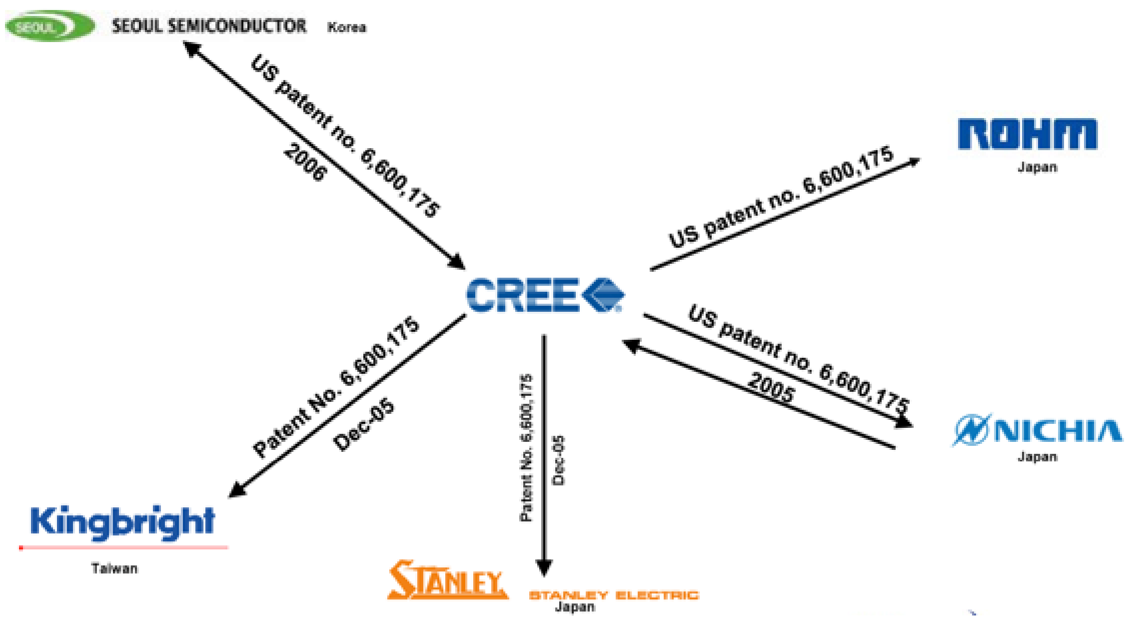


Figure 53 - Cree patents and cross-licence strategy [Yole Développement, 2007]

Figure 54 shows the major firms' LED sales revenues and employees for 2009. In addition, integrated LED lighting solutions will put pressure on many of the smaller luminaire players that will be unable to keep up with product development. This should drive increased consolidation in the luminaire segment, especially in Europe (~800 players), but overall the market is expected to remain fragmented.

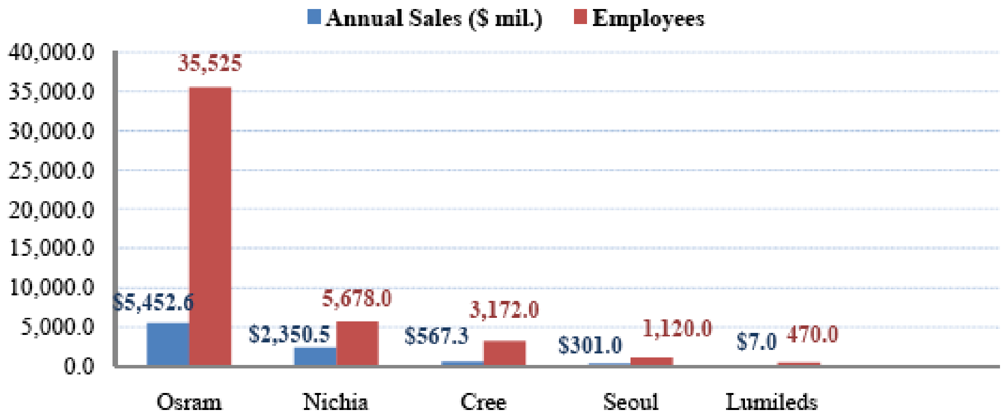


Figure 54 - Major companies' LED sales revenues and employees for 2009 [Hoovers Online Pro 2010]. Note: Osram employee figure refers to the lighting company total, not just LED lighting

The situation can be different from one major market player to another, due to its own development strategy. However, all indicators show that LED-Lighting will be dominant within the next five to ten years. For example, the following paragraphs are dedicated to data collected from various sources illustrating companies' market shares and strategies.

Regional developments

- **USA**: The growth in LED is attracting many new players to the luminaire market, notably in **the US**. The annual LED luminaire design competition, sponsored by the US Department of Energy, saw in February 2011, 126 entries from 60 different companies, many of which are small start-ups (incidentally, the four winners were Finelite, Specstile, GE Lighting and Philips). Acuity is the number one fixtures and controls supplier in the US, with a claimed market share of around 17% in 2009. Management of GE estimates that the top four (Acuity, Philips, Hubbell and Cooper) hold over 50% of the US lighting fixtures and controls market. At the end of January, Acuity and Samsung LED Co. announced collaboration in the field of LED lighting, designed to accelerate the adoption of LED lighting technologies. Cooper buys in the LEDs from Nichia, Lumileds and Cree and focuses on applications – thermal and optical controls – as well as design. In 2009, Cooper increased the number of LED solutions from 10 to 200 for commercial applications. Similar to Cooper, Hubbell is active across various electrical end markets, including energy transport and distribution, wiring devices and lighting. In lighting, the group offers a wide range of fixtures for commercial, industrial and residential applications, with over 20 different specialised brands. The company is active in lighting controls and supplies through three separate brands (Bryant, Hubbell Building Automation and Hubbell Wiring Device-Kellems) dimmers, sensors and timers.
- **Europe** has some specific characteristics. Whereas the European manufacturing base is strong in the downstream segments of the value chain close to the application, with more than 40% of general lighting manufacturing in Europe, it is weaker in the upstream segments, with 11% of Light Emitting Diode (LED) packaging and approximately 10% of global production of devices (LED chips) and advanced materials (compound semiconductor ingots and wafers). However, it is noted that the majority of key MOCVD (Metal-Organic Chemical Vapour Deposition) equipment for LED chip production is still manufactured in Europe. One may conclude that although significant initial technology development and industrialisation for all lighting value chain segments originated in Europe less than 10 years ago, the manufacturing fabric upstream from the "lighting solutions" level is weak. The market is in its infancy and struggles to really take-off due to several reasons.
- Beyond Zumtobel, the ecosystem of European LED luminaire manufacturers is much more fragmented than in the US. Many companies are family-owned SMEs, specialised regional

players, generating sales of around €30-40 million. These include iGuzzini, Targetti, Artemide (Italy), Erco (Germany), Etap (Belgium) and Fagerhult (Sweden).[18] Fagerhult is the largest lighting group in the Nordic region with sales of SEK 2.4 billion (263 million €) in 2009 and around 1 900 employees. The group aims to become 'one of the largest players' in the European LED lighting market through internal and external growth.

- **Germany's** semiconductor industry has become a major global partner and driver of development and research of LED technology; however, Germany is a net importer of light-emitting diodes. Over the last five years Germany has seen domestic production decrease while imports of LEDs are steadily increasing to around 1 767 tons, accounting for a market share of €299 024 in 2009. In contrast to the year 2007, the number of units produced dropped by 36.0%. Reasons for this decrease may be a mix of drivers, such as increasing domestic production costs, specialisation of domestic production from normal LEDs to HB and UHB LEDs, outsourcing production to subsidiaries abroad and increased competition by foreign manufacturers. The tables below illustrate this shift over the course of eight years. The following table gives the production of light emitting diodes in the country [Federal Statistical Office Germany (Statistisches Bundesamt), 2009].
- **Taiwan** grabbed a dominant position in the LED chip arena in 2007. Taiwan emerged as the top region for blue LED chip capacity (i.e. mainly targeting displays and TVs) and occupied the second spot in LED chip packaging in 2007, according to Taiwan's Photonics Industry Technology & Development Association (PIDA). Taiwan's LED industry became ever stronger in 2008 with the advanced development of the semiconductor industry and the upstream to downstream integration of the LED industry. Taiwan topped the world's blue LED chip capacity sector with almost 40% of global production, Japan, Europe, the US and South Korea following. In the LED chip packaging segment, Taiwan's production value jumped from $1.29 billion in 2006 to 1.54 billion in 2007, trailing Japan's $2.99 billion in 2007, followed by Europe, South Korea, the US and China. Despite Taiwan being able to produce 1.8 billion units of blue LED chip, manufacturers still estimated a 20 – 30% shortfall during 2008. Since April 2007, orders for LED chips have exceeded makers' capacity by an average of 30%. Downstream packaging manufacturers experienced the same situation. A maximum, and expanding capacity, was reached for packaging, while a continuing boom market is expected until 2020. Major players in the industry are raising funds to aggressively expand their production capacity. Taiwan established a complete LED industry value chain, as shown in Figure 55.
- **South Korea:** In South Korea, the white LED activity has been driven primarily by the needs of the backlighting industry through major display and television manufacturers, such as Samsung and LG. LED manufacturing and R&D capabilities are now well established and this expertise is expected to be turned increasingly toward the production of lighting class LEDs as the demand for LED televisions begins to saturate and oversupply begins to erode prices. Samsung LED (established in April 2009) has been highly successful in backlighting for flat screen TVs and is now looking to expand into general lighting. Cooper Lighting generates annual sales of around $1.1 billion, of which around 80% in the US. The company aims to globalise its business and benefit from energy efficiency upgrades where it is focusing on growth opportunities in controls and LED. Over 50% of sales are in the commercial sector, around 25% in residential (Halo: no 1 recessed lighting brand) and the remainder in industry and roadways, where the company claims the broadest LED offering in the industry.

[18] This is not an exhaustive list.

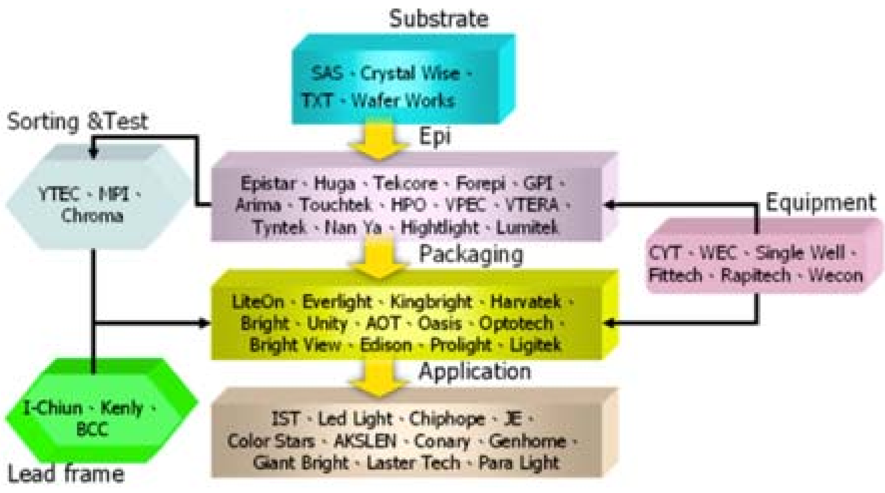


Figure 55 - Taiwanese LED value chain [PIDA 2007/11]

- In **China**, the LED lighting industry has been growing prosperously in recent years as the Chinese Government has given its strong support to developing the industry. The Chinese Government decided on a massive investment of $3.5 billion/year into LED industry for the period 2010-12. It is also because of the strong government intervention that various market uncertainties arose. Despite market uncertainty, China has a huge domestic market, thus attracting world-leading manufacturers like Cree and Taiwanese manufacturers to make aggressive deployment. In November 2009, US LED manufacturer Cree announced the signing of a LED chip factory contract with Huizhou City Government in Guangdong. This is the first LED chip mass-production base ever established by Cree outside of North America. With an initial investment of $50 million, production was foreseen to begin in mid-2010. This suggests that Cree is optimistic about the developmental potential of the Chinese LED market. Taiwanese manufacturers have also made aggressive deployment in the Chinese market. For example, in 2009, Taiwanese manufacturers, including UMC, Epistar, Lite-on and Formosa Epitaxy announced an increase in investment in the Chinese market to expand their production bases. As the Chinese domestic market is huge, there are opportunities for China to grasp the smile curve of the entire industry in the future, making the balance of competitiveness across the strait slide toward China.

Registration - number	Product	unit	2001	2002	2003	2004	2005	2006	2007	2008
3210 52 350 (old)	Light Emitting Diodes	1000 pcs. 1000 €	620836 68549	528303 57871	738011 101238	1010393 100647	518912 64851	491898 65843	369183 66752	236260 55289
2611 22 200 (new in 2009)		€/piece	0,1104	0,1095	0,1372	0,0996	0,1250	0,1339	0,1808	0,2340
change in production compared to the previous year		in %	100%	85,10% -14,91%	139,69% 39,69%	136,91% 36,91%	51,36% -48,64%	94,79% -5,21%	75,05% -24,95%	64,00% -36,00%
change in production compared to 2004		in %	61,45	52,29	73,04	100,00	51,36	48,68	36,54	23,38

Table 4 - Production of LEDs in Germany [Federal Statistical Office Germany (Statistisches Bundesamt), 2009]

Figure 56 shows the main exporters to Germany. The largest part is coming from China and then from Malaysia (this is to be expected because Osram-Opto has a manufacturing facility in this country). One of the key contributors to domestic demand is the large automotive industry.

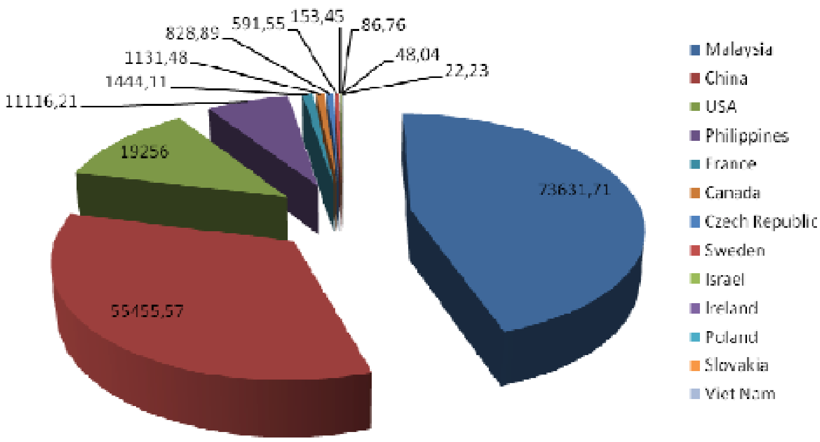


Figure 56 - Germany LED imports (in value) [Federal Statistical Office Germany (Statistisches Bundesamt), 2009]

The following table shows how four major players are involved in the LED for lighting market via their subsidiaries.

	Epi/Chip	Packaging	Control	Fixture
Philips	Lumileds	Lumileds	Color Kinetics	Genlyte
SIMENS (OSRAM)	OSRAM Opto Semiconductor		OSRAM LED Systems	OSRAM Sylvania
GE	Nichia (전략적 제휴)		GE Lumination	
CREE	CREE	Cotco	LLF	LLF

Table 5 - Involvement of major players in LED value chain

The following figure (Figure 57) gives an industry outlook in LED Lighting Competitive Landscape.

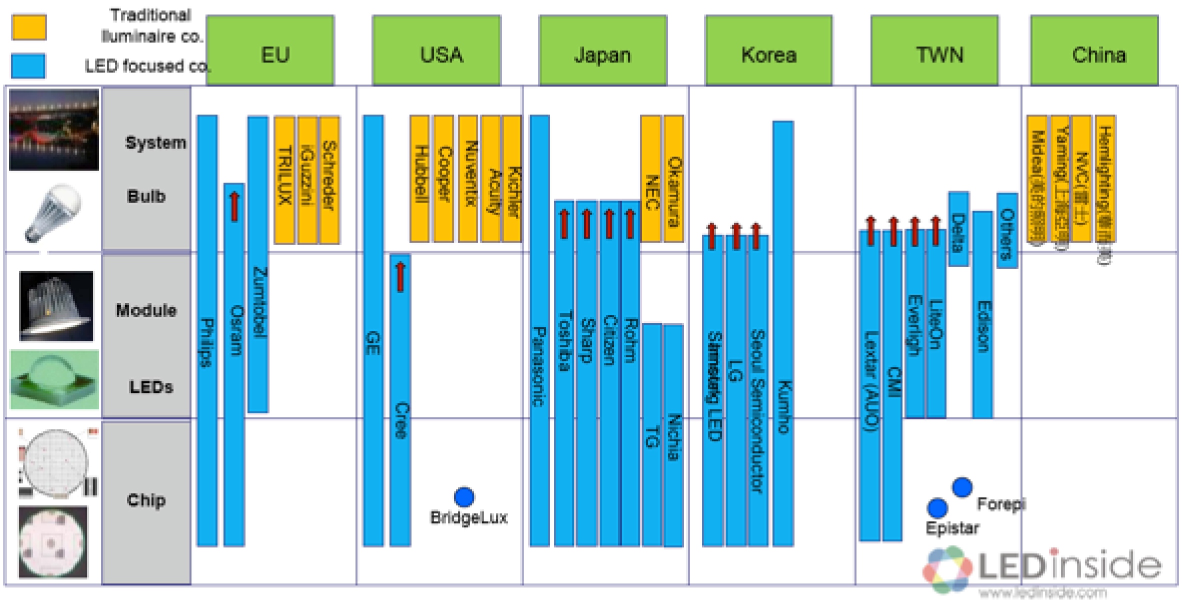


Figure 57 - Industry outlook in LED Lighting Competitive Landscape [Chu R, LedInside, November 2010]

The SSL industry is a fragmented industry. Dies are produced mainly in Asia. Major players are based in the US, Europe (Germany, Italy, the United Kingdom and the Netherlands) and Asia (China, Japan, Taiwan, Malaysia, Korea and Singapore).

The big three in the SSL industry are the traditional lighting players Philips, Osram and GE. The manufacturing structure consists of a) product design, b) product manufacturing and c) marketing and sales. In Asia, companies do a) and b) often for non-Asian firms who are in charge of marketing and sales. European companies are active in market design and marketing and sales and often outsource manufacturing in Asia (sometimes through a subsidiary).

3.4. Worldwide R&D in SSL Technology

LED-based SSL technology has its roots in the initial demonstration of a high performance blue LED-based using GaN by Nichia in 1993. More specifically, a few years later, the same group demonstrated a white LED through combining the blue LED with a YAG phosphor. This major technology development set the scene for SSL. Subsequently to these announcements there was an explosion of R&D activity worldwide, culminating in the commercial availability of white HB LEDs from Nichia (Japan), Toyoda Gosei (Japan), Philips Lumileds (US), Cree (US), and Osram (Europe).

These companies continue to be major players in this market, but patent cross licensing has opened up the market to other players and has broadened the R&D base. A 2009 analysis of worldwide patent activity recognised growing R&D activity in Asia, partly in Korea because of Samsung's role, and partly in Taiwan and mainland China. LED manufacturing is now a global business and the supporting R&D activities are also located globally.

R&D activity in **Europe** is generally coordinated through the Photoinics21 European Technology Platform. Much of the government funding is channelled through European Union collaborative R&D projects. In the area of LED-based SSL technology there are a number of projects currently underway – in the framework of EU's Seventh Framework Programme for Research (FP7) including FAST2Light, SSL4EU, OLED100.eu, SCOOP, LAMP, IMOLA, CSSL, ENLIGHT, SMASH and THERMOGRIND. These projects have a combined project cost of approximately €110 million with project funding of more than €80 million from the EU, and last typically three years. The two largest programmes (SSL4EU and SMASH) are coordinated by Osram. Recently, Directorate Information Society of the European

Commission selected projects for pilot actions in SSL technology to be launched in 2012 with a budget of €6.5 million (CIP SSL demo actions).

In **Taiwan**, the total investment in the LED industry was about US$600 million in 2010, the largest amount worldwide. The primary source of R&D funding is the business sector, at around 70%, followed by the government, at around 30%. The main research institute for LED R&D is the Industrial Technology Research Institute (ITRI) which recently announced it was setting up a LED research centre and has embarked on a three-year project to develop cheaper, longer lasting LED backlights. Key companies are reported to be planning to establish a vertically integrated activity covering epitaxy, packaging and module manufacture, and to release their own brand of LED lighting sources and light engines.

The private sector is also a key player in **Korean** R&D activities, contributing around 74% of R&D funding in 2007 (the global amount for R&D dedicated in Korea for SSL is estimated in the order of €90-120 millions[19]). The major contributors to Korean R&D activity are Korean global companies in high tech industries, such as Samsung electronics, LG electronics, Hynix and Hyundai Automobile.

China has identified LED manufacturing as a strategic market and has provided significant financial incentives for companies to locate in China, including tax incentives, equipment subsidies, and funding for R&D. In particular, the government has provided approximately US$1.6 billion in subsidies for the purchase of metal organic chemical vapour deposition (MOCVD) equipment. A total of thirteen industrial science parks have been established throughout the country for SSL R&D and manufacturing. Patent activity in China has increased significantly in the past few years with 28,912 LED related patents at the end of 2009, including 59% on applications and 13% on packaging.

Until recently, R&D in **OLED** technologies has focused on display applications. The initial research in the 1980s was performed in the US and Europe, following the pioneering work on small molecule emitters by Eastman Kodak and on light-emitting polymers at Cambridge University and Cambridge Display Technologies.

Since 2000, the manufacturing of OLED displays has been pursued almost exclusively by Asian companies and the production has been supported by a broad range of R&D activities. OLED lighting research in Asia has been stimulated by government-supported consortia in Taiwan, Korea and Japan. In 2003 the New Energy and Industrial Technology Development Organisation of Japan (NEDO) sponsored the formation of the Research Institute for Organic Electronics in Yamagata.

The R&D Effort has resulted in the huge improvement in the LED performance in the last decade (Figure 58) enabling SSL to compete basically in all types of lighting applications.

[19] This amount includes OLED R&D effort.

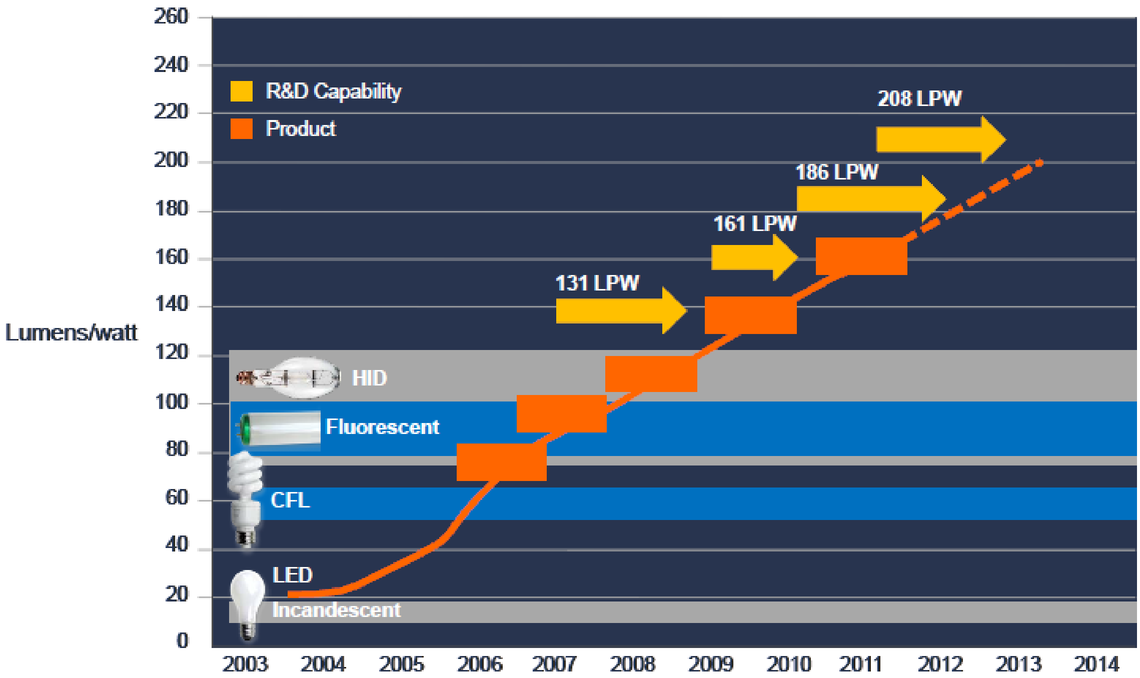


Figure 58 - Lighting-Class Performance and R&D Capability [Merritt, 2011]

Recent R&D efforts are focused on several areas including:

- Developing LEDs and OLEDs with higher efficacy, and higher lumen output at different colour temperatures.
- Development of cost-effective lamps which can replace incandescent and CFL lamps. There are some first-price LED lamps replacing the 60 W incandescent bulbs available for 10 to 15 €[20], but products delivering the same quantity of light, such as the Philips Ambient LED, are available on the European market at around 40-60 €.
- Better cooling with passive methods and improved low-cost heat sinks. Novel methods include an ioniser, where a mesh of wires near the LED chip creates an electric field with a small electric charge. The ions create a breeze, which in turn eliminates heat. Another approach uses a tiny device that creates a vortex of wind near the chip to dissipate heat.

[20] In August 2011 Lighting Science announced an 8.5 W LED lamp to replace a 60 W incandescent lamp, costing 10 €.

Figure 59 - 12 W LED lamp to replace a 60 W incandescent lamp

- Quantum Dot LEDs: In recent experiments, LEDs emitting blue light were coated with quantum dots. These dots glow in response to the blue light of the LED, resulting in a warm yellow light similar to that of incandescent lamps. Quantum dots have unique properties which enable them to create almost any colour on the visible spectrum. This increases the possibilities of LED use in display screens, as well as lighting.
- Development of high efficiency and long-life LED drivers.
- Development of integrated controls, which can have embedded sensors for intelligent control.
- Development of lamps without DC converters for better efficiency, as well as to decrease costs and weight.

Summarising, LEDs and OLEDs have only recently started to enter the lighting market and there is still tremendous potential for improvement in order to become more competitive. Two key factors are dominating R&D: performance and cost. A collaborative approach across all relevant research areas is needed in order to fulfil all relevant market needs (CELMA; ELCFED, 2011; US Department of Energy, 2011).

R&D takes place mainly in Japan, the US and Europe. Through patent cross-licensing however the research base becomes broader, including China, Taiwan and South Korea. Europe is suffering from fragmented funding. Taiwan has the largest investment worldwide, estimated at $600 million, 70% being private. Korea's R&D is also mainly privately financed, whereas in China, the government is investing heavily in research.

3.5. LED Commercialisation channels

LEDs represent a complex system with a great deal of interplay. Factors that have to be taken into consideration include the driver, the control, the optics, the LEDs, thermal issues, surge protection and interconnection. Addressing these factors will enable the construction of an acceptable mass-market product. Could a future market evolve where consumers pay for the light itself – the quality and controllability of the light, not just the style of the light fixture?

Essentially, increased customer acceptance of efficient lighting in domestic environments will require a two-pronged approach. Professionals must be aware of all the possibilities and options available with efficient lighting in order to set new trends, and consumers must be informed about the choices they have today. A key point is consumer/end-user information and training. Growing awareness of LEDs is reflected in an increase in media coverage. In 2007, US newspapers and wire services published 712 articles that mentioned LED lighting. In 2008, media coverage grew to 846 articles, an increase of 19% [Based on a review by D&R International using LexisNexis databases of the appearance of LED lighting in US newspapers and wires from 2004 to 2008]. Since then, the number of papers in the press concerning LED Lighting has increased in an exponential way, including the general press, also in Europe.

Other practical factors of commercialised products include the ability to have equivalent replacement parts over a period of years, when the market for LEDs is moving so quickly. Also, warranties must be offered for products, to protect consumer interests – particularly for this new, unfamiliar technology. Finally, **installer training** is a critical part of the LED revolution, so that the electrical contractors who are in charge of installing these products in the professional market receive the necessary specialist training to ensure they handle LED luminaires safely and properly.

One factor that will greatly facilitate commercialisation of LED technology will be the standardisation of interconnects used. On an international level, Philips has initiated the establishment of the **Zhaga consortium**[21] to discuss and develop a set of LED interconnects. This consortium has broad support from a range of players in North America, Europe and Asia, including Cooper, Philips, Toshiba, Osram, Panasonic, Zumtobel, Acuity Brands, Havells Sylvania, General Electric and Tyco Electronics. With over 23 members participating in Zhaga, the group is defining interfaces for a variety of application-specific light engines. These standards will address physical dimensions, as well as the photometric, electrical and thermal behaviour of LED light engines. By standardising the interconnects for lamps, consumers will be able to replace LED light engines that fail in their new fixtures, rather than have to purchase a whole new fixture and/or have it installed.

The commercialisation channels are strongly dependent on the country "ecosystems". The following paragraphs are illustrative:

- In Germany, there are several domestic distribution channels for foreign LED manufacturers. Direct links can be made to assembling manufacturers in Germany, such as Osram, Stanley Electric, Traxon that concentrate on general lighting products. Other channels may be the automotive industries, on the one hand, and the distribution to end-consumers, on the other hand. Regarding the channels mentioned, direct distribution to end-consumers is rather unimportant for high capacity LED manufacturers, because of a narrow demand of target consumers. However, lighting and electrical distributors are the most important channels that LED manufacturers can use to reach the end customer with their individual product message. A domestic distribution partner is of vital importance, since they are in the best position to establish producers' products on the local market and to find suitable buyers for the products.
- In France, LED components can be purchased directly from electronic component wholesale or retail stores. For LED luminaires, fixtures and lamps, the circuit is more complex, as illustrated by Figure 60.
- In Japan, LED (and CFL) light bulbs are not sold in the supermarket, but in electronics shops. In those shops, salesmen receive special training about these products and can best advise clients. In addition, a whole department of the shop is dedicated to light bulbs. The first clients that have been targeted are those who need more assistance, i.e. elderly people and single young women. If the LED light bulbs are successful with these people, then it will be likewise for the others.

  For Europe to be as successful as Japan, the whole model of the distribution channels should be overhauled. The model for selling light bulbs in the supermarket was adapted for incandescent lighting. But CFLs, and in particular LED bulbs, as an electronic product, require another

[21] Zhaga consortium is an industry-led effort aimed at the development of standard specifications for the interfaces of LED modules within fixtures. Zhaga will enable interchangeability of LED modules between products made by various manufacturers. For more information, visit: http://www.zhagastandard.org/

commercialisation channel. LED bulbs are indeed complex electronic products which require a commercialisation channel similar to other electronic products, such as PCs or TVs, that is lighting and electronics distributors.

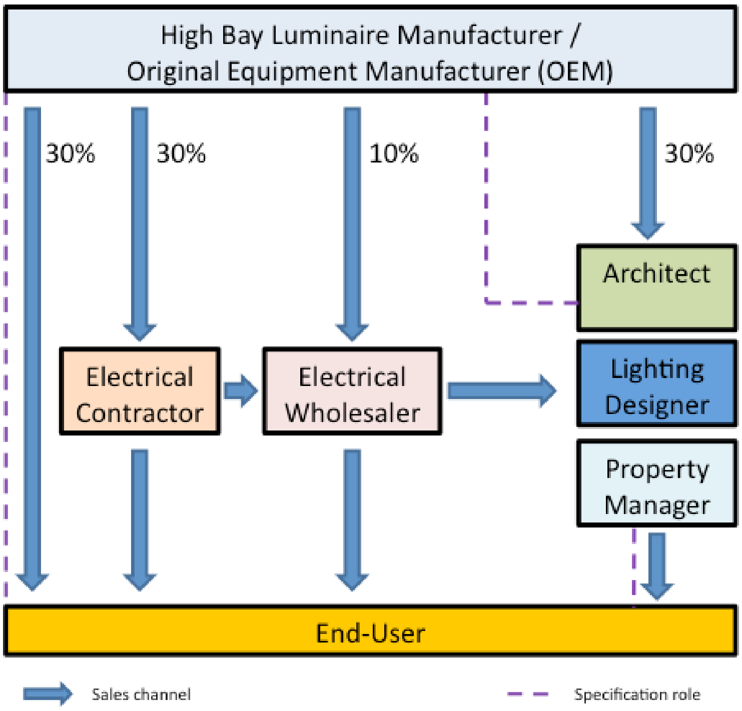


Figure 60 - Luminaire distribution channels in France [Syndicat de l'Eclairage, 2008]

- In the US, the market is more concentrated around the manufacturers, as shown in Figure 61

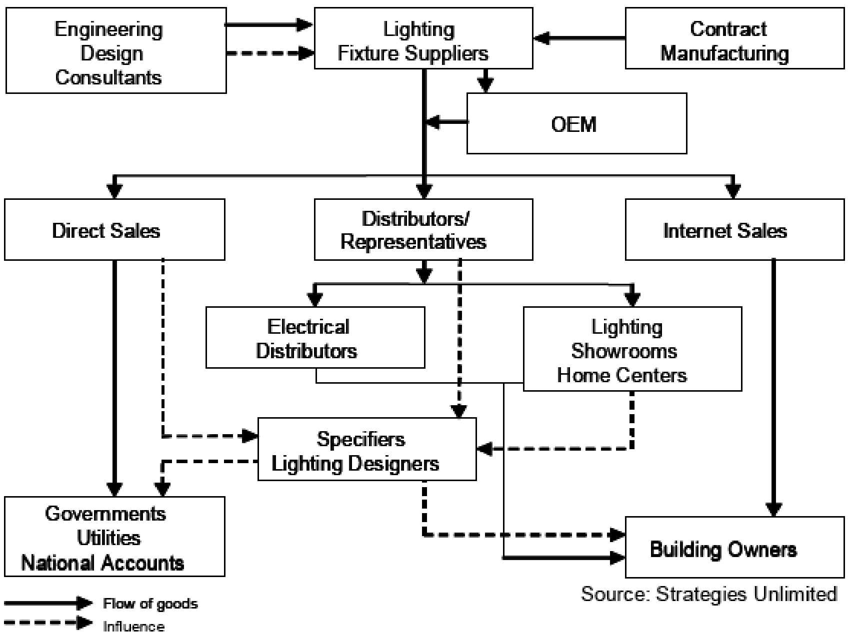


Figure 61 - USA lighting market structure and distribution channels

LED commercialisation channels might face a reshuffle, in particular when the industry will be moving to lighting services. For LEDs to penetrate the market more, end-user information and training, as well as training for installers, would be useful.

3.6. LED for lighting pricing

LED-based lighting products are still expensive and this impedes a rapid penetration in general lighting and more especially in the domestic segment. Lamp and luminaire prices can vary widely depending upon the application, decorative enhancements and control features.

Since the introduction on the market of LED-based products, the Average Sale Price (ASP) is continuously decreasing, as has been predicted by R. Haitz [Haitz R., Kish F., Tsao J., Nelson J., Compound Semiconductor Magazine, March 2002] and in parallel technological performance (namely luminous efficacy and number of lumens per package) is increasing. Figure 62 shows the actual tendencies for ASP per 1000 lm and number of lumens per package.

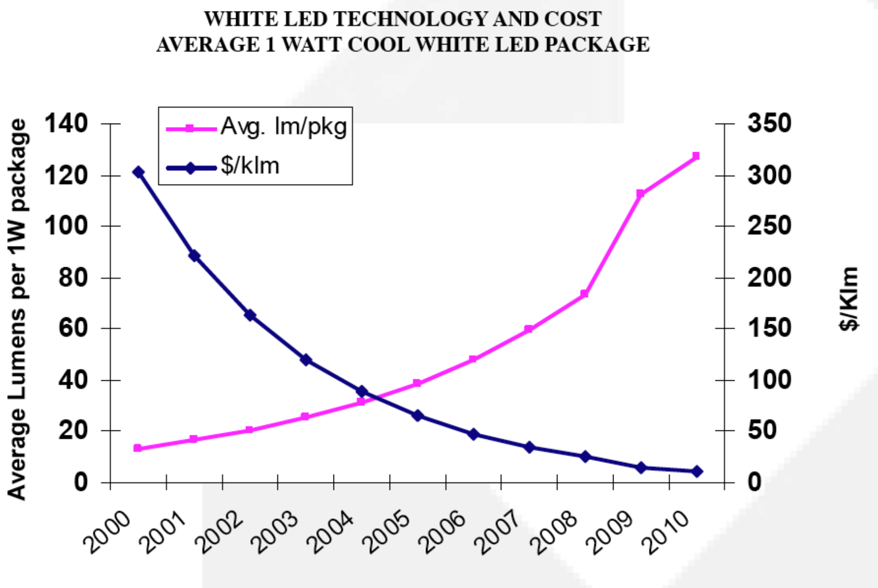


Figure 62 - Evolution of ASP and number of lumens per package for LED lighting products [Bhandarkar V., Strategies Unlimited, October 2011]

However, quality and reliability are the other important factors for boosting new technology penetration. Today, the quality of LED products available in the market is very variable.

To validate the progress on price reductions for LED-based lighting, a comparison of replacement lamps is both practical and appropriate. Figure 63 shows a comparison of an integrated white light LED replacement lamp to a 13 W compact fluorescent lamp, and to the revised Multi-Year Programme Plan (MYPP) targets. The price estimates represent the average retail purchase price. The year 2010 has seen a significant number of good quality replacement lamps emerge, often appearing on the shelves at big box retail stores. Prices for such products have decreased rapidly, with a typical retail price of $20 for a 400 lm (40 W equivalent) warm white A19 replacement lamp and around $40 for an 800 lm (60 W equivalent) product. As a consequence, normalised prices in 2010 have dropped to around $50/klm, some two years ahead of the original schedule.

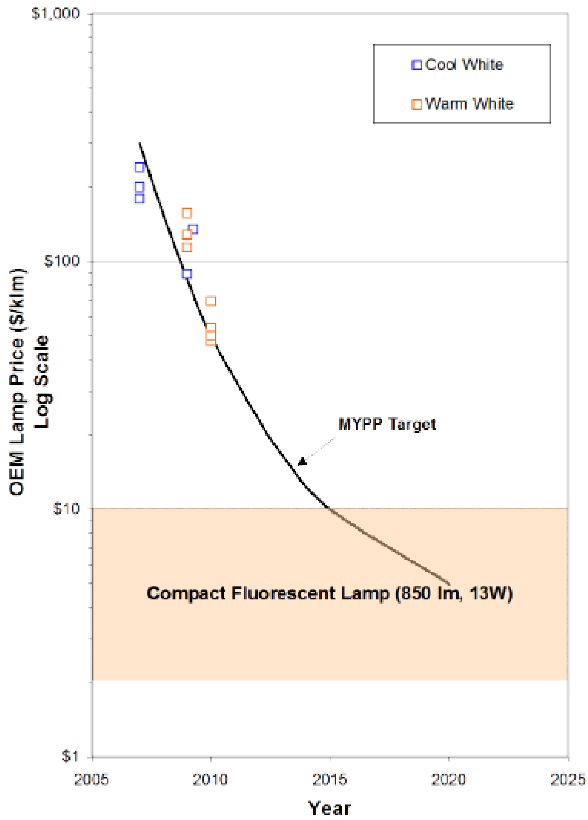


Figure 63 - White Light Integrated LED Lamp Price Projection (Logarithmic Scale) [Bardsley Consulting, DoE, March 2011]

Directional lamps[22] have also become more competitive during 2010 with prices in the $20 to $30 range for a 6 to 7 W MR16 lamp (250-350 lm) and in the $40 to $60 range for a 17 to 18 W PAR38 lamp (750-850 lm). Downlights have also benefited from significant price reductions with products now available in the $50 range ($87/klm). It is important to keep in mind that energy savings, replacement cost and labour costs factor into a lamp's overall cost of ownership.

For now, manufacturers are targeting commercial and industrial customers, for whom the savings can be substantial. But as prices fall, LEDs could become the general lighting of choice in the mass market.

Indeed, for packages designed for current densities of 35 A/cm^2 (Ampere per square centimetre), prices have continued to fall in 2010, and performance has continued to improve. This behaviour is illustrated in Figure 64. Note that there is a lot of scatter in the data, so ellipses have been superimposed on the chart for each major time period in order to identify the mean and standard deviation of each distribution.

[22] Directional includes reflector Parabolic Aluminised Reflector (PAR) lamps and Multifaceted Reflector MR16-type socket spots.

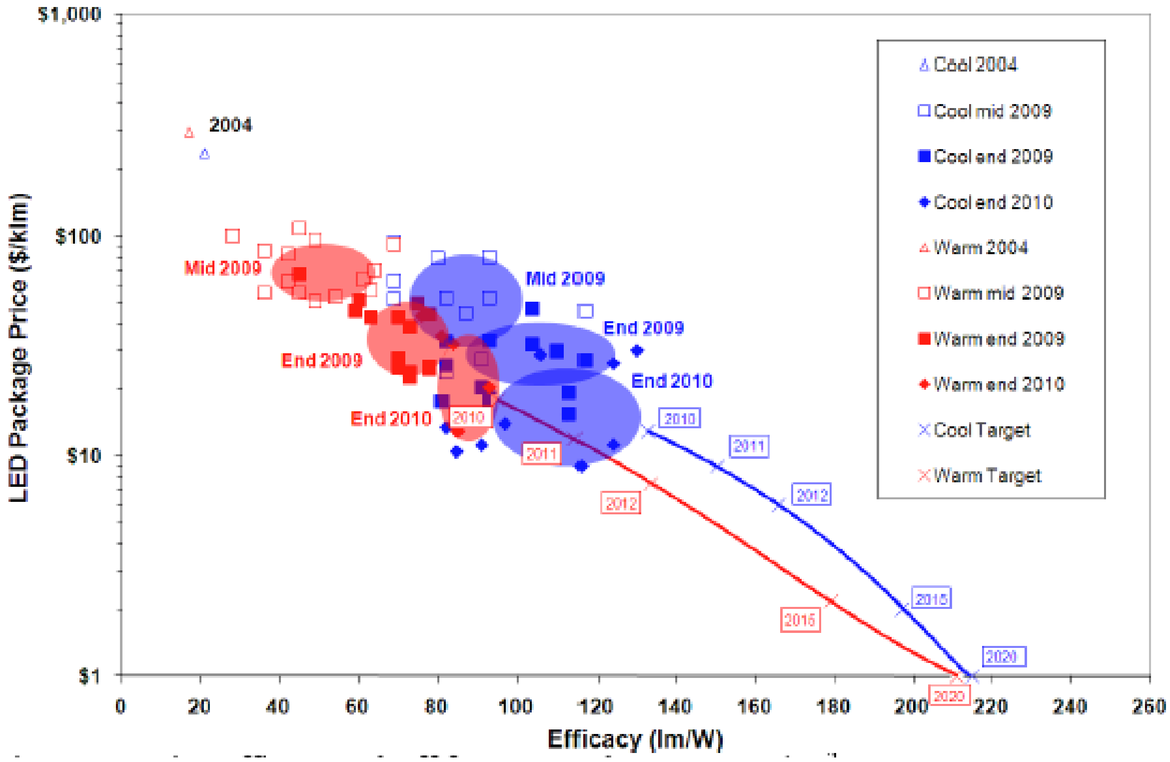
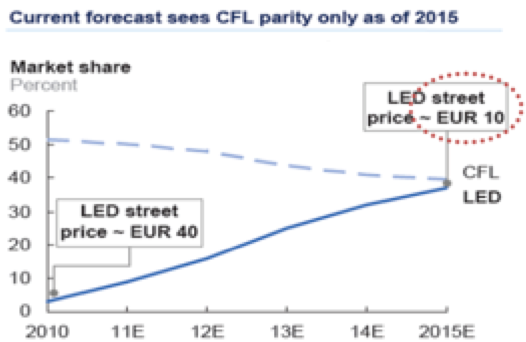


Figure 64 - Price-Efficacy trade-off for LED Packages at 35 A/cm². The solid lines represent the US-DoE MYPP program; Cool white packages assume CCT=4746-7040K and CRI=70-80; warm white packages assume CCT=2580-3710K and CRI=80-90 [Bardsley Consulting, DoE, March 2011]

CFL	LED Equivalent	Price Ratio	Penetration
$3	$99	33	0.10%
$3	$30	10	4%
$3	$15	5	10%
$3	$8	2.5	25%



LED Bulb street price: ~ $8 / ~ €10

LED Bulb FOB: ~ $3 / ~ €4

Figure 65 - LED Penetration rate projection as function of retail ASP [Lee BJ., Epistar, DoE manufacturing Workshop, 2011]

Taking into account that the penetration rate of a technology is directly correlated to the associated retail price (Figure 65), it can be demonstrated that for a 60W replacement lamp based on LED technology (>800 lm package) 25% of market penetration can be achieved at $8 price[23]. From a cost perspective, the DOE projects SSL to drop from US$170 per klm today to $5 per klm by 2030 for high CRI products. The market response curve indicates that the residential sector is less willing to accept a longer-term payback than the commercial and industrial sectors. A two-year payback would only lead to 20% adoption rate in residential (Figure 66).

[23] This is much less than the current price on the European market (see page 50).

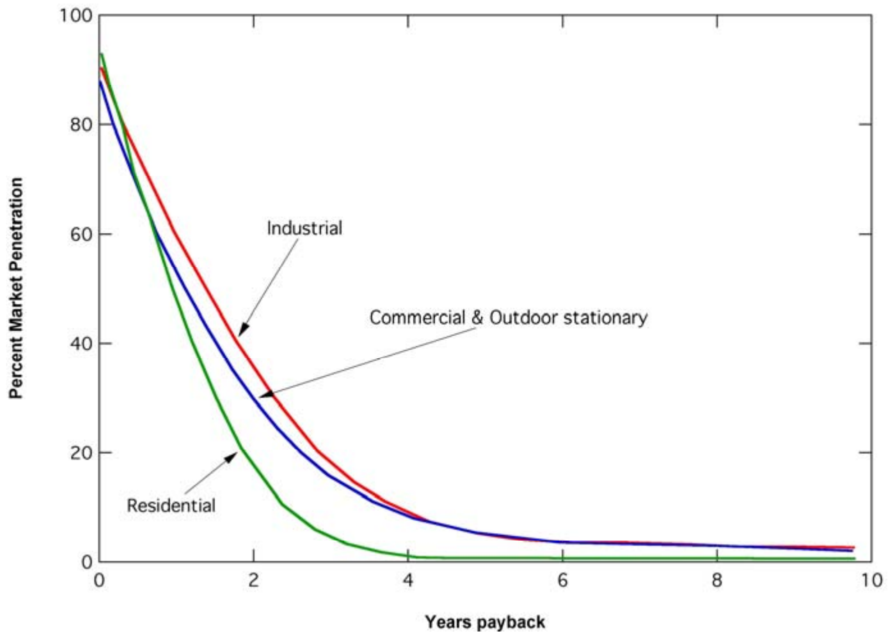


Figure 66 - Market response curve for three different application sectors [Little AD, DoE]

Furthermore, in **Europe** for the same replacement lamp, when the price will attain 10€ in average, the LED-based product penetration is expected to be in parity with CFL penetration (this situation is expected by 2015, today the 800 lm LED lamp is sold in French supermarkets at 60€ in average).

In **Japan**, Sharp announced in June 2009 a significant price reduction of LED bulbs by 50%. Furthermore, in July it launched a total of nine new models of household LED bulbs. In terms of equivalence to a 60W incandescent bulb, the projected sales price will be: JPY 8000 (69 €) and JPY 3900 (33€). Other Japanese manufacturers have also reduced the price of their products in response to Sharp. Furthermore, other manufacturers, such as Matsushita Electric, Hitachi, NEC and Mitsubishi Electric are planning to launch LED bulbs and have also set the sales price between JPY 5000 (43€) and JPY 4000 (34€) in order to seize the market. In this price reduction strategy, it is believed that Japanese manufacturers are testing the price flexibility and acceptance of LED lighting fixtures in the Japanese market. If this movement boosts sales, they can plan their marketing strategy with such pricing information for the LED lighting markets in industrialised countries, such as Europe and the USA. Also, from the costing point of view, although the reduced LED bulb prices are very close to the production cost, manufacturers are continuing with the low-price competition. If the market grows accordingly, this foreshadows that a price war will occur in the LED bulb market. If this happens, costing and price competitiveness will be the key to the success of manufacturers. As if in preparation, Sharp has adopted a massive outsourcing strategy to reduce the cost of the LED and power supply parts and materials.

Today, some **Taiwanese** firms are selling white light LED bulbs at US$12–15, compared with the US$20–35 LED bulb cost average cost worldwide.

Another important issue concerns the need to establish a *common cost model* to describe the manufacturing of LED-based components and fixtures. Such a model would allow industry to identify those areas that had the largest impact on final device and luminaire costs. This information could then be used to help focus efforts into the most sensitive areas. The need for a cost model was particularly important with respect to making decisions on equipment development (see section 2.3.3). The use of cost of ownership modelling was agreed to be the most suitable criterion for evaluating the impact of introducing new equipment into the manufacturing process. As discussed earlier, the same type of modelling can also be used to (i) evaluate the long-term benefit of manufacturing changes, (ii) help with decisions about materials use, equipment operations, and process improvements, (iii) identify bottlenecks in the process, and (iv) foster communication and understanding throughout the supply chain.

Significant efforts are made in order to reduce the global LED-based luminaire price; Figure 67 shows a model for luminaire manufacturing cost shrinking for the coming years.

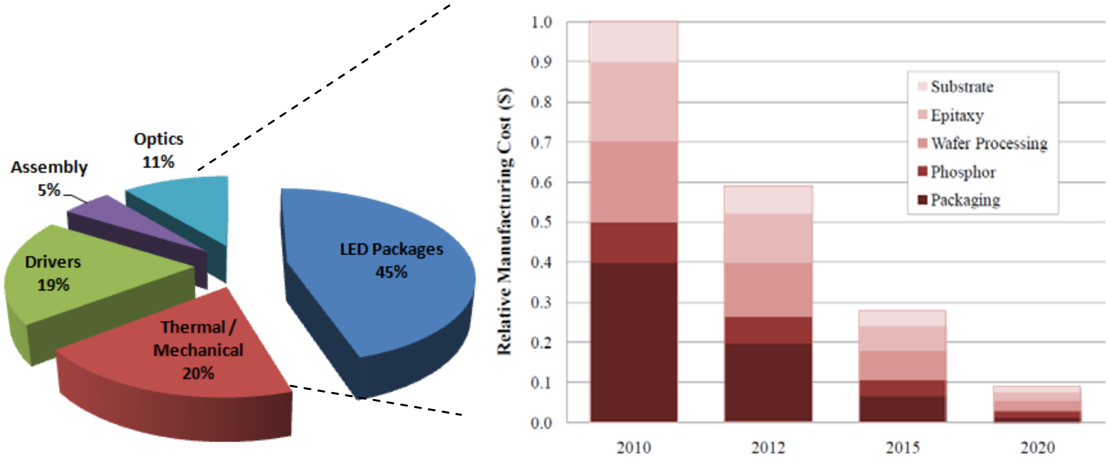


Figure 67 - LED Typical Cost Structure Track [Yole Développement, 2010]
1€=1.4$.

It is clear that the LED component price weight in the luminaire price is rapidly decreasing. It will drop from 40% of the luminaire price in 2009 to 20% in 2015. In fact, manufacturing scale will continue to drive down production costs. As the LED industry is fragmented, a lot of market participants are involved in the value chain, which increases the price compared to an integrated industry. As production volumes increase, companies will gain a competitive advantage as fixed price per unit LED declines. McKinsey estimates that companies operating at 2 billion units per annum are able to produce LEDs for approximately 20% less than those producing a half billion per year, based on assumptions on fixed and variable cost, and cost of expanding production. As an example, Figure 68 shows clearly this effect on the retail price of the regular white and blue LEDs, a similar effect is observed for HB-LEDs, but no reliable data could be found.

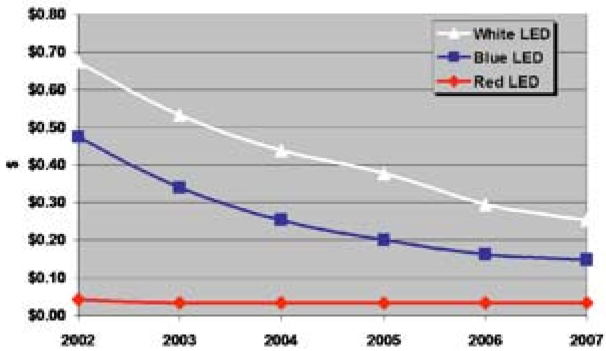


Figure 68 - Retail price evolution for regular LED components [YOLE Développement, 2007]

LED is still a costly product, in particular in the general lighting segment where alternatives remain cheaper. The price needed for mass adoption has not yet been reached. It is estimated that a price of $8 would allow a 25% market share for LEDs. In Europe, a price of €10 would allow to reach, after some time, a 50% market share for LEDs versus 50% for CFLs in the residential sector. It is to be noted that the price for LED bulbs differs from one continent (and one country) to another, e.g. LED bulbs are cheaper in Japan than they are in the US or Europe.

3.7. *Lighting as Demand Side Management*[24]

This section will examine which benefits lighting systems and services can bring to some users in addition to lamps.

The outer boundaries of today's intelligent lighting allude to where it is believed that the industry is heading. Lights are one of many sources of energy demand or curtailable load. Other sources – which originate from the same homes, offices, and factories as lights – include heating, ventilation and air conditioning (HVAC), refrigeration, commercial and industrial production, and what is broadly called IT (charging mobile devices, computers, servers, etc.). After all: a) Lighting is just one component of this demand, b) The demand is originating from similar or shared locations and c) Supply is also originating from centralised sources like utilities and Independent Power Producers (IPPs). That is why vendors will seek to simplify demand-side curtailable load by aggregating all types of energy demand and blurring the distinction between demand response, building management systems, and smart lighting. In addition to the improved simplicity and larger addressable market involved in managing all sources of demand, research indicates that customers are increasingly asking for integrated demand management solutions. While all customers are driven by the desire to save more money, some customer segments have other, secondary motivations. For instance, large corporations have expressed a desire to avoid evaluating a wide variety of vendors and solutions outside their core business and have expressed a market preference – through their relationships with "full service" players like IBM, Honeywell, or Johnson Controls – to select vendors who can provide as wide an array of services as possible. From primary interviews and secondary research on industry "case studies," Cleantech Group has documented how and why different customer segments are pushing for integrated solutions in the chart below [Cleantech Group Analysis, April 2011].

Type of Customer	Reason for buying lighting controls & services	Reason for integrated solution
Corporations with multiple buildings	• Corporate sustainability goals • Energy savings	• No time, desire, or sophistication to sort through variety of vendors and/or solutions
REITs	• Cost savings • LEED certification	• "One stop shop" that can be deployed across portfolio
Government	• Federal or state mandates for GhG reductions • Energy efficiency savings	• Time savings • Scale • Reduced procurement beaucracry
Utilities	• Reducing overall & peak loads • Cost savings can be split w/ consumer	• Fewer vendors reduces time & cost of interaction / coordination
ESCOs / DR / BMS	• Improving lighting control system in proprietary BMS • Ability to offer customer integrated solution if it can't do so already	• See above – customers demanding integrated solutions

Table 6 - How and why different customer segments are pushing for integrated solutions

Note: REIT: Real Estate Investment Trust, LEED: Leadership in Energy and Environment Design

[24] This section is coming from Cleantech Group Analysis, published April 2011.

Vendors, not surprisingly, are responding to their customer needs by broadening their product, offering to include more elements of demand management. Traditional lighting vendors like Philips, Osram and GE are investing in R&D and making acquisitions to expand their software footprint, have partnerships with major building management vendors like JCI, and further integration with building automation and even demand response vendors is expected in the future.

Building management players are interested in expanding their existing lighting partnerships to include control vendors, and have made “software” related acquisitions like Honeywell’s purchase of Tridium and JCI’s acquisition of National Energy Services. Demand response vendors are also trying to move further inside the building, as evidenced by EnerNOC’s string of acquisitions to fill out its “EfficiencySMART” suite of services. Even IT players – leveraging their core expertise in software and experience in managing data – have branched into lighting and building management, as evidenced by Cisco’s acquisition of Richards-Zeta in 2009, Google’s expressed desire to use PowerMeter for lighting control systems, and a slew of rumours about in-house R&D moves from companies like HP and Juniper. In short, it is expected that, in coming years, it will be increasingly difficult to distinguish between demand response, building automation, and lighting vendors, as it is in the “current state”. There will be a trend moving to **lighting services**.

3.8. Conclusions

The SSL industry value chain is rather wide, covering domains from raw materials to product commercialisation and services sector. In general, the higher the level in the value chain, the higher the product complexity, added value and profit.

LEDs are made from a variety of semiconductor materials, including different combinations of gallium, indium, arsenic, nitrogen, and phosphors. Various Rare Earth Elements (REE) are used in the manufacturing process of LEDs. Supply of these REE (especially indium and gallium) might constitute an important issue for the coming years. As large parts of the natural resources for these key materials are controlled by China, this creates a high dependence for the EU-based industry. Opening new mines or recycling REE could make it possible to limit this dependence on imported REE from China.

The centre of gravity for the LED manufacturing industry has clearly moved to Asia (Taiwan, Korea, China and Japan) in terms of revenues, in particular for chips and epiwafers, but also for packaged LEDs. Because of the profits it can bring, many new companies have been created in the last years in the LED chip manufacturing segment, many of them being Chinese. However, European companies have also significant fabrication facilities in Asia.

European capacity MOCVD (Metal-Organic Chemical Vapour Deposition) is rather small (3%), but it is expected to increase rapidly, as shown by the recent establishment of new facilities. The majority of key MOCVD equipment for LED chip production is still manufactured in Europe.

Whereas the European manufacturing base is strong in the downstream segments of the value chain close to the application, with more than 40% of general lighting manufacturing in Europe, it is weaker in the upstream segments, with 11% of Light Emitting Diode (LED) packaging and approximately 10% of global production of devices (LED chips) and advanced materials (compound semiconductor ingots and wafers).

In the upstream segments of this value chain, reports show that the technology development competences are available in Europe, but this part of the value chain faces a significant threat of relocation to Asian manufacturing locations with favourable costs, a higher growth potential in nearby markets and quickly improving technological competence associated with increasing manufacturing experience, the successful agglomeration of critical complementary industries and services, as well as a decidedly pro-active strategy to improve R&D capabilities and their industrial use. A significant obstacle for the realisation of large-scale manufacturing capacity increases in SSL is the limited availability of funding caused by the risk adversity in the European banking sector.

The big three in the SSL industry are the traditional lighting players Philips, Osram and GE and the European industry has still a predominant position today. However, China is investing massively in this segment and will become a serious challenger for the next years, unless quality issues arise. Companies in Europe, in contrast to Asia-based firms, tend to do product design, marketing and selling, but—with the notable exceptions of Philips Lumileds and a number of smaller firms—many outsource the manufacturing to Asian subcontractors.

In Europe the fixture market, contrary to the US, is highly fragmented and this could constitute an additional threat for Europe if SMEs don't join forces. With approximately 800 players in the luminaire segment in Europe, market consolidation is necessary, but overall it is expected to remain a fragmented market. Figure 69 shows the lighting fixture production among European counties.

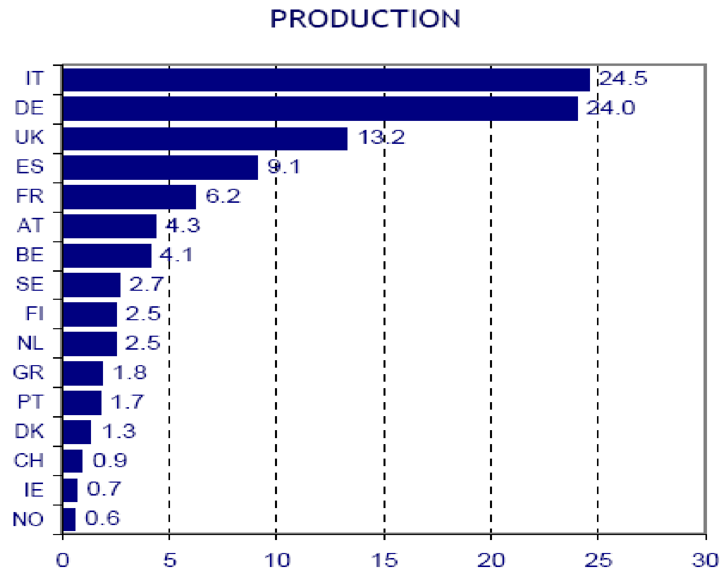


Figure 69 - Percentage of lighting fixture production distribution among EU countries [CSIL study, the European Market for Lighting Fixtures, 2007]

R&D takes place mainly in Japan, the US and Europe. Through patent cross-licensing, however, the research base becomes broader, including China, Taiwan and South Korea. Europe is suffering from fragmented funding. Taiwan has the largest investment worldwide, estimated at $600 million, 70% being private. Korea's R&D is also mainly privately financed, whereas in China the government is investing heavily in research.

LED commercialisation channels might face a reshuffle, in particular, when the industry will be moving to lighting services. For LEDs to penetrate the market more, end-user information and training, as well as training for installers would be useful.

LED is still a costly product, in particular in the general lighting segment where alternatives remain cheaper. The price needed for mass adoption has not yet been reached. It is estimated that a price of $8 would allow a 25% market share for LEDs. In Europe, a price of €10 would allow to reach after some time a 50% market share for LEDs versus 50% for CFLs in the residential sector. It is to be noted that the price for LED bulbs differs from one continent (and one country) to another, e.g. LED bulbs are cheaper in Japan than they are in the US or in Europe.

Existing and new enterprises, including start-ups and new SMEs, will create new platforms for growth and further contribution to the EU’s GDP. Exporting our leadership to developing and emerging countries will facilitate even further growth, including business in adjacent areas.

The above value chain analysis highlights significant challenges in current European industry translation of R&D into commercial products within an EU footprint.

4. LED-Lighting challenges, drivers, threats and trends

The LED-lighting industry is facing the following challenges and drivers[25]:

Drivers:

- The capabilities offered by LED technology are one of the key driving factors enabling the adoption of LED lighting applications and this can be attributed to its lifetime, efficacy and energy saving.
- LED light sources with high light quality and high functionality: The visual experience is one of the prime consumer considerations in purchasing lighting systems. True colour rendering will be important. Moreover, colour consistency has to be guaranteed. In case of phosphor-conversion, this requires better phosphors with temperature-stable colour coordinates. For RGB solutions, colour-controls are needed, which compensate for the ageing of different coloured LEDs. From the manufacturing side, a simple method for binning will be advantageous to increase the yields in production and to lower the cost.
- LED luminaires and intelligent light management: Due to the projected lifetime of LEDs, even surpassing the one of the luminaires they are accommodated in, ultimately there will no longer be a market for replacement lamps, while today the majority of the lamps sold are used for this purpose. As a consequence, the focus of the lighting market will shift towards initial LED-based luminaires and systems. It is not only the lamp that determines the performance of the lighting installation. Besides the necessary efficiency increase of the LED itself, it is the system efficiency that needs to be focussed on in order to create a highly efficient light source including electronics, thermal management and optics.
- Quality of light. The numerous possibilities offered by LED lighting allow for products that are adapted to the needs of users, such as elderly people. This driver is more important for developed countries like Europe, than for developing economies.
- Legislation, such as the phasing out of incandescent lights in the European Union and other – mainly OECD – countries is a key driver.
- In the European Union, the Energy Performance Buildings Directive (EPBD), in particular the provisions for nearly-zero energy buildings, would drive towards use of LED lighting in buildings.

Challenges:

- Cost: Besides superior performance, one of the crucial factors to reach broad market penetration of LED light solutions is a moderate price. The initial purchase cost for LEDs today is usually very high, even though their economic cost will be lower due to their long lifetime and high-energy efficiency. The market price of LED lamps tends to be ten times higher than for standard lamps with the same performance. LED-based luminaires are sold at a price two to four times that of the standard luminaire they replace. This situation is particularly true in Europe. To reduce the initial costs, all components of the system need to be considered:
    - LEDs need to be manufactured on large scale with low-cost substrates in a highly automated production environment. High-throughput fabrication is a prerequisite to decrease cost.
    - Simplified packaging is required.
    - Low cost and low-loss optics have to be explored to avoid waste of light and light pollution.

[25] Ana Ong [Study of LED Industry, January 2010]

- Reliable and long-lifetime driver electronics are too expensive to be used in LED luminaires today and the cheaper solutions may ruin the positive LED image. Low cost, but at the same time highly reliable, driver electronics are needed.
- Standardised LED lamps and modules to increase throughput in production must be defined.

- Technology: Inorganic LEDs went through an impressive improvement curve with a brightness increase of a factor of three within the last three years. In 2011, the efficacy in production for cold white LED light sources is already greater than 130 lm/W and for warm-white LEDs around 80-85 lm/W. These white light sources are based on a blue emitting LED combined with a conversion phosphor. In 2011, the wall-plug efficiency of these white LEDs equals 35% and is expected to reach more than 55% in 2020. No other light source offers such high efficiency improvement potentials as SSL sources today. Thus, efficacies of up to 180 lm/W for warm-white LEDs and even 220 lm/W for cold white LEDs seem feasible within the next decade. High levels of research efforts and investments are, however, needed to reach this ambitious goal. Europe has some world-class academic teams working on this issue and the Commission invests significant amounts of money in order to promote research.
- Other technological issues remain, pertaining to achieving the desired performance in terms of light extraction efficiency, colour performance and quality. It is also important to ensure that thermal resistance is minimised from the junction to the external package. This is mainly because for LEDs, heat is transferred via conduction from the junction to the system enclosure, unlike traditional lighting technologies wherein the heat is radiated. The light extraction efficiency of the LED is affected by the mismatch in refractive index between the semiconductor chip and the encapsulant. More than 60% of the photons generated by the semiconductor chip are reflected internally and lost inside the LED package. High-index encapsulants, shaping the LED chip, and roughening the top surface of the LED chip are some of the techniques investigated to reduce refractive index mismatch. An additional threat for LED light sources is undesirable light flickering from low quality products. Flicker can have many undesirable effects on the light perception by the end users. Today many marketed products show high flickering potential, especially if coupled with classic triac dimmers. This may indispose residential users in the future.

The most important **threats/risks** for LED Lighting industry are the following:

- Oversupply of LED chips may happen at the end of 2011. Upstream industry facing consolidation. Key risks to supply side assumptions include 1) bottlenecks in raw material[26] and equipment, 2) higher-than-expected LED chip output from some countries and more especially Taiwan.
- The LED intellectual property (IP) landscape is still complicated and highly litigious, surpassed only perhaps by the biotech industry. As real customers have emerged, there appears to have been some reduction in the level of incestuous IP litigation. This is not because the value of LED IP has diminished, but at a chip-level, it is hard to litigate. It is expected that in the coming years, phosphor IP will become more important, as it is easier to define and to litigate, and it will be highly valuable in general lighting applications. With the rise in R&D activity around LED-related lighting technologies in the last decades, large businesses have established their interest through significant investments. By grouping the patent filings by companies, it is possible to establish who the top assignees or key players in LED lighting are – these are shown in the following tables (sorted by company and country) [Gridlogics Patent iNSIGHT, 2010]:

[26] Indium, one of the key elements for many of the existing LEDs, is a rare material: 61st rank in terms of quantity found on earth (0.24 ppm in weight).

ASSIGNEE NAME	TOTAL
KONINKLIJKE PHILIPS ELECTRONICS N V	135
SAMSUNG ELECTRO MECHANICS CO	128
PHILIPS SOLID-STATE LIGHTING SOLUTIONS INC.	80
KOITO MANUFACTURING CO. LTD.	55
FU ZHUN PRECISION INDUSTRY (SHEN ZHEN) CO. LTD.	47
DONGGUAN KINGSUN OPTOELECTRONICS CO	37
TOYODA GOSEI CO. LTD.	36
SONY CORPORATION	34
MATSUSHITA ELECTRIC WORKS LTD	30
SHARP KABUSHIKI KAISHA	28

Country Code	Total
US	7845
CN	3238
JP	2521
DE	1223
KR	1034
TW	813
GB	809
AU	770
CA	701
AT	291
FR	177
ES	165
IN	150
MX	133
IT	106
BR	101
HK	84
NL	81

Figure 70 – LED patents [Gridlogics Patent iNSIGHT, 2010]

With companies like Philips, Samsung and Koito leading the table with the most patents, a number of the leading companies in the general lighting systems space appear to be pursuing LED technology with enthusiasm as a future technology which has strong potential in commercial markets.

- The LED market is highly fragmented and competitive. As such, probability of companies entering into collaborative developments / agreements (mergers and acquisitions, cross licensing agreements, intellectual property and distribution partnerships) is high.
- As many SMEs are dealing with LEDs, which is yet to mature in terms of technology innovations, any significant changes in the production processes may result in technology obsolescence of both fixed and current assets, such as inventories, which in turn can affect the company.

The main **trends** of the industry are:

1. A small number of players will continue to dominate the chip/packaging market and the industry is unlikely to fragment. Scale will drive down cost, but it will not be a winner-take-all, and litigious activity will be used to try to preserve the oligopoly market structure.
2. Modulling is a technology race and will be a short-term profit gainer in the value chain. Functions and value can be integrated into the modules, with the intensity and quality of light significantly influenced by smart modulling techniques. In the long run, modulling technology will get commoditised and low-cost players will gain market share.
3. Lamp and luminaire retrofit market – big players get bigger and a profitability gap opens up between established manufacturers and new entrants. Retrofit suppliers need to quickly scale-up in order to drive down LED chip cost. Companies like Philips and Osram will leverage their brand and existing relationships with retailers to ensure they get shelf-space.
4. Emerging market for LED solutions is built around energy-efficiency, through down-stream market integration, as well as software and building integration. This presents opportunities for new entrants to challenge the incumbents that own the current customer relations.

Source: Mc Kinsey 2011

4.1. Barriers to adoption of LED-based lighting

The following lists some of the technical, cost, and market barriers to LEDs. Overcoming these barriers is essential to the rapid market deployment of SSL.

- Cost: The initial cost of LED-based general illumination sources is too high, in comparison with conventional lighting technologies (see Section 3.4). Prices are kept high due to smaller scale of production and also due to a high demand for LED in other applications like automotive and displays. Since the lighting market has historically been strongly affected by first cost, lifetime benefits notwithstanding, lower cost LED package and luminaire materials are needed, as well as low-cost, high-volume, reliable manufacturing methods. One trend is the continuing decline of LED retail prices, dropping at a rate of 20-25% per year compared to incumbent technologies where prices are flat or are declining much more slowly. A narrowing price differential between LEDs and more traditional forms of lighting is therefore slowly removing one of the key barriers to mass adoption.
- Payback time: the payback time is the time necessary for a LED customer to break even on his/her investment in a more expensive LED bulb. Based on extensive research in Japan where energy prices are very high, thus lowering the time to payback for more efficient bulbs, customers have a 10% chance of adopting a technology if payback is two years, a 30% chance if payback is one year, and a 40% if payback is six months. Therefore, the time to payback metric helps to predict LED adoption with some historical and empirical accuracy. The fact that payback periods are shrinking along with LED retail prices will ensure significant market penetration (50 %+) in the next decade.
- Quality: The market is flooded with LED luminaires and replacement lamps of questionable quality (low efficacy, poor colour rendition, short lifetime). Establishing consumer confidence is a key factor for the development of the LED lighting market. Well-known problems incurred with “non-mature” CFLs are poisoning the market and the customer is not feeling in confidence with new technologies.[27]
- Luminous Efficacy: the luminous efficacy (lm/W) of LEDs is already above 100 lm/W, but it can still improve. Although the luminous efficacy of LED luminaires has surpassed that of the incandescent and compact fluorescent lamps, improvement is still needed to compete with other conventional lighting solutions and to maximise the energy savings from this technology. The efficacy of commercial LEDs is not yet near its fundamental limit. Further improvements in LED efficacy can lead to even greater energy savings and can impact the cost of SSL sources, which can accelerate adoption of efficient LED products. In general, improving the efficacy of the LED impacts the number of LEDs required for the lighting application, as well as the thermal handling demands in the LED luminaire, thus reducing costs.
- Lifetime: A definition of lifetime that focuses on lumen maintenance is inadequate for luminaires. Lumen maintenance is only one component of the lifetime of a luminaire that may be subject to other failure mechanisms, such as colour shifts, optics degradation, or even catastrophic failure. How the LED is incorporated into the luminaire design can also have considerable impact on the lifetime of the system, inadequate thermal handling can reduce the LED lifetime and the design of the power supply can also impact the lifetime of the LED. A better understanding of the luminaire system lifetime and reliability is necessary for accelerated adoption of energy saving LED-based light sources.
- Educational barriers: LED-based lighting remains a new technology that is not well known in the marketplace. This unfamiliarity applies equally for users at all experience levels: lighting designers, residential and commercial users, installers, building inspectors, and government code officials. Most lighting designers are used to thinking, designing, and working with white light sources, instead of coloured light sources. They are also not accustomed to taking advantage of the energy-efficiency, long-life and maintenance characteristics of LEDs.

[27] The EU LED Quality Charter is an attempt to address this issue.

- Testing: The reported lumen output and efficacies of LED products in the market do not always match laboratory tests of performance. While standardised testing protocols for performance metrics have been developed for light output, colour and efficacy, there are still many products that do not match the stated performance claims. The US Department of Energy (DOE) has supported the development of the **Lighting Facts** Label to standardise performance reporting. Still, an important barrier for luminaire integrators appears to be the difference in stated LED device specifications versus the actual LED performance at continuous operation in a luminaire. LED manufacturers have begun to address this problem by providing 'hot' performance data on the LEDs. Furthermore, accelerated reliability testing methods for systems and materials would greatly reduce costs and time-to-market. Such tests, capable of providing accurate projections of life, do not currently exist. Uncertainty, in both device and luminaire lifetimes, creates risk for manufacturers and consumers, potentially reducing adoption rates.
- Manufacturing: Lack of process and component uniformity will be an important issue for LEDs and is a barrier to reduced costs, as well as a problem for uniform quality of light. LEDs still have a number of technological hurdles to overcome. Additional work also remains to be done in the systems design and integration area before LEDs can fully compete as a viable light source in the general lighting market. A few years ago no consistent approach to creating a LED system existed, now this issue is under solution.
- Lack/high cost of capital: This traditional market barrier is associated with the lack and/or high cost of capital required to make the larger investments in the implementation of LED lighting systems.
- Aversion to risk: The uncertainty on product performance, particularly the required lifetime to justify the investment, can negatively influence decision-makers.
- Lack of time: Most users of lighting systems are time-constrained and have to weigh up the benefits of optimising their information and decision-making about lighting systems, against many other competing demands on their time. This is particularly true for SMEs.
- There is one final threat linked to the impact of the phase-out regulations of which policy-makers should be aware. The total number of lighting products sold will fall dramatically. This fall will be greatest in those markets that currently have low penetrations of LEDs (or CFLs) and where these products are adopted rapidly. However, a fall in sales should be noticeable in all markets where regulations cause the substitution of (generally) short lifetime, inefficient lamps with more efficient, longer life alternatives. Such a fall in sales is already being witnessed in Australia and the UK. Without a full model of the installed stock in each country, it is impossible to predict accurately what the ultimate levels of sales will be. But for the UK it is estimated that total number of lamp sales in 2014 will be 75% lower than total lamp sales in 2009 if current trends continue.

Sources: CELMA-ELCFED, 2011; Ecos Consulting, 2003; IEA, 2006; US Department of Energy, 2011

4.2. The case of Europe

Concerning Europe, the situation is more complex. Europe has been at the forefront of SSL technology development: until recently, two out of three main SSL producers were European and had substantial manufacturing activities in Europe. The current manufacturing shift to Asia has heavily impacted this industry. Explosive growth in China is reinforcing this trend with Asian companies now threatening to overtake former European market leaders.

Europe faces a significant threat of relocation to Asian manufacturing locations with favourable costs, a higher growth potential in nearby markets and quickly improving technological competence associated with increasing manufacturing experience, the successful agglomeration of critical complementary industries and services and a decidedly pro-active strategy to improve R&D

capabilities and their industrial use. A significant obstacle for the realisation of large-scale manufacturing capacity increase in SSL is the limited availability of funding caused by the risk adversity in the European banking sector.

Whilst European R&D is generally strong in new technologies, it is observed that the transition from device to product and scale-up demonstration is crucial, and is the weakest stage in European-enabled value chains. In particular in Key Enabling Technology (KET) commercialisation, there are very large initial investment costs in new plants and processes that may lead to short-term lack of competitiveness. There is now an acknowledged growing problem with escalating competition from emerging economies. The relocation of manufacturing tends to be followed by relocation of R&D. This situation has been commonly identified across the KETs and is known in broad terms as the "valley of death" issue. Its effects can include not only relocation of manufacturing and R&D, but also the disruption of the entire value chains with their ultimate consequences on the sustainability of various strategic sectors in Europe. This "valley of death" is demonstrated graphically in Figure 71.

Europe finds itself incapable of crossing in a systematic and efficient manner the "valley of death" which separates the creative idea from the global market. Whilst the Americans excel in this crossing and Asians commit their energy and finances to ensure a rapid and unencumbered crossing, this "valley of death" constitutes a major hurdle for Europe. Europe thus is often losing first-mover-advantages that establish whole industries, and subsequently being surpassed on the way to the marketplace by more nimble competitors [HLG KET working document, June 2011][28].

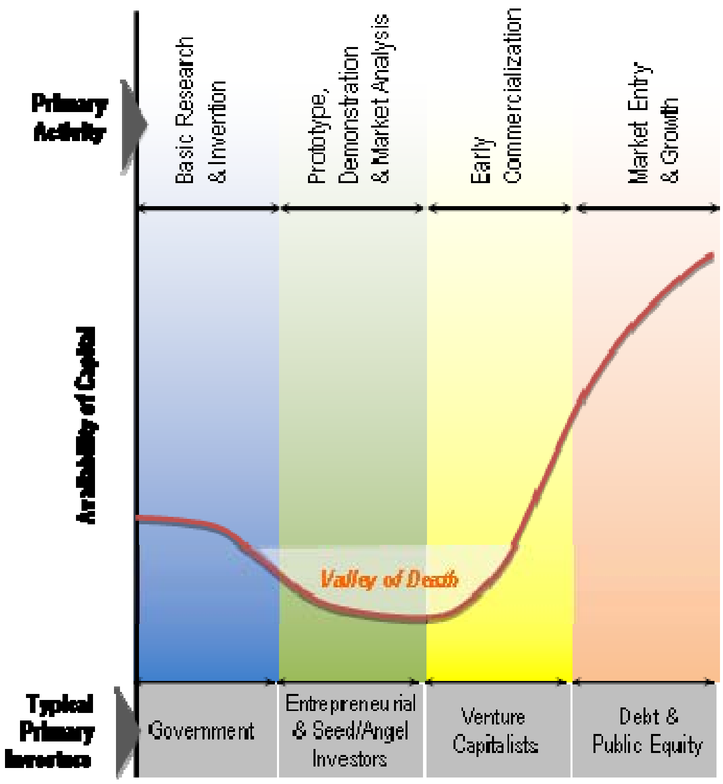


Figure 71 - Graphic representation for "The Valley of Death" concept [HLG KET working document, June 2011]]

The EU has a lack of market-oriented public-private partnerships and programmes that combine transnational research through coordinated action specifically aimed at shortening time to market, even if there are some successful examples. Factors that lead to success include: securing a significant size of the action; ensuring the early involvement of relevant value chain partners (SMEs,

[28] ec.europa.eu/enterprise/sectors/ict/files/kets/hlg-working-document_en.pdf

spin-offs, suppliers and end-user industry); and providing access to flexible manufacturing capabilities. Public and long-term (beyond 5 years) funding via entities, such as the European Investment Bank, can go hand in hand with venture capital private funds. However, for venture capital funding, the usual requirement for a relatively short exit horizon (say three years) from their investment is often too short. This means that hybrid public–private financing models are needed to fill a potential investment shortfall.

The main **drawbacks** of Europe are:

Residential market:	**Professional Market:**
1. CFL story & history (bad experiences)	1. Antiquated Business Model from fixture makers
2. Lack of incentives from governments	2. Fragmented luminaire market
3. Poor Quality & inferior Marketing of LED Bulbs	3. Small volume
4. Current sales channels are inappropriate	4. Poor management of Supply Chain
5. Lack of solid Value proposition for LED bulbs	5. Very expensive Supply Chain
	6. Lack of electronic expertise from fixture companies
	7. Stagnant construction market
	8. (Lack of incentives for building owners)

These drawbacks are coming from a private communication 2011 with C. Mesnager (TG-Europe, 2011), but they are corroborated by other sources presented in the previous chapters of this report.

Concerning IP issues, it should be pointed out that Germany and UK are part of the top-10 LED-related patent filing nations far beyond US and China. Furthermore, Philips is the top assignee in this domain, followed closely by Asia-based companies, losing this leading place in short term can be considered as an important threat.

During the Photonics21 General Assembly in February 2010, John Magan (European Commission) presented the following SWOT analysis for SSL market in Europe.

5. Norms, labels and standards

The last years have seen a rapid performance improvement of LEDs. Nevertheless, due to the existence of a great number of manufacturers, and of different systems they use for specifying their LED products, comparison of different products has become difficult, if not impossible. Without standards, customers are having difficulties when purchasing LED-based products, and the whole market can easily become full of confusion and disorder. In fact, standardisation is assumed to:

- Enable products to work interchangeably/together
- Provide assurance that a product meets performance levels
- Provide the means for designers, manufacturers and users to communicate – terminology/common language
- Provide strict methods for measurement thus allowing comparison.

Technical standards can be classified in many ways. For LEDs for general lighting, the following classification can be proposed (Jackson, 2010):

- Measurement Standards - define testing protocols to allow direct comparisons of product characteristics;
- Performance standards - provide methods for uniformly determining product performance and for rating products, according to a predefined scale;
- Electromagnetic Compatibility - determination of unintentional generation, propagation and reception of electromagnetic energy;
- Technology Development - documents that contain best practices and that outline standards needs for advancement of SSL technology;
- Design standards - establish dimensions, tolerances or other physical characteristics of products, to enable interfacing and interchangeability;
- Communication Standards - define the basic terms, symbols and other communication tools;
- Safety Standards - define electrical, mechanical, thermal, optical radiation, or other safety considerations.

There is an overriding concern to identify applicable product safety certification requirements pertaining to their specific targeted global markets (CELMA, 2010), before any business opportunity can be addressed.

The availability of standard test procedures covering all key performance aspects can support manufacturers' product development efforts, evaluation of progress towards achieving higher quality (comparison to established benchmarks) and competitive analysis.

The immediate and long-term benefits of standardisation are obvious for manufacturers, end-users and governments:

Manufacturers	▪ Provide uniform methods for testing and rating products ▪ Help to assure system integrity and safety for the application and thus reduce liability ▪ Encourage new product development ▪ Help to avoid confusion in communicating with customers ▪ To enable products to work interchangeably or together o Rapid growth and adoption of SSL Technology o Modular approach economics o Rapid fixture and luminaire innovation o Innovative product platform designs

End-users	▪ Help educate users of LED lighting technology ▪ Product performance and how it is measured, allowing comparison ▪ Provide a common language for communication ▪ Drive novel and creative applications of lighting ▪ Provide embedded options for lighting through replacement with colour and other dimensions of lighting ▪ Provide repair/replacement components – economics ▪ Larger choice!
Governm ents	▪ Needed for incentive programmes ▪ Needed for Energy Efficiency requirements

Given that LEDs are evolving rapidly, even existing standards have to be revisited more frequently than is the usual case with other products and technologies. Many standards committees around the world have been working on developing standards for LED lighting products, based on their energy savings and performance. So, for example, the first criteria being used to qualify a lighting product for Energy Star (International Standard for Energy Efficient Consumer Products) is the energy-efficiency measure of luminous efficacy in lumen per watt.

There are a number of standards-making bodies that are working on LED standards now. Many **standards** are established, or are under development, including the Illuminating Engineering Society (IES), Underwriters Laboratories (UL), American National Standards Institute (ANSI), the National Electrical Manufacturers Association (NEMA), the International Commission on Illumination (CIE), the International Electrotechnical Commission (IEC), Cenelec and several others. These groups are working in partnership with stakeholders to develop standards, which will protect consumer's interests, and finally, the LED market. As already discussed, the Zhaga standard on interoperability is being defined.

For all the above-cited reasons, many organisations have initiated an important activity on standardisation worldwide. The following list gives the existing standards promoted by various organisms and countries[29].

ANSI	▪ ANSI C78.377-2008, "Specifications for the Chromaticity of Solid-State Lighting Products," specifies recommended chromaticity or colour ranges for white light-emitting diodes (LEDs) with various correlated colour temperatures (CCTs). ▪ ANSI C82.77-2002, "Harmonic Emission Limits — Related Power Quality Requirements for Lighting," specifies the maximum allowable harmonic emission of SSL power supplies.
CIE	▪ CIE 13.3-1995, "Method of Measuring and Specifying Colour Rendering Properties of Light Sources," is the official document defining the CRI metric. (Referenced by ANSI C78.377) ▪ CIE 15:2004, "Colorimetry, Third Ed.," is the official document defining various CIE chromaticity and CCT metrics. (Referenced by ANSI C78.377) ▪ CIE 127:2007, "Measurements of LEDs," addresses LED luminous intensity measurement; applies only to individual LEDs, not to arrays or luminaires. ▪ CIE S 009/E:2002, "Photobiological Safety of Lamps and Lamp Systems," specifies measurement techniques to evaluate optical radiation hazards and eye safety risks of LEDs and LED clusters.
FCC	▪ CC 47 CFR Part 15, "Radio Frequency Devices," specifies FCC requirements for maximum allowable unintended radio-frequency emissions from electronic components, including SSL power supplies and electronic drivers

[29] This list is not exhaustive

IESNA	▪ ESNA G-2, "Guideline for the Application of General Illumination ('White') Light- Emitting Diode (LED) Technologies," provides lighting and design professionals with a general understanding of LED technology as it pertains to interior and exterior illumination, as well as useful design and application guidance for effective use of LEDs. ▪ IESNA LM-79-2008, "Approved Method for the Electrical and Photometric Testing of Solid-State Lighting Devices," specifies a standard test method for measuring the photometric properties of SSL devices, allowing calculation of luminaire efficacy. ▪ IESNA LM-80-2008, "Approved Method for Measuring Lumen Depreciation of LED Light Sources," specifies a standard method for measuring the lumen depreciation of LEDs, allowing calculation of LED lifetime. ▪ IESNA RP-16 Addenda A and B, "Nomenclature and Definitions for Illuminating Engineering," provides industry-standard definitions for terminology related to SSL. ▪ IESNA TM-16-05, "Technical Memorandum on Light Emitting Diode Sources and Systems," provides a general description of LED devices and systems and answers common questions about the use of LEDs.
NEMA	▪ NEMA.SSL-1, "Electric Drivers for LED Devices, Arrays, or Systems," specifies operational characteristics and electrical safety of SSL power supplies and drivers. ▪ NEMA SSL 3-2010, "High-Power White LED Binning for General Illumination," provides a consistent format for categorising, or binning, colour varieties of LEDs during their production and integration into lighting products. ▪ NEMA SSL-6, "Solid State Lighting for Incandescent Replacement — Dimming," specifies recommendations for the dimming and design of screw-based incandescent replacement SSL products.
NFPA	▪ NFPA 70-2005, "National Electrical Code," requires most SSL products to be installed in accordance with the National Electrical Code.
UL	▪ UL 8750, "Safety Standard for Light Emitting Diode Equipment for Use in Lighting Products," specifies the minimum safety requirements for SSL components, including LEDs and LED arrays, power supplies, and control circuitry. ▪ UL 1598, "Luminaires," specifies the minimum safety requirements for luminaires. The requirements in this document may be referenced in other documents such as UL 8750 or separately used as part of the requirements for SSL products. ▪ UL 153, "Portable Electric Luminaires," specifies the minimum safety requirements for corded portable luminaires. ▪ UL 1012, "Power Units Other Than Class 2," specifies the minimum safety requirements for power supplies other than Class 2 (as defined in NFPA 70-2005). UL 1310, "Class 2 Power Units," specifies the minimum safety requirements for Class 2 power supplies (as defined in NFPA 70-2005). ▪ UL 1574, "Track Lighting Systems," specifies the minimum safety requirements for track lighting systems. ▪ UL 2108, "Low-Voltage Lighting Systems," specifies the minimum safety requirements for low-voltage lighting systems. ▪ UL 60950-1, "Information Technology Equipment — Safety — Part 1: General Requirements," specifies the minimum safety requirements for electronic hardware.

IEC	▪ IEC62504 Terms and Definitions for LEDs and LED Modules in General Lighting [in progress] ▪ IEC SC 34A - Non-ballasted single capped LED lamps for general lighting (< 50V) – performance requirements [in progress] ▪ IEC 62612, Self-ballasted LED lamps > 50 V [in progress] ▪ IEC 60838-2-2, Connectors for LED modules ▪ IEC 61347-2-13:2006 - Lamp Control gear ▪ IEC 62384 - DC or AC supplied electronic control gear for LED modules ▪ IEC 62386-207, Digital addressable lighting interface - Part 207: Particular requirements for control gears; LED modules ▪ IEC 60598-1 Edition 72008, LED luminaires ▪ IEC 60950-1 Information Technology Equipment – Safety – Part 1: General Requirements ▪ IEC 62031:2008 LED modules - Safety ▪ IEC 62471-2 Photobiological Safety of Lamps and Lamp Systems ▪ IEC 62560 Self-Ballasted LED Lamps ▪ IEC 62547 LED EMC/Immunity ▪ IEC 61000-3-2 LED EMC/Harmonics

Table 7 - International Standards on Lighting and LED [CLASP, 2011]

In general, LEDs are lacking mature test standards globally. Although efforts are being made in this area, some attention shall be paid to improving and promoting the existing standards, rather than establishing new ones in order to raise the work efficiency and pave the way for harmonisation. Table 8 presents a summary of existing LED-related standards and voluntary labelling programmes in some of the main economies.

Programme	**Performance Standard**	**Test Method Standard**
China GB/T	GB/T 24908-2010: performance requirements for self-ballasted LED lamps for general lighting; GB/T 24823-2009: performance requirements for LED modules for general lighting.	GB/T 24908-2010: performance requirements for self-ballasted LED lamps for general lighting; GB/T 24824-2009: measurement methods of LED modules for general lighting.
ELI	ELI Voluntary Technical Specification for Self-Ballasted LED Lamps for General Lighting Services.	ELI Voluntary Technical Specification for Self-Ballasted LED Lamps for General Lighting Services.
EU	EU 244/2009 (ecodesign requirements for non-directional household lamps); EC JRC LED Quality Charter.	EU 98/11/EC (Directive on energy labelling of household lamps); EU 244/2009 (Ecodesign Requirements for non-directional household lamps); New Eco-design Regulation for directional lamps coming in 2012.
IEC	IEC/PAS 62612: Performance requirements for self-ballasted LED lamps for general lighting.	IEC/PAS 62612: Performance requirements for self-ballasted LED lamps for general lighting.
UK Energy Savings Trust	EST LED Lamps and Modules V2.0.	N/A

Programme	Performance Standard	Test Method Standard
US ENERGY STAR	ES Program Requirements for Integral LED Lamps V1.3.	LM 79-08: electrical and photometric measurement of SSL products; LM 80-08: measurement of lumen maintenance of LED light sources.

Table 8 - LED Related Standards, Voluntary Labelling Programmes, and International Standards [CLASP, 2011]

There are also a series of voluntary and mandatory labels:

- CE Marking (safety) – mandatory

  The CE marking is required for many products. It states that the product is assessed before being placed on the market and meets EU safety, health and environmental protection requirements.

  CE marking is a key indicator of a product's compliance, with EU legislation and enables the free movement of, products within the European market. By affixing the CE, marking on a product, a manufacturer is declaring, on his, sole responsibility, conformity with all of the legal requirements, to achieve CE marking and therefore ensuring, validity for that product to be sold throughout the European, Economic Area (EEA, the 27 Member States of the, EU and EFTA countries Iceland, Norway, Liechtenstein), as, well as Turkey. This also applies to products made in third, countries which are sold in the EEA and Turkey. EU Energy Label - mandatory

- EU energy label – mandatory

  This label is obligatory for lighting sources. The energy efficiency of the appliance is rated in terms of a set of energy efficiency classes from A to G on the label, A being the most energy efficient, G the least efficient. The labels also give other useful information to the customer as they choose between various models. The information should also be given in catalogues and included by internet retailers on their websites.

  The legal basis is Directive 2010/30/EU. For light bulbs, every label shows:

  - the energy efficiency category from A to G
  - the luminous flux of the bulb in lumens
  - the electricity consumption of the lamp in watts
  - the average life length in hours

  According to the light bulb's electrical consumption relative to a standard (GLS or incandescent), the light bulb is in one of the following classes:

A	B	C	D	E	F	G
20–50%	50–75%	75–90%	90–100%	100–110%	110–125%	>125%

- DOE Lighting Facts – voluntary

  The LED Lighting Facts® is a programme of the U.S. Department of Energy that showcases LED products for general illumination from manufacturers who commit to testing products and reporting performance results according to industry standards. For lighting buyers, designers, and energy efficiency programmes, the LED Lighting Facts label provides information essential to evaluating products and identifying the best options.

- Underwriter Laboratories Label – voluntary

The Underwriter Laboratories (UL) Mark on a product means that UL has tested and evaluated representative samples of that product and determined that they meet UL requirements. Under a variety of programmes, products are periodically checked by UL at the manufacturing facility to make sure they continue to meet UL requirements. The UL Marks may be only used on or in connection with products certified by UL and under the terms of written agreement with UL. In addition to these marks, UL also provides access to the marks required in a number of other key world markets. As an example, UL EU is a voluntary mark that is used both in Europe, US and Canada.

In view of the above standards, it will be necessary to fill in the gaps in standardisation, e.g. to define new standards for CRI and to assess the impact of SSL on standard EN 12464-1:2002 Light and lighting - Lighting of work places.

Industry experts share the view that so far the market is lacking standard test procedures or measurement standards, to ensure that tests made on LED lamps are comparable.

Ideally, there should be an international test method standard to be used globally, but such a test method is not available yet. Until there is an international standard of SSL test method available, the regional test methods will be very important for laboratory accreditation and SSL testing.

Status for the time being seems to be:

- IES LM-79 (IESNA LM-79-2008) with further development will continue to be used in the USA, as well as in European countries' laboratories that participate in the ENERGY STAR program, the EU LED Quality Charter and in actual LED testing.
- The CEN TC169/CIE TC2-71 test method standard is expected to be used in Europe and internationally when published.
- The IEC performance standards have methods of measurement in their annexes, which might be used for accreditation.

It is also worth mentioning the IEA 4E SSL Annex Task 2. It is working to harmonise SSL Performance Testing by working with global testing laboratories to increase the quality and confidence of SSL laboratory test results; to assess a range of existing SSL test procedures and to build a system of testing that is manageable, robust and acceptable to a broad range of stakeholders.[30]

The IEA 4E SSL Annex is not a standards-making organisation and its proposals for Performance tiers should not be considered a proposed "Performance Standard". It is rather to be considered as input to the work going on in IEC, CEN, CIE and regional standardising bodies (producing SSL test methods).

As far as energy efficiency is concerned, the US Energy Star Label is a good example that could be a source of inspiration for Europe.

Because of the numerous low-quality products in the market, it would be necessary to define minimum performance requirements (MPR) for SSL products. Products not meeting these requirements should not be allowed on the EU market. These should cover light quality, energy efficiency, environmental impact, and safety of use. In the absence of a specific legislation defining these MPR, they could take the form of a quality label.

As SSL products would over time evolve to lighting systems, a new holistic approach should be adopted and MPR would apply at a system level.

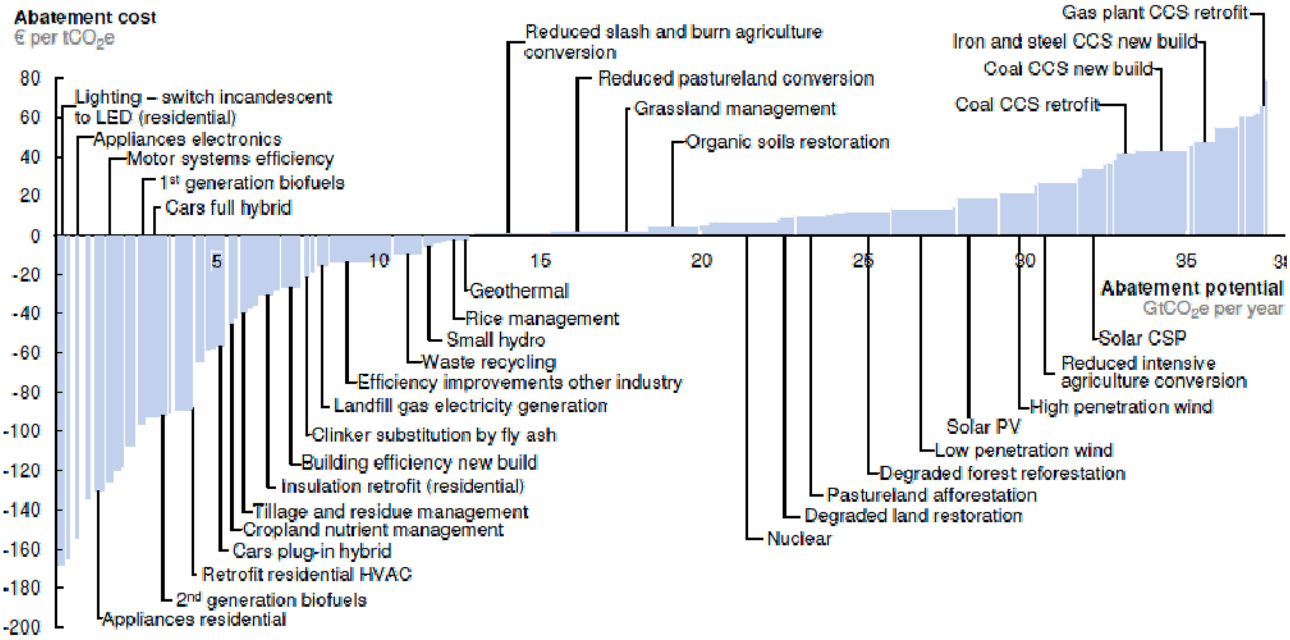
[30] http://ssl.iea-4e.org/about-the-annex/task-2-ssl-testing

Since SSL is a fast-evolving technology, standards should not be static but evolving over time as technology evolves. Ideally, standards should be defined world-wide. In the meantime, test procedures or measurement standards could be determined at European level for the various components of a LED light source (from chip to luminaire).

6. SSL environmental and health aspects

6.1. *INTRODUCTION*

LEDs are emerging not only as having high energy efficiency, but also as having some important environmental advantages compared to conventional light sources. Lower energy consumption leads to lower carbon emissions and LEDs do not contain glass, filaments or mercury, i.e., they are made from non-toxic materials, therefore having many economic and environmental advantages, being one of the most cost-effective technologies to reduce GHG (Figure 72).



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €80 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.1

Figure 72- Savings potential and cost of carbon savings for different supply and demand-side technologies [McKinsey & Company, 2010]

As mentioned, LEDs do not contain mercury. However, they do contain one or more chips (also called dies) that may contain very small amounts of mildly problematic materials such as arsenic, gallium, indium, and/or antimony (combined with nitrogen and phosphors). However, it is not yet clear, whether the material content of the LEDs, which generally includes group III-V semiconductors, presents its own set of potential environmental impacts, human health and ecological toxicity effects, especially when disposed of at the end of their lifecycle. Furthermore, a LED chip is assembled into a usable pin-type device through the application of leads, wires, solders, glues, and adhesives, as well as heat sinks for thermal dissipation management. These ancillary technologies contain additional metals, such as copper, gold, nickel, as well as other metals, such as aluminium as a heat sink. It will be desirable to find proper ways to recycle these materials as well as gallium and indium as more LEDs enter the market. In LED manufacturing, no glass is used in LEDs so there is nothing that can shatter and pose a health risk. This makes it a much safer alternative to current lighting technologies in retail, commercial and industrial applications. One example might be a supermarket with food preparation areas, where a broken light could be a serious health risk in an area such as this (Lim, et al., 2011; IEA, 2006; Aalto University, 2010). To be more precise, a broken lamp may present a health hazard, particularly lamps:

- Having an outside glass envelope (such as incandescent and discharge lamps): if the glass breaks the fragments may be dangerous;
- Discharge lamps (such as CFLs and fluorescents) contain small amounts of mercury which will be released when the lamps breaks.

Long LED life lengthens replacement cycles, while also existing fixture life and thereby reducing the burden on the waste stream.

6.2. LEDs and the WEEE & RoHS Environmental Regulations

Based on the need to limit a product's environmental impact, the European Commission published two complementary Directives (RoHS & WEEE) on environment preservation. In short RoHS regulates the hazardous substances used in electrical and electronic equipment, while WEEE regulates the disposal of that same equipment.

The **Waste Electrical and Electronic Equipment (WEEE) Regulations** (2002/96/EC Directive) initially came into effect in 2007 to meet the requirements of the EU Directive of the same name, whose aims are to prevent the generation of waste from electrical and electronic equipment. It promotes the reuse, recycling and other ways of recovery of such waste to reduce the disposal. The Directive compels producers to be responsible for the collection, treatment, recovery and environmentally-sound disposal of WEEE.

The WEEE Directive covers a wide range of electrical and electronic products. It applies namely also to lighting equipment in which the following products are included (Aalto University, 2010):

- Luminaires for fluorescent lamps, except luminaires in households;
- Linear fluorescent lamps;
- Compact fluorescent lamps;
- High-intensity discharge lamps, including high-pressure sodium lamps and metal halide lamps;
- Low pressure sodium lamps;
- Other lighting or equipment for the purpose of spreading or controlling light, except filament bulbs.

Bare LEDs are not included in the Directives as lamps. However, when LEDs are equipped with reflectors, lenses, they are considered as luminaires and then as products under the scope of the WEEE Directive.

The WEEE Directive is currently undergoing a review, and LEDs will be specifically named in the scope of the recast Directive, which is due to be finalised in 2012. Meanwhile SSL have been classed by the Environment Agency as in scope for the WEEE Regulations. As a result, companies importing, or producing, SSL lamps need to comply with the WEEE regulations (Aalto University, 2010; European Commission, 2011; PennWell's Technology Group, 2011).

The **Restriction of the use of Hazardous Substances in Electrical and Electronic Equipment (RoHS) legislation** (2002/95/EC Directive) restricts the use of specific hazardous materials found in electrical and electronic products. Since July 2006, it is no longer allowed to put on the market, products with hazardous substances (lead, mercury, cadmium and hexavalent chromium) and polybrominated diphenyl ethers [PBDE]), exceeding fixed limits.

The aim of the Directive is to protect human health and the environment, and to encourage environmentally-sound recovery and disposal of waste electrical and electronic equipment. The Directive includes a list of exemptions. Some hazardous substances may be present in different components of equipments used for lighting. For example (Aalto University, 2010):

- Lead in soldering alloys, electronic components, and in glass;
- Cadmium in glass;
- Mercury in discharge lamps (fluorescent lamps, high-pressure sodium lamp, etc.).

LEDs sold individually are considered to be components, rather than an electrical product, and therefore are not within the scope of RoHS. However, when being used as part of electrical equipment, LEDs do fall within scope and therefore should be compliant. For instance, a LED lamp is covered by the Directive (European Commission, 2011; PennWell's Technology Group, 2011).

6.3. LIFE-CYCLE ANALYSIS OF SSL

Life-Cycle Analysis (LCA) gives an overview of the energy and raw materials use of a product from cradle to grave. It considers also how much solid, liquid and gaseous waste and emissions are generated in each stage of the product's life.

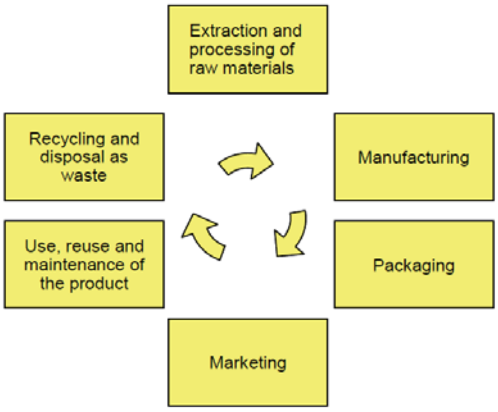


Figure 73 - Schematic of a Life-Cycle Analysis [IEA, 2010]

The LCA is a useful tool in environmentally conscious product design. Environmental impact assessment of lamps over their life cycle is based on an inventory of environmental effects that result from all activities needed to generate a certain quantity of light. This indicates that resources (materials), lamp manufacturing and lamp disposal have a small impact on the environment, compared to electricity consumption during lamp use. From an environmental point of view this means that energy efficient lamps are by far the best choice. During the life cycle of a lamp, 90% or more of the lamp's environmental impact is represented by the use phase, which is the energy consumption of a lamp. The environmental effect of electricity consumption originates mainly from the power generation, where fossil energy carriers, like coal, natural gas or oil, are converted into electricity, releasing GHG and other emissions.

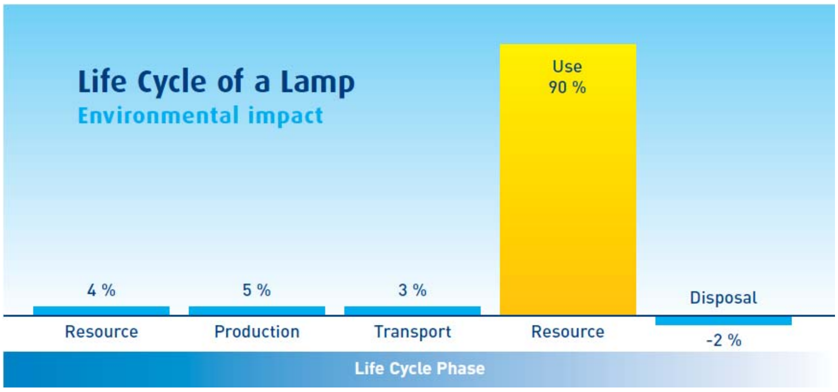


Figure 74-Typical Life Cycle of a Lamp [ELC, 2009]

The results of the LCA can be used to compare products and technologies. The ecodesign results indicate which paths should be taken to minimise impacts in a cost-effective way. The results of an LCA are often given as environmental impact categories, or as the so-called single-scale indices. Environmental impact categories are for example primary energy, toxicological impacts, global warming potential and acidification potential. These values allow the comparison from the point of view of a single type of environmental impact. This makes the comparison of the total environmental impact of products easier.

Figure 75 presents one LCA. It compares CO_2 emissions during the lifetime of an incandescent lamp, a CFL and a LED light source. A 75W incandescent lamp with luminous efficacy of 12 lm/W, a 15W CFL with luminous efficacy of 60 lm/W and a 6 W LED light source with luminous efficacy of 150 lm/W were compared to provide the same light output. The lifetime of the LED light source is assumed to be 25000h. The calculation was done for 25 000 lamp-burning hours. During this period, one LED, three CFLs and twenty-one incandescent lamps were needed. Most of the energy consumption and CO_2 were caused in the operating phase of the lamps. CO_2 emissions of the electricity production were considered to be 370 g/KWh (typical emissions of a combined-cycle gas-turbine power plant and similar to average EU emissions).

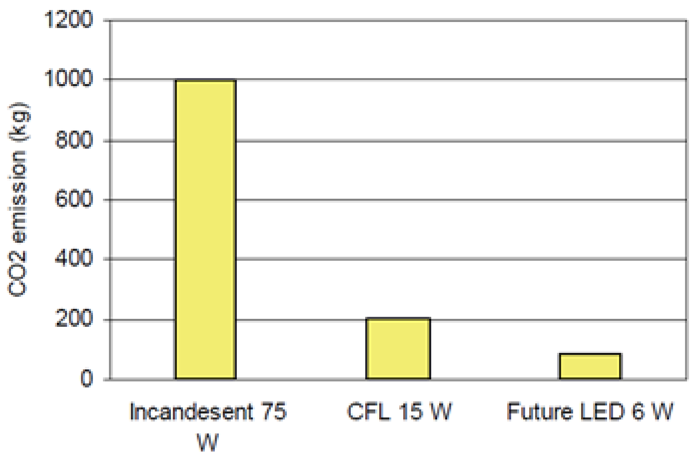


Figure 75 - Comparison of CO_2 emissions during life cycle (calculated for 25 000 hours of time) of an incandescent lamp (12lm/W), CFL (60 lm/W) and future LED light source (150 lm/W) [Aalto University, 2010]

The CO_2 emissions during production of the lamps are also considered in the calculation (Aalto University, 2010).

Literature suggests that the ban of incandescent lamps and their replacement by equivalent compact fluorescent lamps (CFL) will lead to important energy savings and associated reduction of greenhouse gas emissions (GHG). High-efficiency lighting systems using LEDs (over 120 lm/W overall plug efficacy) can cut the energy consumption by a factor of two compared to CFLs. LEDs with intelligent controls can further extend the energy savings in all sectors (Chapter 9) leading to GHG emission reductions of over 40 Mt of CO_2.

However, such LCAs should be analysed with caution. Indeed, there is no consensus on the scope of a light source LCA, that is, which environmental impacts to take into account. This is important in order to be able to compare the LCA with conventional light sources. So is the selection of testing conditions to use in the absence of testing standards. It is worth mentioning that manufacturing process data are difficult to obtain, as manufacturers are reluctant to divulge it. In addition, LED technology is evolving rapidly in terms of performance (luminous efficacy, lifetime, colour rendering and lumen maintenance) (US DOE, 2011). In view of the large product variety, it is difficult to choose the right luminaire or lamp. Finally, the impact of light itself, such as glare or light pollution, should be included. However, there is no method for quantifying the impacts of light on human and flora and fauna.

Despite the above-mentioned caveats and the uncertainties in the assessment of the end-of life, LCAs indicate that the energy consumption in use is the major environmental aspect. For LED lights, the situation is more favourable than for traditional light sources.

In conclusion, there is a need for conducting a full LCA of LED light sources. Further research into LED lighting LCA would be necessary to come up with a definite outcome.

6.4. POTENTIAL HEALTH EFFECTS ASSOCIATED TO LEDS

The potential health risks of these new light sources need to be explored. Due to specific spectral and energetic characteristics of white LEDs, as compared to other domestic light sources, some concerns have been raised regarding their safety for human health and particularly potential harmful risks for the eye.

The evidence that artificial light may produce adverse consequences to human health and environment remains incomplete (US Department of Energy, 2010). The photopic lumen is currently used in all lighting applications, be they interior or exterior, daytime or night-time. Investigations into the possible visual performance benefits of “spectrally enhanced” electric lighting for interior and exterior use are ongoing. Similarly, researchers are seeking to establish recommended requirements and restrictions for minimum daytime and maximum night-time exposures to light. Due to the continuous growth of artificial lighting, namely in streets, roads, bridges, airports, commercial and industrial buildings, parking lots, sport centres and homes, this problem is increasingly debated and many countries have developed regulations to constrain the wasteful loss of light into the sky and environment.

SSL technology offers a number of potential advantages for outdoor lighting applications. LEDs can distribute light more directionally (minimising spillage and light pollution), allowing for reduced average light levels in some applications, such as outdoor lighting, and thereby further reducing the power consumption. The most efficient LEDs can already produce light using less wattage than would be required using a traditional light source. Reductions in the connected load can be accomplished by a combination of improved luminaire efficacy and the reduction or elimination of wasted light directed upward or outward beyond the target.

After moving from outside with brighter lighting to indoor conditions, or during the transition from daylight to darkness, the human eye adapts to the low light levels. As part of this transition process, the eye gradually shifts from photopic (cone) vision toward scotopic (rod) vision, such that both rods and cones are contributing to vision. With low illumination levels the visual performance improves with lower wavelengths, as shown in Figure 76. Lower wavelengths are derived from high colour temperature sources (e.g. 5000 °K and above).

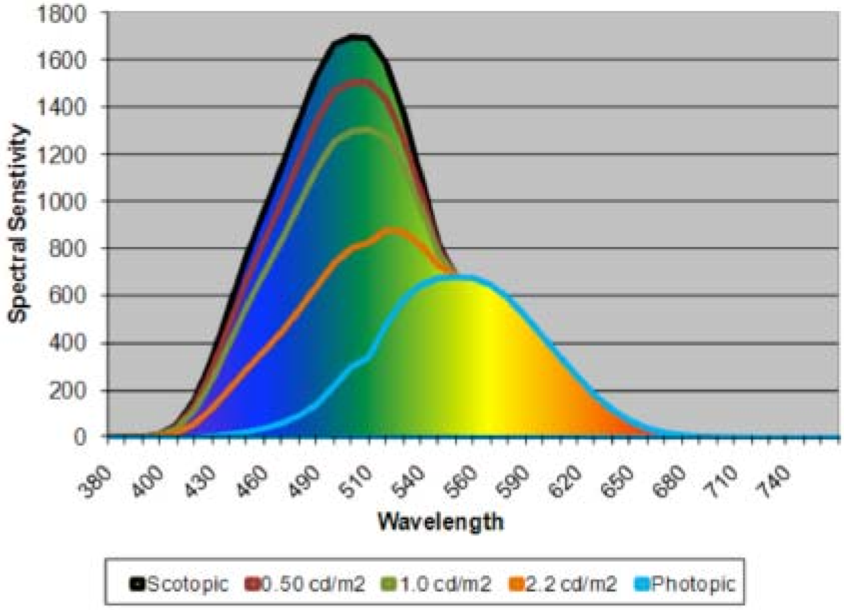


Figure 76 - Spectral Sensitivity [US Department of Energy, 2010]

With regards to human health impacts, to date there are no doubts that exposure to light at night decreases the melatonin production and secretion, and may interfere with circadian daily rhythms. Short wavelength light (light emitted below 500 nm, as indicated by the shaded section of Figure 77) has a greater tendency to affect living organisms through disruption of their biological processes that rely upon natural cycles of daylight and darkness, such as the circadian rhythm, as shown in Figure 77. Human visual sensitivity, depicted by the thin solid line, is higher and centred in the green and yellow part of the spectrum. Circadian rhythms are controlled by light emitted within the dashed curve. The colour of light emitted by a typical cool-white 5500 Kelvin LED is depicted by the bold line.

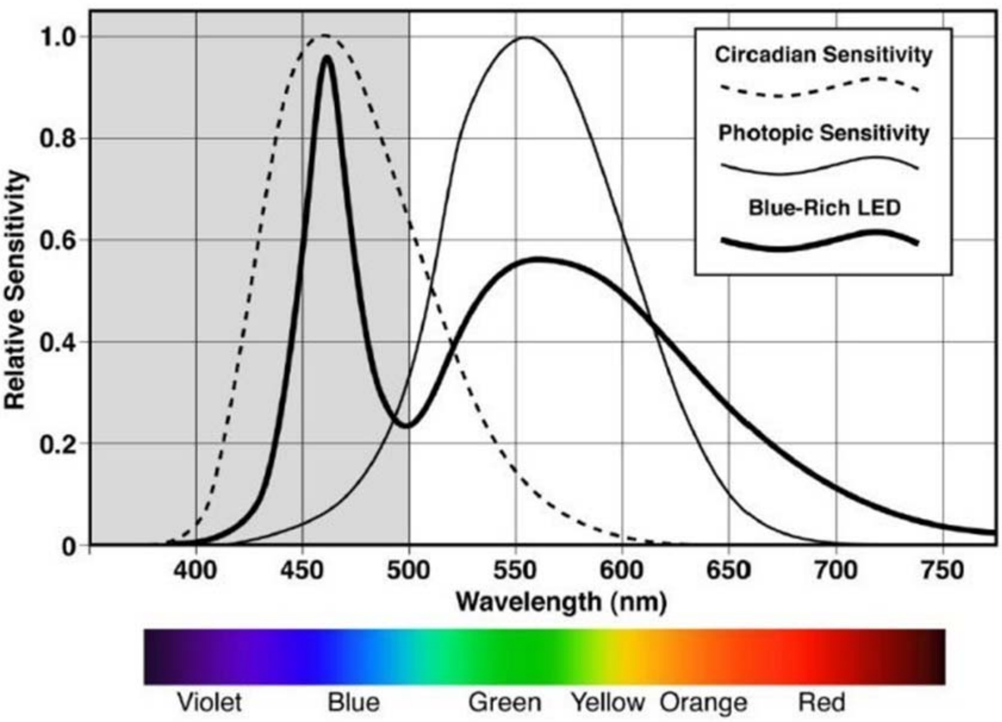


Figure 77 - Action spectrum for melatonin production [US Department of Energy, 2010]

In general "cool" white LEDs are more efficient than those having a "warm" appearance, since short-wavelength spectral content plays a role in the photopic efficacy of LEDs.

Due to this fact, health may be impaired more by blue light, and it is advised to use warm white lamps (up to 120 lumen/W achieved in 2011, CCT of about 3000 °K, with a colour rendition index above 90) in residential areas and to use medium white (up to 150 lumen/W achieved in 2011, CCT around 4000 °K with a colour rendition index above 90) in office areas. In situations in which visual performance is desirable for safety reasons, such as in high-traffic roads, tunnels and parking lots, cool white (CCT equal or above 5000 °K, with a colour rendition index above 70) may be used. High-efficacy, warm and medium white LEDs are an environmental, ecological, and technological breakthrough that will help over time to minimise the impact of artificial lighting on the night environment. Their development is a significant technological achievement to encourage all LED manufacturers to strive for further reductions in short wavelength, blue light emission (US Department of Energy, 2010; Falchi, et al., 2011).

Recently, at least two studies on the potential health effects of LEDs have been conducted independently by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES)[31], a public body reporting to the French Ministry for Ecology and the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) providing opinions to European Commission's DG Health and Consumers[32].

Interaction of radiation with biological systems occurs through absorption, the radiant energy is transferred to the material in which the effect takes place. Two main mechanisms can be distinguished through which the absorbed radiant energy can take effect by heat and by photochemical processes. In fact, light is an electromagnetic radiation visible by the intact adult human eye in the range of 380 to 780 nm, spanning from violet to red light. Like all radiations, light

[31] Report published in October 2010

[32] Public consultation phase and hearing finished in September 2010

carries energy, the shorter wavelengths being the most energetic ones; the interaction of each wavelength with live tissues is fundamentally different and depends on many parameters. A light-emitting diode is intrinsically monochromatic. The dominant wavelength emitted by the semi-conductor junction is mainly determined by the value of the energy gap between the conduction and valence bands. High-brightness LEDs used for lighting emit blue radiation, absorbed partially by a phosphor which re-emits yellow radiation. The combination of blue and yellow radiation leads to a white light perception by the human eye. It should be noticed here that the resulting LED spectrum is fundamentally different from daylight and also from the spectrum emitted by any other artificial light source. Generally, the spectrum of white LEDs contains a non-negligible proportion of blue radiation. Several macular pigments lying on the eye retina strongly absorb blue radiation and this may lead to their destruction. The potential phototoxic retinal damage is thus expected to occur with wavelengths in the blue light spectrum between 400 and 460 nm (blue-light hazard). In the above-sited reports, the blue-light risk assessment was carried out in compliance with the requirements of the EN 62471 Standard. This Standard, which concerns the photobiological safety of lamps and devices using lamps, recommends exposure limits for radiation from these light sources. It provides a system of classification based on radiance and irradiance. The Standard considers all of the photobiological hazards that may affect the eye and the skin (thermal and photochemical hazards) from ultraviolet to infrared wavelengths and defines four risk groups, according to the value of the maximum permissible exposure time: from 0 (no risk) to 3 (high risk). In ANSES report radiance measurements have been carried out in order to determine risk group and the associated hazard. The radiance measurements show that certain LEDs, currently on sale to the general public and potentially used in domestic lighting situations, for signage and guide lights, fall into Risk Group 2, whereas all the other light sources currently on sale to the public fall into either Risk Groups 0 or 1. The safe exposure limit times implied by placing these items in Group 2 vary from a few seconds for certain royal blue LEDs to a few tens of seconds for certain cold-white LEDs. It is important to emphasise that other widely-used sources of lighting, particularly high-pressure gas discharge lamps (metal halide lamps for outdoor lighting), are also in Risk Group 2. However, this last example is intended for clearly identified uses and can only be installed by professionals who are required to limit the exposure level for the population. With the arrival on the domestic lighting market of LEDs, light sources falling into Risk Group 2 thus become available to the general public, without details of the risk incurred appearing on the labelling. With regard to glare-related risks, the standards lay down certain references covering visual ergonomics and safety. In the LED lighting systems available on the market, the LEDs are often directly visible in order to avoid attenuating the level of brightness produced. This could lead to non-compliance with the requirements laid down in the standards.

Besides blue LEDs that are used commonly for decorative purposes, white LEDs provide retinal exposures to violet, indigo and blue light at much higher levels than in previous light sources. This is the first time that the population will be exposed to such substantial blue light. Will such retinal exposure induce increased macular degeneration or perturbations of circadian cycles? Nobody can tell today. However, when analysing all the knowledge that has been accumulating on blue-light hazards, we cannot rule out a yet undiscovered risk for chronic daylong, lifetime exposure, since photochemical damages may not induce any visible changes, but cumulatively induce photoreceptors loss.

ANSES emitted some recommendations that suggest limiting the sale of LEDs for domestic use, or for the general public, to LEDs falling into Risk Groups equal to or higher than 1 (when assessed at an observation distance of 200 mm); to avoid cold-white LEDs in proximity of children; and to force professionals designing lighting systems using LEDs to apply all standards concerning the quality of lighting. SCENHIR seems to be less gloomy on the subject. However, both ANSES and SCENHIR agree that there is an urgent need for a better evaluation of potential light toxicity, depending on the different artificial light sources available, and upon chronic exposure of different populations to define clear guidelines for domestic light manufacturers. A strong common recommendation is to clarify the IEC 62 471-2 Standard (‘Photobiological safety of lamps and lamp systems’) for its application to lighting systems using LEDs.

In short, LEDs offer many possibilities, but it is important to use the appropriate type of LED for the right environment.

Further life-cycle analysis and studies of the health effects of the substances used for LED manufacturing will be necessary to confirm the benefits of LEDs in these areas too.

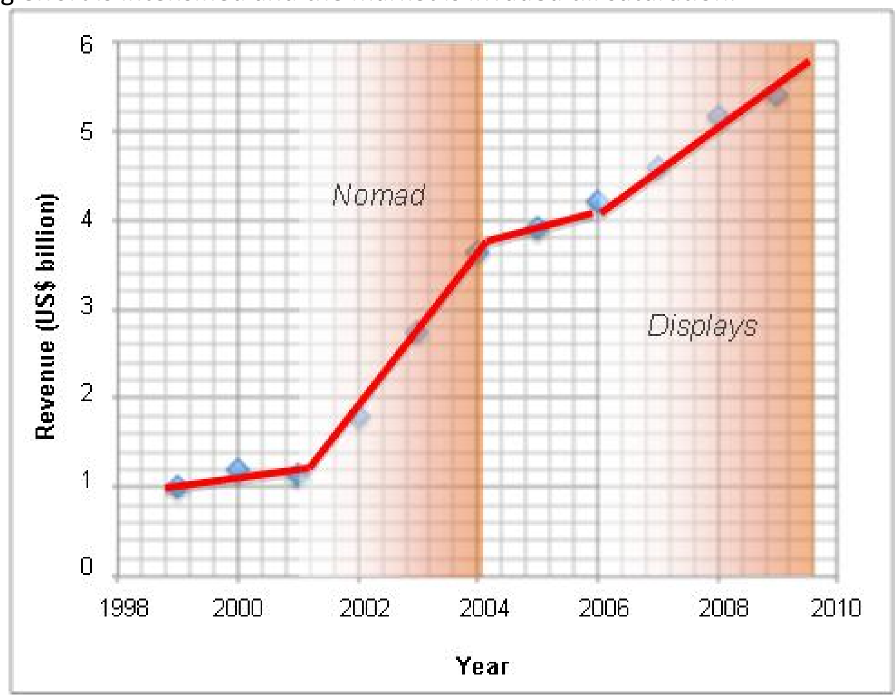
7. Critical analysis of the LED-Lighting market status

To start any market-analysis process, it is necessary to answer the following fundamental question: Which specific market is the product targeting?

For LEDs the answer seems, in a first instance, to be straightforward: General (indoor and outdoor) lighting. In reality, this is the ultimate target for LEDs. The question here is when this will happen? To answer, it is necessary to understand the LED market growth process.

In the past, LEDs penetrated gradually various market segments till saturation, afterwards they jumped from one saturated segment to another. For example, till 2004 the market was driven by nomad applications and the CAGR was maintained as high as 45%/year. Then, as this segment attained saturation the global CAGR brutally reduced to 8%/year for the next four years[33]. Then, from 2008, the main market segments that LEDs are trying to conquer are backlighting for display applications (especially TV screens) and automotive. The projections show that this "jump" will guarantee a CAGR of around 11-12%/year at least till 2016[34]. In fact, this observed saturation is due to both overcapacity production caused by many new players penetrating the market and also significant price collapse that lead to reduction of profit margins, even if the production quantity is increasing.

Based on these observations, the following conclusion can be drawn: LED market growth is "opportunistic" and "invasive". As has been seen in the previous chapters of this report, LEDs represent today a significant market segment for the semiconductor and optoelectronics industry (see Figure 83, Annex II) which is trying to counterpoise shrinking[35] of other classic market segments. Once LEDs reach a performance level that can be considered as satisfactory for a given application, the marketing effort is intensified and the market is invaded till saturation.



[33] The values are from: Roussel Ph., Proc. of SPIE, 2007

[34] CAGR calculated from ElectroniCast forecast (2011) for display and automotive markets. It should be noted that YOLE, in 2007, predicted a CAGR of 18%/year if lighting is included.

[35] Telecoms have been mainly pointed out during the last decade, but PC memories, and generally speaking, microprocessors could be concerned in the near future.

Figure 78 - Illustration of LED market growth mechanism based on historical revenues compiled from literature

Looking at the historical data presented by various analysts (Figure 78), it can be seen that the "marketing cycle" duration is in average of less than 7-10 years: 3-7 years are necessary to saturate the market (following the global market size and the observed OEM lifespan) and then 2-3 years are necessary to concentrate efforts on a new target. This cycle is rather short compared to observed values for OEMs (e.g. for lighting, a product life cycle is estimated to be in the order of 25-30 years[36]). This short cycle is however matching well with the performance evolution of the LED technology (R. Haitz's law[37] predicts that luminous flux will be multiplied by a factor of 2 every 18-24 months). Furthermore, the semiconductor industry is producing "components" and not OEMs, thus the "product cannibalisation" issue is rather marginal.

Assuming that this market growth mechanism is reproduced for each targeted application, it is possible to speculate on what will happen for lighting during the next five to ten years.

In parallel, HB-LED and UHB-LED technologies reached, since 2007, a sufficient performance level (luminous efficacy higher than[38] 110 lm/W, high luminous flux per package, colour uniformity, large available colour temperature range, acceptable colour rendering, etc.) that makes them attractive for general lighting[39]. Under that situation, general lighting will be the next target applications for LEDs. This conclusion is well supported by forecasts for the growth of market shares provided by at least two different analysts. Figure 79 shows the general lighting market segment share for LED industry. The values have been calculated combining the forecasts published from YOLE (2010) and ElectroniCast (2011) and historical observed values reported by Strategies Unlimited (2007).

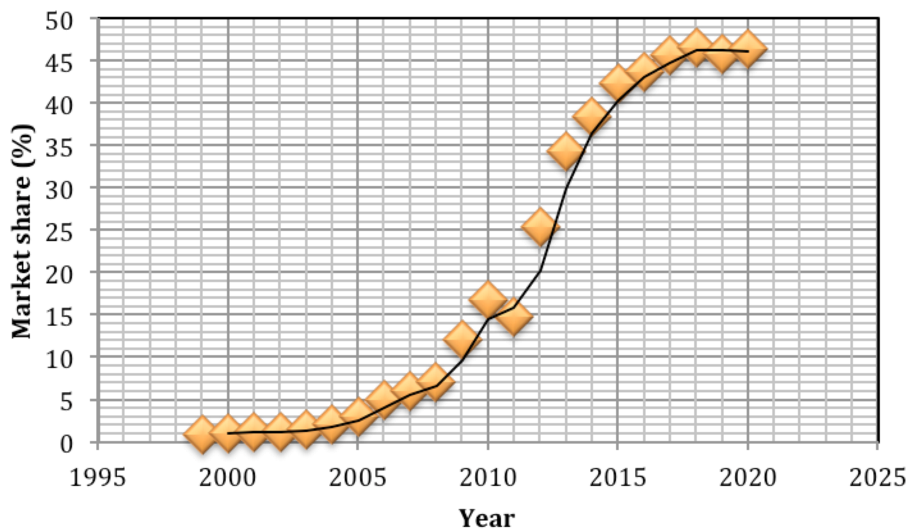


Figure 79 - Market share (in revenue) forecast for general lighting market segment for packaged LED. The solid line is representing the 1-year mobile average

It is observed that both forecasts predict a rapid growth period from 2009 to 2015 and that at saturation level general lighting will represent 45%-47% of the global packaged LED industry revenue. Once again the estimated marketing cycle duration is less than 10 years.

[36] Private communication from lighting industry officials

[37] Haitz R., Kish F., Tsao J., Nelson J., "Another semiconductor revolution: This time it's lighting", Comp. Semiconductor Magazine, March 2002.

[38] Value for commercial products at standard conditions, not at real-life operating conditions.

[39] At least for a 60 W incandescent equivalent.

However, if both analysts seem to agree on the penetration rate growth, we found significant differences concerning the growth model for the absolute revenue evolution. Figure 80 shows the general lighting revenue evolution that we obtain by compiling YOLE's and ElectroniCast's forecasts. The values have been corrected by including an annual inflation rate of 5% till 2020 (see Annex II of the present report).

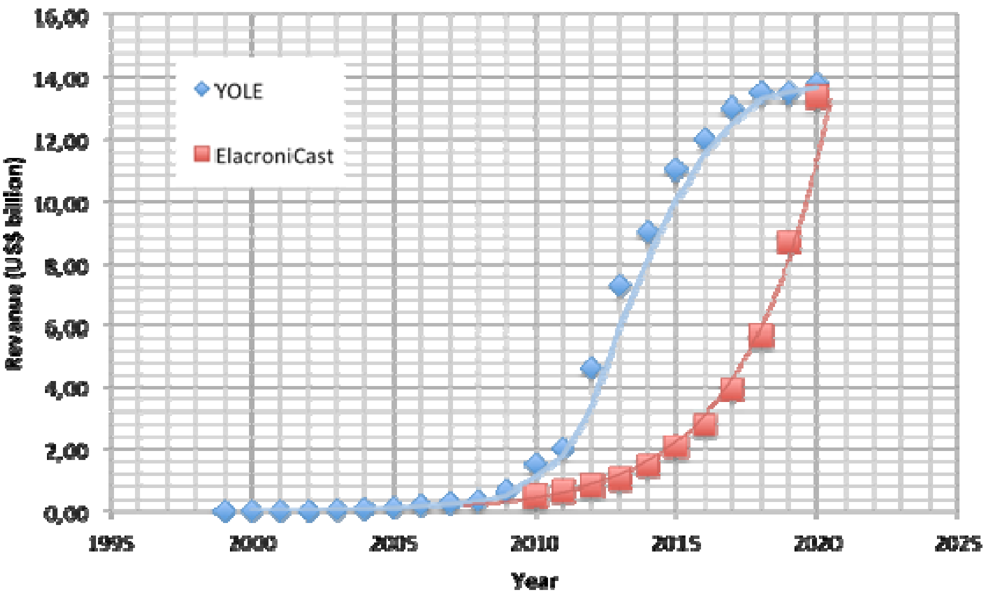


Figure 80 - Packaged LED for General Lighting market revenue forecasts (solid lines are mathematical regressions on the data)

Beyond any observed disagreement between the two studies it is worth saying that both predictions are converging to the main conclusion that LED market share will grow rapidly within the next years till saturation. The final value of around US$ 14 billion for 2020 seems to be realistic, because when added to a value of US$ 15-16 billion, representing packaged LED revenue from segments other that general lighting, global revenue of US$ 30 billion is found for 2020. This value corresponds fairly well with Strategies Unlimited's and Cree's forecasts. We can then accept that value as being realistic, with an estimation margin of ±15%.

To proceed with this analysis, first we have to set the boundaries. In our case, the size of the lighting market seems to be almost independent of the light-source technology used, because it is driven by the system price (this is not true of course for omni-directional lamps, used mainly in residential applications). The maximum size is the upper-boundary for any growth model. Following the Integrated System Technologies analysis published in 2010, Figure 81 shows the above-mentioned forecast.

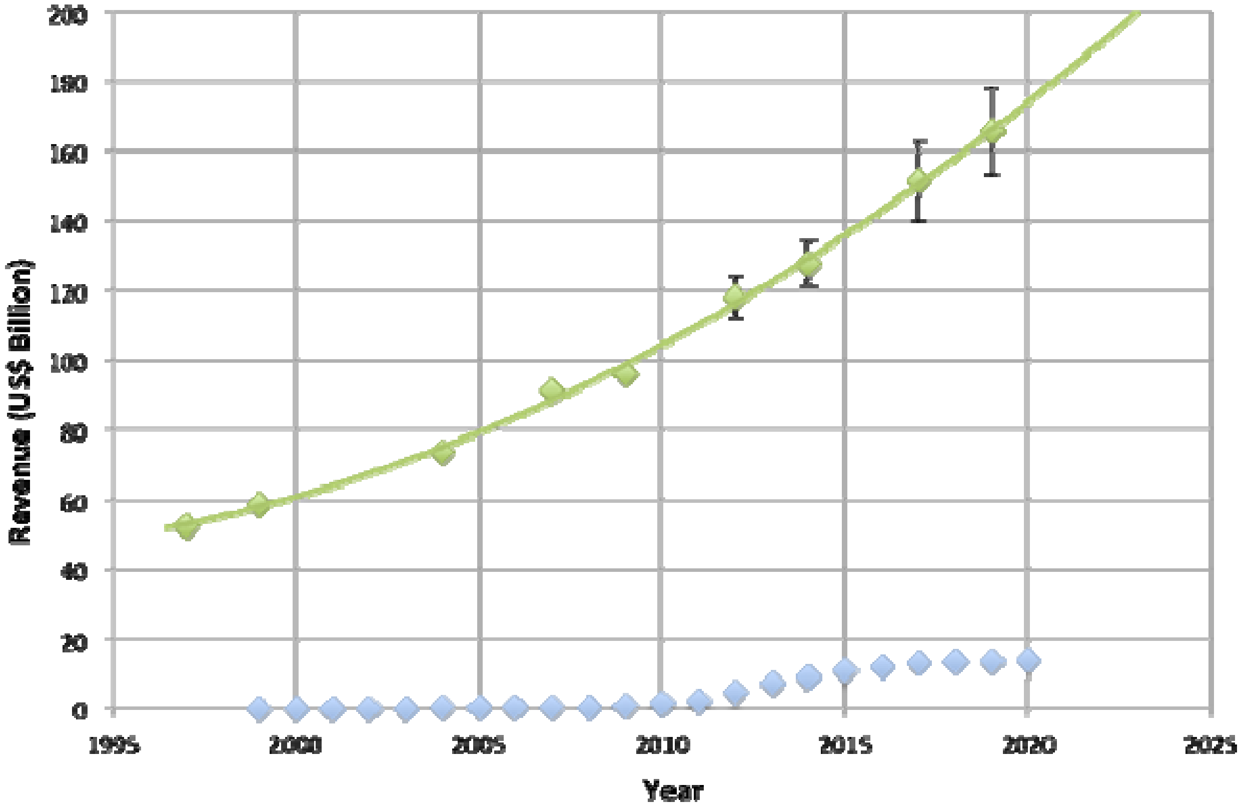


Figure 81 - Global Lighting market size forecast for upper and lower limit. Solid lines are mathematical fits of the proposed values.

For the period 1997 to 2020, the CAGR for the global lighting market size is in the order of 5.3%/year. This slow increase is mainly due to three factors: (1) worldwide population growth; (2) electrical grid expansion; (3) world GDP *per capita* increase[40]. It should be noted here that some forecasts from the lighting industry assume a slight decrease in the annual number of units (lamps) sold during the next decade. This decrease is counterbalanced by the increase of the acquisition cost of the lamp. Looking at the above graphics we can see that a 2nd order polynomial can fit perfectly the values (the confidence parameter R^2 is equal to 0.994). We will adopt then this 2nd order polynomial model in order to set the upper limit of our growth estimations for LED-based lighting systems.

The lower limit is of course the LED-components value used for producing the lighting systems (it is also shown in Figure 81).

In March 2010, James Stellter and Alasdair Leslie from News Street Research published an excellent analysis of LED penetration growth scenarios, based on data from Strategies Unlimited, Strategy Analytics, Freedonia, Philips and Veeco (see Figure 27 of the present report). Three models have been proposed: (1) "the best case" corresponding to a technology breakthrough; (2) "the median" corresponding to average market evolution; and (3) "the worst case" that correspond to basic evolution. Figure 82 shows the three scenarios transposed from growth rates to revenue values.

[40] E. Mills showed in 2002 that there is a strong almost linear correlation between GDP/capita and energy used for lighting production/capita

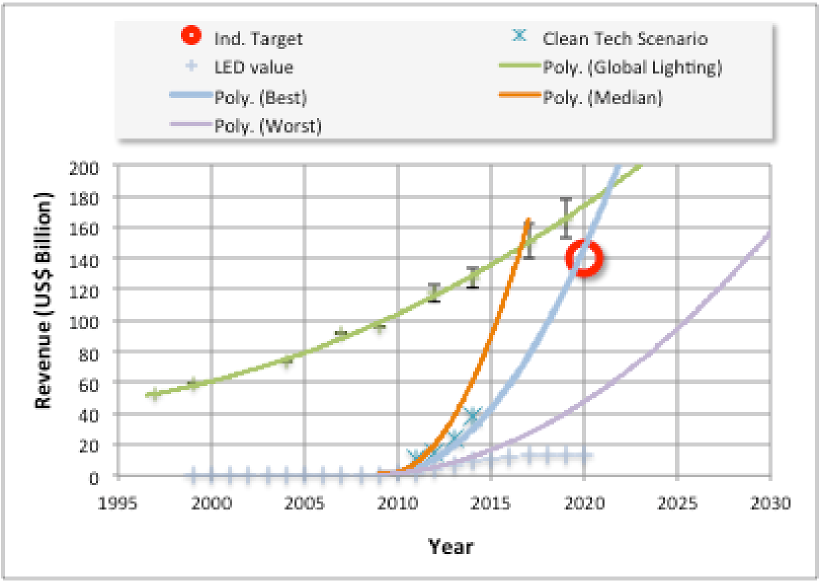


Figure 82 - Growth scenarios analysis for LED-based system penetration in global lighting market.

It can be shown that the above three growth scenarios can be fitted also with a parabolic law (2nd order polynomials)[41]. The upper and lower limits are also indicated (green line and grey crosses respectively). Using these parabolic equations then, it is possible to extrapolate till crossing the upper limit (green line). From this graphical presentation it is possible to draw the following important conclusion: LED, and generally speaking SSL, will be the dominant technology within the next decade. However, at the present state of knowledge, it seems rather difficult to say if they will dominate the market before or after 2020.

[41] In all three cases the fitting confidence parameter R^2 is higher than 0.99.

8. Conclusions

Lighting is a more than a century old industry, dominated by large incumbents: GE, Philips and Osram cover nearly 50% of the market. The age of the industry and its domination by large incumbents has earned it a reputation as stale and lacking in innovation. However, analysts believe the next decade will be a time of unprecedented, radical change in the industry, due to the expansion of SSL (Solid-State Lighting). In the medium/long run LEDs (Light-Emitting Diodes) are believed to massively enter the market as manufacturing scale and innovation rapidly bring costs down. The adoption of LEDs instead of Fluorescent or Compact Fluorescent (FL/CFL) shows a better long-term return on investment, but requires a higher upfront capital cost. That cost differential is why analysts believe that there is plenty of room for FL/CFL-focused companies to grow, targeting the retrofit market, while LED costs decline.

LEDs are foreseen from the semiconductor industry as a major growth market for the years to come. This could largely compensate telecommunication market depreciation, observed in the last years. Packaged LED production is definitively Asia-based: Japan, Taiwan and Korea are the main players. However, China's production capacity is rapidly building up and this country could become the dominant market player within the next five years. Nevertheless, looking at revenue coming from LED-based fixtures, Europe is currently well positioned (1/3 of the market size today, with China as a serious challenger).

Lighting is mainly using high-brightness LEDs[42] while low-power LEDs are still in use for some lighting niche applications. Today architectural, decorative and scenic lighting represent the highest penetration rate for LEDs. In the domain of general lighting, LEDs start penetrating the outdoor lighting sector; however the part for indoor applications is rapidly increasing. Concerning indoor lighting, LED penetration in the residential sector is low and the growth rate still slow.

Growth in the use of LEDs in general lighting applications will be enabled by significant technology and manufacturing efficiency improvements that will allow the cost per lumen of packaged LED to be substantially reduced (up to 10-fold decrease) between 2010 and 2020.

For residential consumers, the initial large exposure to LED for general lighting applications will come in the form of LED bulb replacement that can be used in existing sockets. As initial consumer perception of the technology will come from the first exposure represented by bulb replacement, LED quality and performance will be critical to the future of the industry. Standards and regulations are therefore needed to ensure simplicity of operation and a reasonable level of quality. Dedicated LED modules and luminaires will come in a second wave and deliver the full benefits of the technology. However, additional standardisation efforts are needed to ensure a minimum level of upgradability and interoperability.

The LED **value chain** is well identified and goes from raw materials to lighting services. Raw materials availability is limited and should be considered today as a threat for the industry (this is particularly true for EU-based industry, because the major part of rare earth elements is controlled by China). At this moment, an additional risk is identified to the LED-chip industry: over-production that can lead to supply-demand mismatch and rapid revenue depreciation for the semiconductor industry.

Leaders of the classic lighting industry are directly involved in the LED-lighting value chain from the bottom to the top. However, many newcomers are now challenging the existing market leaders. **Newcomers** are mainly based in Japan, Taiwan and Korea. They have solid anchorage either in the semiconductors or systems industry and have an important financial base that can challenge large groups like Philips, Osram, etc. This situation should be considered as an important threat to the

[42] HB-LEDs and UHB-LEDs account for more than 75% of the total market

European lighting industry. Today, major EU lighting companies are establishing joint ventures and/or production facilities in Asia; in the medium term, there is a possibility that only advanced complex lighting systems (which represent the higher levels of the value chain) will be produced in Europe.

European MOCVD (Metal-Organic Chemical Vapour Deposition) capacity is only 3%, but is expected to grow rapidly, as indicated by the recent establishment of new facilities. The majority of key MOCVD equipment for LED chip production is still manufactured in Europe.

The European manufacturing base is strong in the downstream segments of the value chain (which are close to the application) with more than 40% of general lighting manufactured in Europe. It is weaker in the upstream segments. In this segment, Europe's share represents 11% of Light Emitting Diode (LED) packaging and approximately 10% of global production of devices (LED chips) and advanced materials (compound semiconductor ingots and wafers).

In the upstream segments of the value chain, reports show that the technology development competences are available in Europe, but this part of the value chain faces a significant threat of relocation to Asian manufacturing locations. This is due to favourable costs, a higher growth potential in nearby markets, quickly improving technological competence associated with increasing manufacturing experience, successful agglomeration of critical complementary industries and services, as well as a decidedly pro-active strategy to improve R&D capabilities and their industrial use. In Europe, a significant obstacle, for the realisation of large-scale manufacturing capacity increases in SSL, is the limited availability of funding caused by the risk adversity in the banking sector.

For the LED-lighting industry **IP** (Intellectual Property) is an important issue. Looking at the number of patents in the SSL domain, it can be seen that the major part is held by non-EU based companies. However, cross-licences and joint-venture schemes are being more and more developed. Today, Chinese R&D activities, as well as production capacity building, benefit from an injection of public financing, as was the case for the CFL industry. China has a clear industry policy to push up the LED business. In the US, the Department of Energy (DoE) and the government opened a multi-year programme plan in order to boost R&D. Europe is financing several R&D projects within FP7 (especially ICT) and several individual Member States (in particular Germany) are doing the same, but overall, Europe is suffering from turning good research ideas into innovative products. Nominating the photonics industry as Key Enabling Technology (KET) for the next years could reduce this threat within the next five years, provided that it leads to a concrete strategy with a clear action plan and follow-up.

Contrary to the US or Asia, in Europe the fixture market is highly fragmented. This could constitute an additional threat to European LED production if stronger cooperation between SMEs is not established. With approximately 800 players in the luminaire segment in Europe, market consolidation is necessary. However it is expected to remain a fragmented market.

R&D takes place mainly in Japan, the US and Europe. Nevertheless, through patent cross-licensing the research base becomes broader, including China, Taiwan and South Korea. Europe is suffering from fragmented funding. Taiwan has the largest investment worldwide, estimated at US$600 million, 70% of which is from private sources. Korea's LED-related R&D is also mainly privately financed, whereas in China, the government is investing heavily in research.

The **commercialisation channels** are very different from one country to another. This is especially true within EU Member States. The large classic lighting industries are controlling the distribution channels. The domain of SSL is flourishing and in Europe many new start-ups are being created almost every week. However, many of them have a very limited knowledge of the lighting market and neither do they have access to distribution channels, nor industrial products that fulfil strict quality criteria. For increased market penetration of LEDs, end-user information and training, as well as training of installers would be necessary.

Quality and reliability of SSL products is a major issue. The enthusiasm of designers, architects, engineers and even early adopters of LEDs provides easy sales opportunity. However, the end-user market will not know the difference between low-quality premature products and higher-quality products. The market will expect the energy savings and performance benefits as publicised, and may not understand the difference between laboratory accomplishments and real-world applications. Furthermore, *missing standards* allow the market to be flooded with low-quality and non-reliable products that deceive end-users. The scenario of low quality CFLs that damaged market growth might be repeated for SSL, which could be counterproductive. In addition, a lot of negative publicity about SSL, based on false arguments and values, is conveyed on the internet, by the general and specialised press. Hence the importance of standards, as well as training of market players (designers, installers, resellers and end-users), but also proper market surveillance of products sold in the EU.

For residential users, beyond product reliability, **light quality** is a very important issue. Today many LED lights (especially cheap low-quality systems) are characterised by insufficient light quality[43]. Furthermore, badly designed LED systems can be responsible for high-glare situations that can lead to dangers. On the other hand, well-designed LED systems can improve the quality of life (e.g. lighting quality for elderly people, lighting in hospitals to improve room atmosphere or illuminate a specific area to facilitate an operation). Testing and performance standards, as well as certification and labels, can help overcome these barriers.

Finally, in the coming years, cost and payback time will be important barriers to generalisation of SSL for professional and individual end-users alike. Industry is working hard on these issues and all observers are confident that reduction of the costs will make LED products more attractive. In addition, the development of financial instruments such as PPPs (public-private partnerships) might be a good incentive for market uptake.

All in all, SSL faces a bright future. The main question is: what will be the share of European industry in this competitive global market? High quality and high-added value systems, coupled with strict standards and minimum performance requirements supported by European Directives, might be one part of the answer, the other part being the industry's competitiveness and innovation capacity.

[43] Light quality includes colour rendering, colour temperature and associated ambiance, as well as light stability (flickering), light distribution and colour uniformity.

9. Table of figures

10. List of tables

11. References

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12. Annex I - Methodology, critical analysis of collected data and note on data constancy

Data have been collected from several sources, including specialised consulting firms, trade organisations, press releases, industry annual reports, and presentations in national and international events.

The main difficulty was to be able to distinguish between data concerning LED components and OEMs using LEDs (in the case of lighting: fixtures). In many sources there is not a clear distinction between these two classes of products. It was also difficult to dissociate regular LEDs from HB-LED and UHB-LEDs. Fortunately in the case of lighting applications, HB-LEDs dominate the market and the error made in the market global revenue size, if regular LEDs are included or not in the sources, is lower than 10%.

In this report, we focused only on data concerning the period from 2007 to 2011; older data have been discarded from the report, but we used them in order to check the consistency of the observed trends.

When data from the same analyst are available for several consecutive years, we always used the latest one. This way it is easy to check consistency between predictions and “observed” situations: predictions from older sources can be compared with real data from newer documents. Generally speaking, estimations are accurate within an error margin of ±15%, but “catastrophic” situations can’t be predicted (for example documents from 2007 couldn’t predict market shrinking observed in 2009, due to world economy collapse).

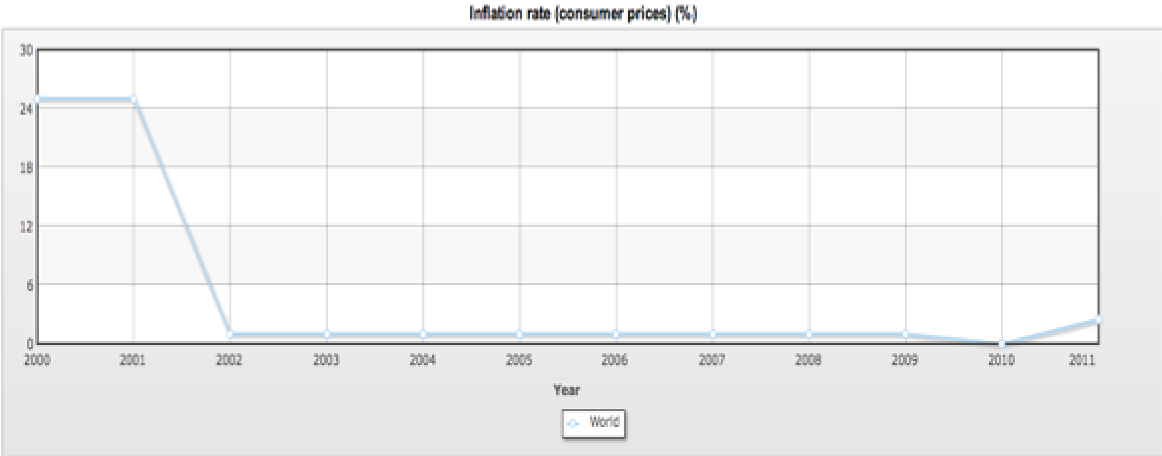
In the case where data from the same year and from different analysts are available, we had the opportunity to check consistency of observed values and compare predictions. Generally, observed values are similar (±2-3%) and this is due to the fact that all analysts use similar data sources. Estimations are quite coherent between the various analysts, showing always the same trend (growth), but the absolute values may vary within a range of ±30%.

However, it should be noted here that a large amount of consistent information is usually coming from a rather limited number of analysts: YOLE, Strategies Unlimited, Center on Globalization Governance and Competitiveness, LED Inside and ElecroniCast being the more important ones. As data seems to be very coherent, it is legitimate to ask if there is any kind of “calibration” between these sources.

In order to guarantee consistency of financial amounts in our report, we applied the following principles:

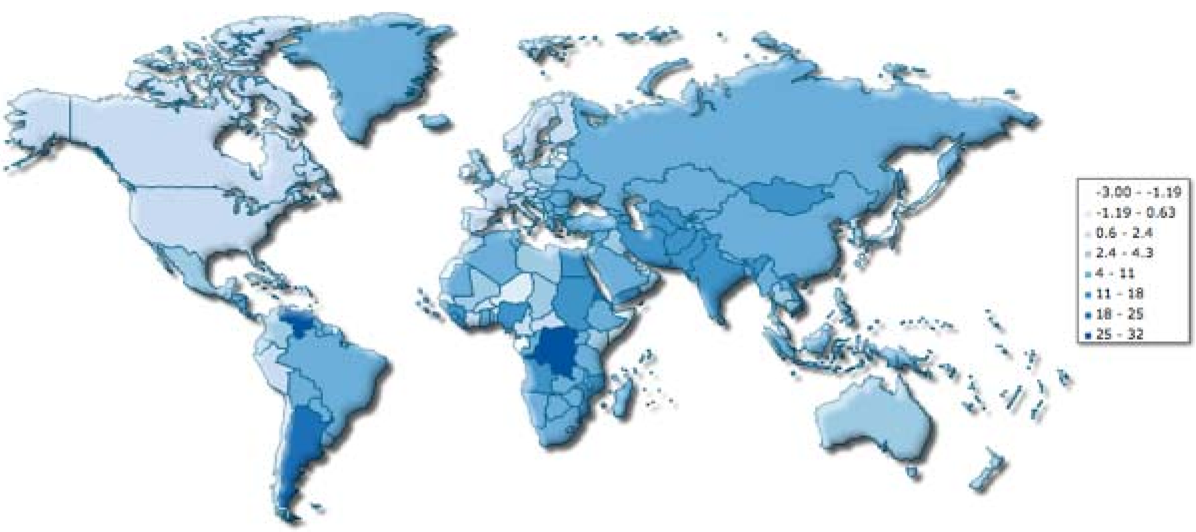
- When foreign currencies are mentioned (excluding US$), the year is always given and the amount transposed in actual (2011) Euros using the rates given in Annex VI.
- As the report concerns only data obtained from recent year documents (2007-2011), and taking into account that during the last years, inflation[44] was stable and lower than 2% (see following graphics), we consider that financial amounts are accurate without correction. In fact, the maximum correction is estimated to be in the order of 5% (2007 values actualised for 2011), but following the above critical analysis on the data constancy, it seems difficult to guarantee that precision of the given values is better than 10-15%.

[44] Annual percent change in consumer prices compared with the previous year's consumer prices.



Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
World	25	25	1	1	1	1	1	1	1	1	0	2.5

(a)



(b)

Figure AI.1. (a) World inflation rate (consumption prices) and (b) inflation rate by country (2011) Source: www.indexmundi.com

13. Annex II - Global LED market situation

Global LED market situation

LEDs have been in commercial production for nearly 40 years. Since then, the LED global market acknowledged an important cumulated growth that has been accelerated in the last years, even if a regression has been noticed in 2009. Figure 83 shows clearly that the HB-LED industry has the strongest growth compared to other optoelectronics branches. However, the main challenge of the LED industry is similar to that for the semiconductor branch: "short product life-cycle – need for rapid product maturity".

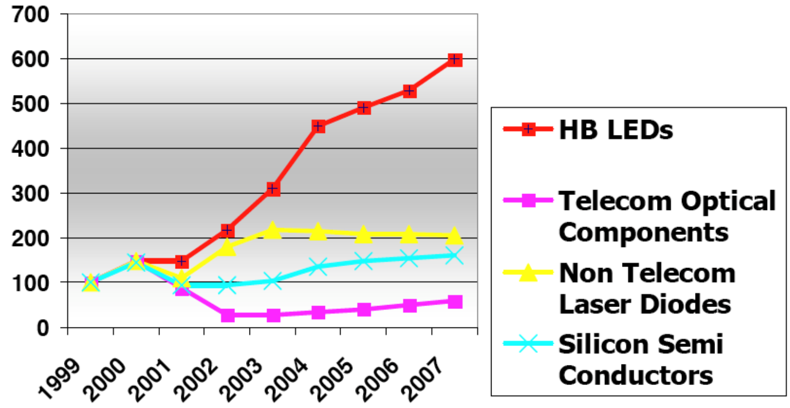


Figure 83 - Relative growth of various optoelectronics industry branches [Le Houedec F., Future Electronics, 2007]

Figure 84 shows the market size (in US$ billions) and the associated growth rate. It should be noticed that High-Brightness LEDs (HB-LEDs) using GaN technology are dominating.

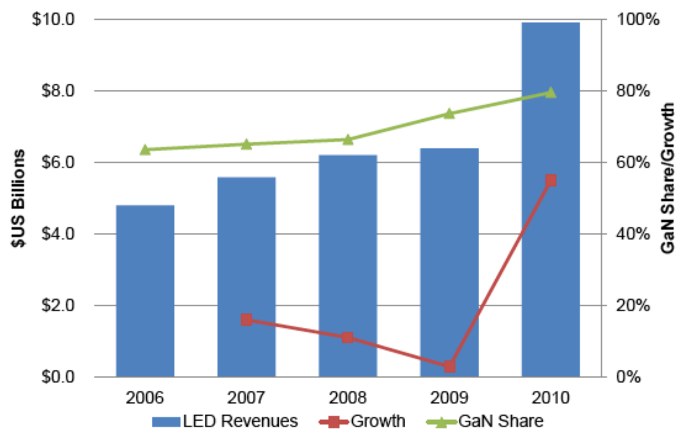


Figure 84 - Global LED market size evolution from 2006 to 2010. The graphics include the growth rate and also the GaN-based LED share [Young R., IMS Research, 2011]

The global LED market leaped from $4.6 billion in 2006 to $9.8 billion in 2010 (revised to $10.8 billion in February 2011) [Business Wire, February 23, 2011][45]), a CAGR of 18.6%. Steele (Strategies Unlimited) predicted in 2007 a CAGR of 20% in the following five years, with a total market size of $11.4 billion in 2012; the market size announced for 2010 confirms Steele's prediction and indicates that the LED industry is emerging from a slow growth phase.

[45] http://www.businesswire.com/news/home/20110223005343/en/2010-Worldwide-High-Brightness-LED-Market-Grew-93

The above-cited figure accounts for both the conventional and High-Brightness (HB) LED market segments. Conventional LEDs are still used in niche applications, as shown in Figure 85, and dominated the market till 2007-08.

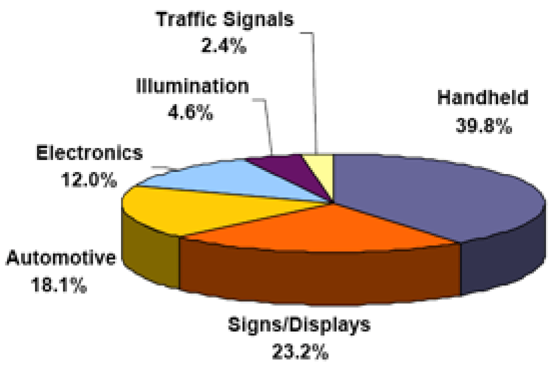


Figure 85 - Conventional LED market segments in 2005 [Erchak A., Luminus Devices, Inc., September 2006]

However, the market share of HB-GaN-based LEDs rose to 67% in 2010 and now accounts for 79% of the LED market. Figure 86 shows the market size and growth rate since 1999.

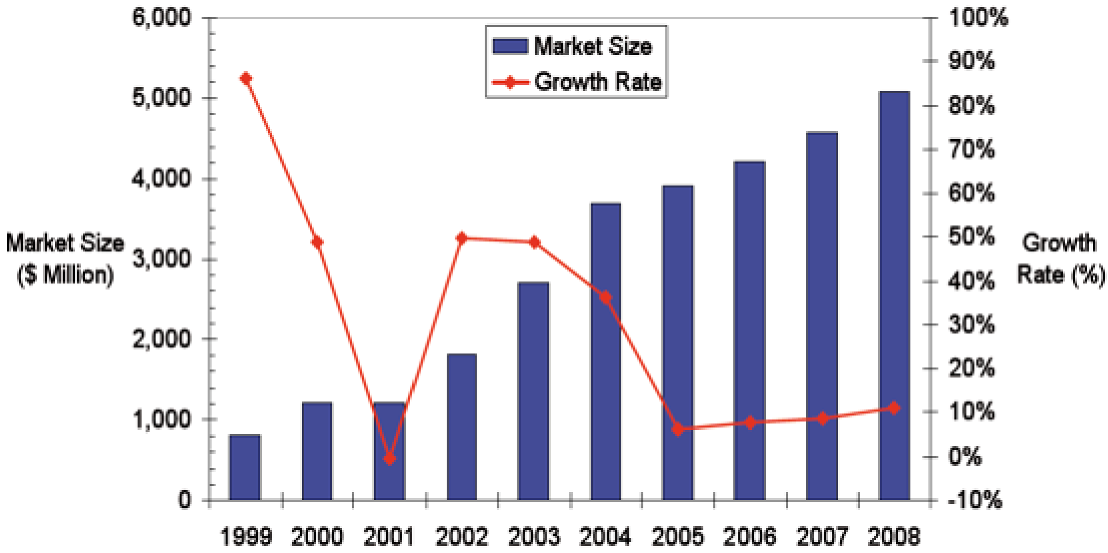


Figure 86 - Global LED market size and growth rate evolutions from 1999 to 2008 [Steele R, Strategies Unlimited, July 2009]

Most of LED sales growth to date has come from High-Brightness (HB) LEDs. Globally, sales of HB LEDs were €7.7 billion in 2010, and are estimated to grow to €13.5 billion in 2015, with a further expected increase to over €35 billion by 2020 (Lighting Research and Development US Department of Energy, 2011).

In 2010, approximately €640 million of the HB-LED revenues, or just 8%, was attributable to lighting applications (lamps) with the remaining 92% representing mobile displays, entertainment, automotive lighting, signs and displays, signals, and other small indicator lighting applications.

LED market by application

Figure 87 shows the "maturity degree" of the HB-LED market segments, based on the S-curve concept for 2008.

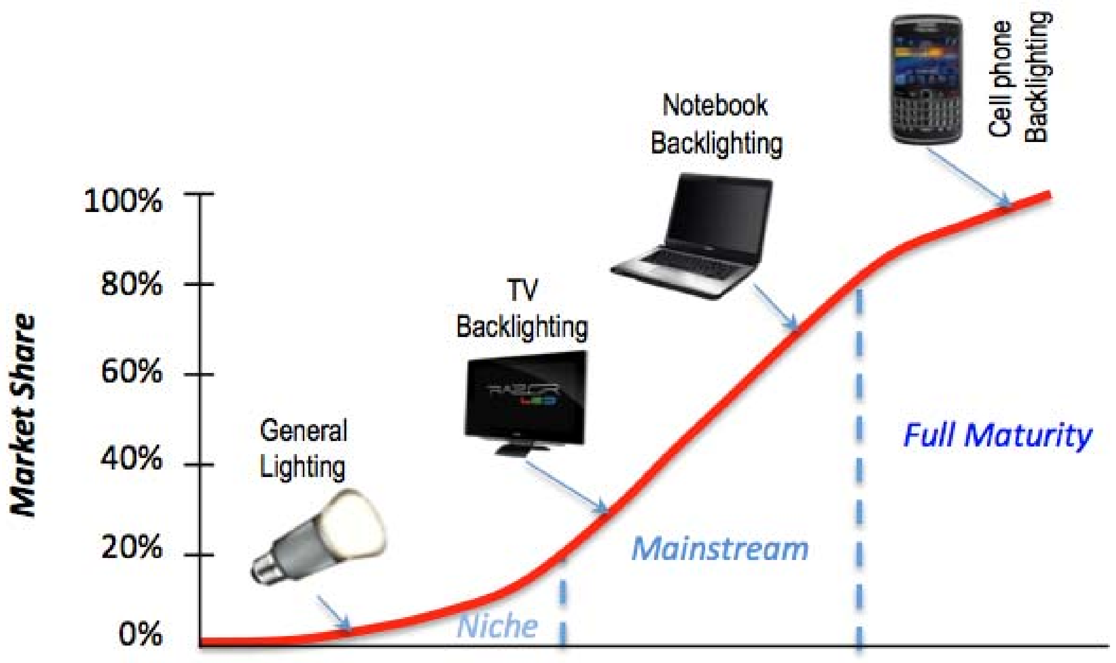


Figure 87 - Maturity degree for the various HB-LED market segments (2008 snapshot) [Yole, Strategies Unlimited, Soitec]

Different maturity levels can directly be correlated with differentiated growth rates. Figure 88 illustrates each market segment growth (CAGR) for the period 2000-09. It can be seen that the lighting segment accounts for the strongest CAGR for this period.

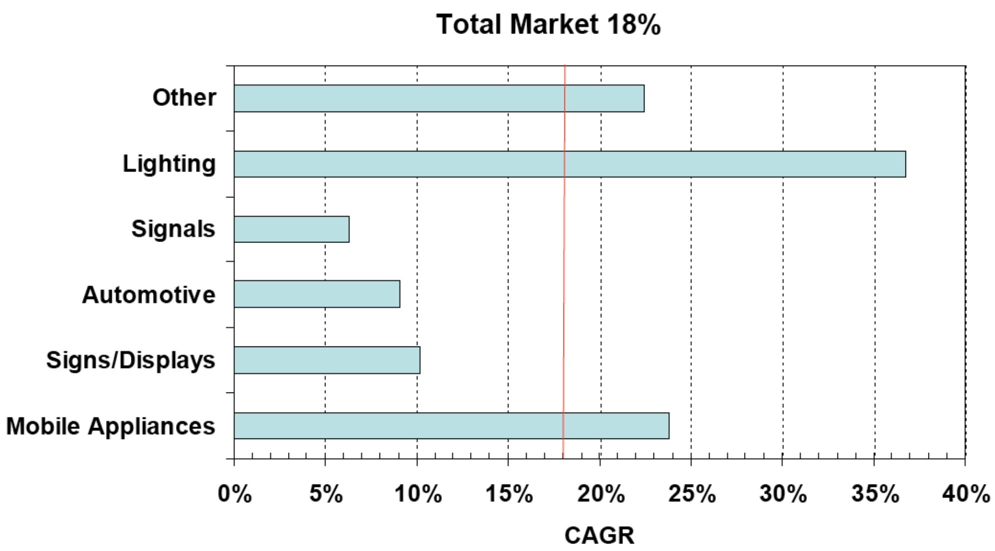


Figure 88 - HB-LED CAGR by segments [Bhandarkar V., Strategies Unlimited, July 2010]

LED & SSL market trends

During the last few years the Chinese Government has deployed an important effort in the direction of the national LED and LED appliance industries. This effort will most probably lead China in the short term (3-5 years) to the first position worldwide. It should be noted here that, according to R. Steele, Japan represented 43% of the revenue share in 2008.

It is expected that the global LED market will grow in the next years and this, regardless of market evolution of specific segments. Strategies Unlimited predicts that in 2013 the global HB-LED market size will be $12.3 billion [Steele R, Strategies Unlimited, ACG SSL Investment Summit, July 2009] when iSuppli predicts that the same year, the global LED market (Regular and HB-LEDs) will reach $14.3 billion. Furthermore the HB-LEDs' share is expected to reach $18.9 billion in 2015 [Business Wire, February 23, 2011][46].

Figure 89 illustrates the forecast for the HB-LED market. It is clear that so far the market will be driven by displays (mainly TV backlight), but lighting is also rapidly growing and will be the dominant application from 2020.

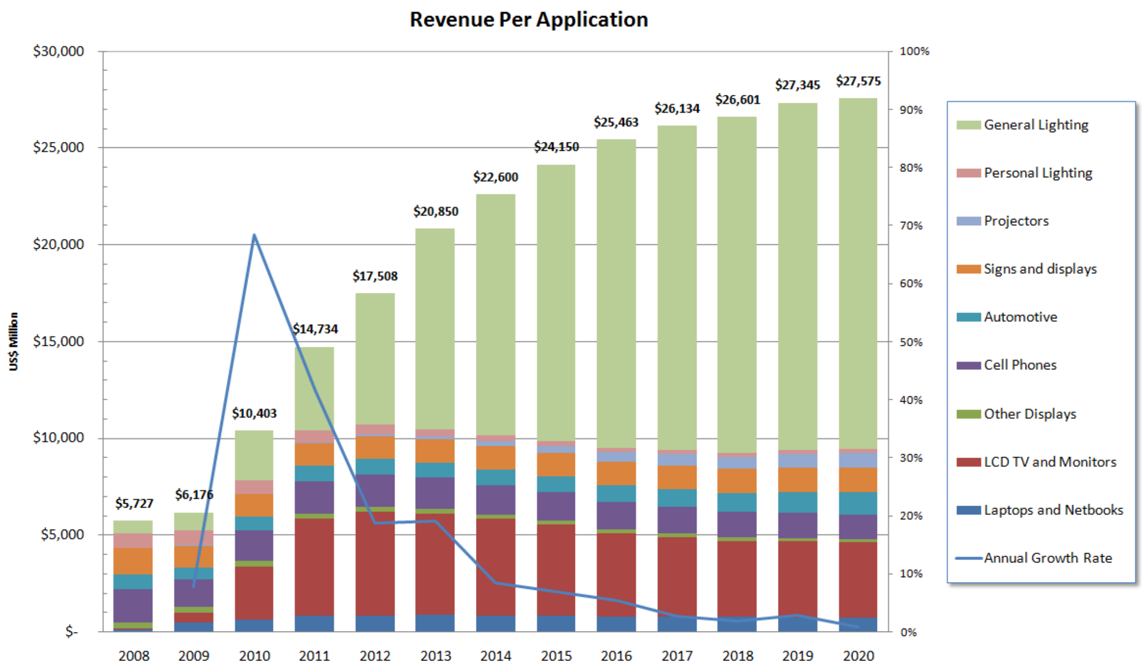
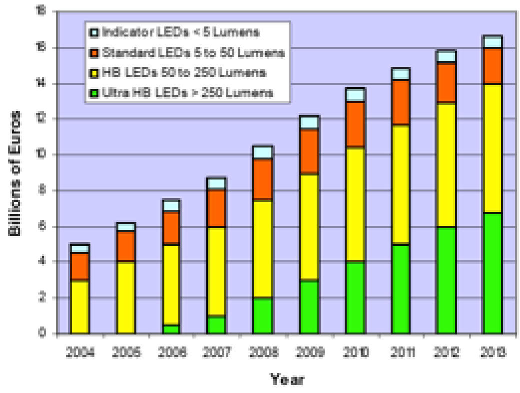


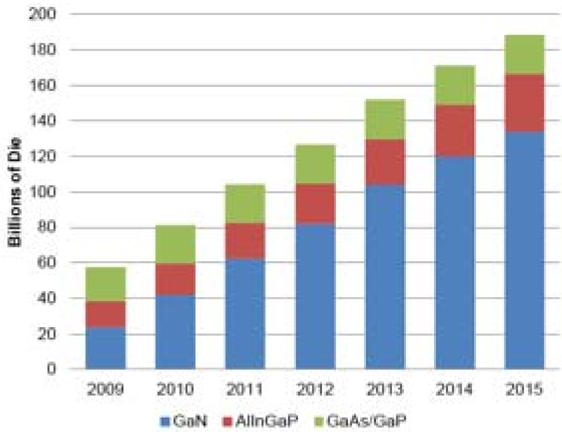
Figure 89 - LED Market in the world [Yole Développement, 2011]
1€=1.4$.

As expected, the solid-state lighting market for HB and high-flux devices will outpace the overall LED market growth through the year 2013. The low-power LED market will decline by about 2.5 %, while the market for HB-LEDs will grow by 6.7% to approximately $5.4 billion. The market for high-flux LEDs grew by almost 53% to reach $7.8 billion [iSuppli, LED Lighting Lights up the 2009 Holiday Season, news release 2009]. The UHB-LED market was only $500 million in 2006, but it is expected to double in size every year, reaching $4.0 billion in 2010 [Pearsall TP, EPIC, SPIE Vol. 6797, 679702-1, 2007].

[46] $19.6 billion following Strategies Unlimited, (June 2010) forecast for 2014.



(a)



(b)

Figure 90 - (a) Global LED technology market shares in revenue [Pearsall TP, EPIC, 2007] (b) HB-LED technology share forecast (in number of units) [Young R., IMS Research, 2011]

Figure 90a shows the predicted growth for the various LED technologies, whereas Figure 90b focuses on HB-LEDs. It is clear that GaN technology will become dominant and this may induce the raw material market stress for gallium.

Looking at the evolution of the HB-LED share, it can be concluded that the market was driven, for the period from 2001-04, by mobile appliances (45% CAGR/year), from 2004-08 the mobile appliance market CAGR slowed down to 8% per year due to ASP decrease and finally from 2008 the CAGR resumed to 18% thanks to automotive, lighting and displays. It is expected that from 2015, lighting will be the main driving force of this market.

14. Annex III - Detailed situation of major players

- **Cree** produces many types of LED products, but the firm's primary focus is on high-power LEDs for the general lighting market. The company is a market leader in LED chips, LED components, LED lighting products, power switching and wireless communications devices. Headquartered in Durham, North Carolina, Cree operates in the United States, Europe, Japan, Malaysia, Hong Kong, and China. In fact, Cree now has over 2100 employees in the United States, 2400 in China and roughly 200 employees in other locations. The company recorded revenues of $567.3 million in the fiscal year ended June 2009, an increase of 15% over 2008. In April 2010, Cree announced record revenue of $234.1 million for its third quarter of the 2010 fiscal year. This is 78% higher than the $131.1 million, reported in 2009 (Figure 91).

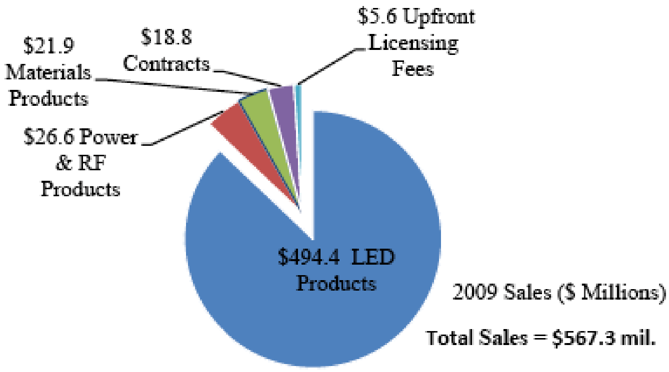


Figure 91 - Cree's global product sales, 2009 [Cree Inc., 2009a]

Asia accounts for about 66% of Cree's sales, the United States 20%, Europe 10% and other parts of the world 2%. China is Cree's fastest growing and largest market, accounting for almost 40% of its global sales (Figure 92). Cree launched a strategic alliance with Zumtobel in 2009 to introduce technology to the European market. Cree sells only at systems level in the US – its core market – and is moving into Europe through this cooperation agreement.

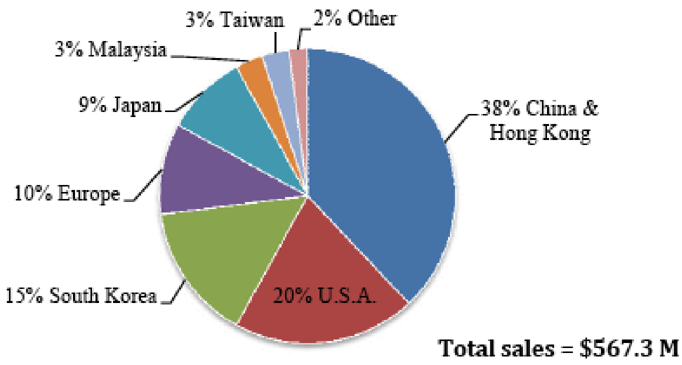


Figure 92 - Cree's global sales % by region/country, 2009 [Cree Inc., 2009a]

- Having failed to secure a buyer for its lighting business over the past years, **GE** took the decision last year to keep it. In 2009, only 6% of sales could be attributed to LEDs. LED retrofit lamps have been launched also in 2009. Management of GE is now looking to benefit from the growth opportunities offered by the LED market, as highlighted in an interview with the European Head of GE Lighting in the Handelsblatt (1st March 2010). Whilst highlighting the growth opportunities, GE stated that it expects more competitors to enter the LED market, including semiconductor and consumer electronics suppliers out of Japan, Korea, Taiwan and China. The company is currently looking for cooperation partners. There is an existing strategic cooperation with Nichia. GE dedicated 4% of sales invested in R&D and over 50% (~US$50 million) being invested in LEDs and OLEDs.

- **Nichia** is number one player in LED chip production. Founded in 1956, privately held Japan-based Nichia (5 100 employees, 2007 sales of $2.3 billion) has grown in the field of manufacturing and sales of fine chemicals, particularly inorganic luminescent materials (phosphors). The company succeeded in developing and commercialising the super high-brightness gallium nitride blue LED in 1993. Since then, nitride-based LEDs in different colours, ranging from ultraviolet to yellow, have been contributing to the diversification of LED application fields. Today, as shown Figure 93, the company's revenue is in majority coming from LEDs, rather than from phosphors.

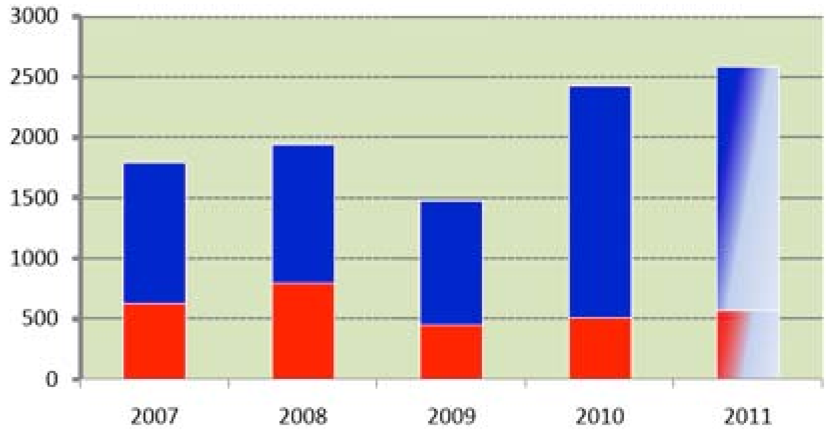
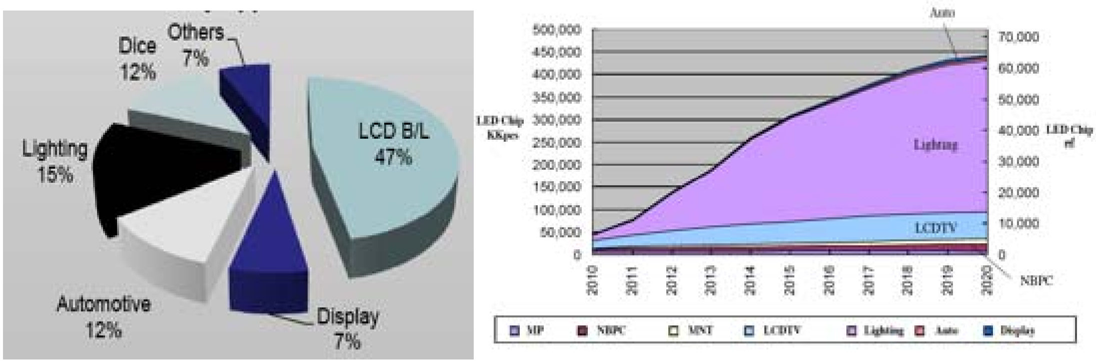


Figure 93 - Nichia's revenues from LED (blue bar) and phosphors (red bar) [Nichia Corporate presentation 2010]

In addition to LEDs, a lot of resources are now being focused on the development of bluish-purple laser diodes, which will play a key role for the further expansion of the information media industry. Management believes that nitride-based semiconductors will become one of the most exciting areas of the semiconductor industry in the near future. The company remains majority owned by the founding Ogawa family. Nichia continues to aggressively protect its intellectual property rights in LEDs and over the past years has filed lawsuits against Shenzhen Jiawei in China, Everlight in Taiwan and Seoul Semiconductors in South Korea, which resulted in a cross-licensing agreement. Figure II.18a shows the split of the company's sale revenue for LEDs; the lighting applications represent a share of 15% in 2011, but as shown in figure II.18b, this share is expected to grow rapidly and exceed 75% from 2015.



(a) **(b)**

Figure 94 - (a) Nichia's LED sales revenue by market segment and (b) evolution forecast [Nichia Corporate presentation 2010]

However, the main market for Nichia is Japan (46%). Europe (including Russia) represents a small revenue share that shrank from 7% of the global overseas revenue in 2010 to 5% in 2011.

- **Osram**, a 100% owned subsidiary of Siemens, is the number two lighting supplier behind Philips. In 2010, Osram's SSL sales accounted for 17-18% of the overall company income [Goetzeler M., CEO Osram Division, Capital Market Days-Industry, Munich, March 26, 2010]. Concerning products in catalogues, in 2011, 30% of the company's portfolio is directly linked to LEDs [RLC, May 2011]. Osram Opto semiconductor branch has been established in 1999 and in September 2009 had a turnover of $800 million and 4600 employees worldwide. Following Strategies Unlimited, and as shown in Figure 95, Osram Opto is established as market leader for Europe and a strong number 2 worldwide. Around 50% of Osram's R&D budget (6% of sales) is spent on LED technology.

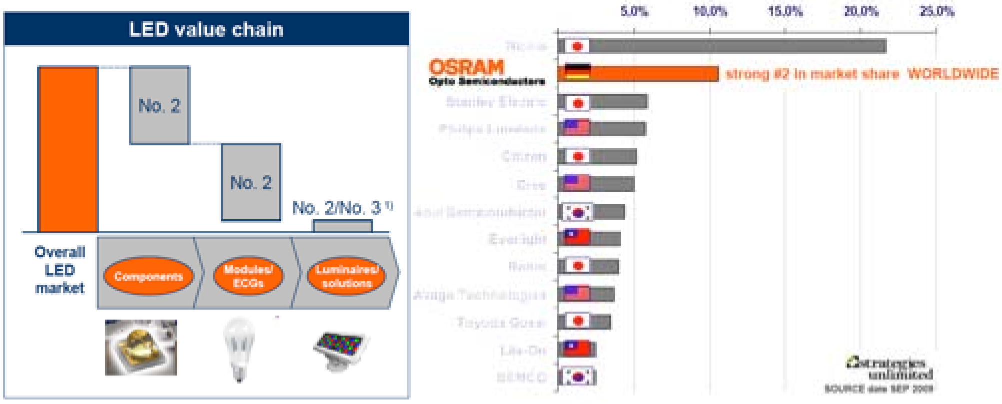


Figure 95 - Position of Osram-SO in the world market of HB-LEDs (across the full value chain)

In mid 2009, Osram inaugurated a 35 000 m² facility in Penang, Malaysia, to manufacture 4-inch-wafer-based indium gallium nitride semiconductor chips. These chips form the basis for the blue, green and white LEDs, primarily used in architecture and general lighting, for display backlighting and in mobile terminal devices. At the moment, management remains sceptical about the mid-term margin opportunities in luminaires, given the risk of commoditisation. The company is also aware that increased Asian competition will push down margins on the semiconductor chip side over the medium term. Furthermore, Siemens is sitting on the fence. Having decided not to integrate Osram into Building Technologies, the company is trying to find the sweet spot in the new lighting market before committing to large strategic moves, such as the sale of the business or the entry into the luminaire market.

- **Philips** and Agilent founded **Lumileds** as a joint venture in 1999 and Philips bought out its partner's share in 2005. This marked the beginning of a €4 billion acquisition spree in lighting, focused mainly on LED downstream applications. Philips is pushing into applications. Having acquired numerous companies in the application/fixtures field, Philips has more flexibility on the upstream supply of light sources, given a) the ongoing fragmentation of this market and b) the attractive multiples of the peer group. Philips continually states the need to retain access to both technology and supply of LEDs. For Philips Lighting, the branch, Lumileds, represented in 2005 just 5% of the global lighting sector of the company, but with 24% of CAGR was responsible for 1% additional growth of all Philips Lighting. Figure 96 illustrates the Philips evolution of LED market shares for business and domestic sectors (document established in 2006 that estimates three times the LED component market, as stated by Strategies Unlimited).

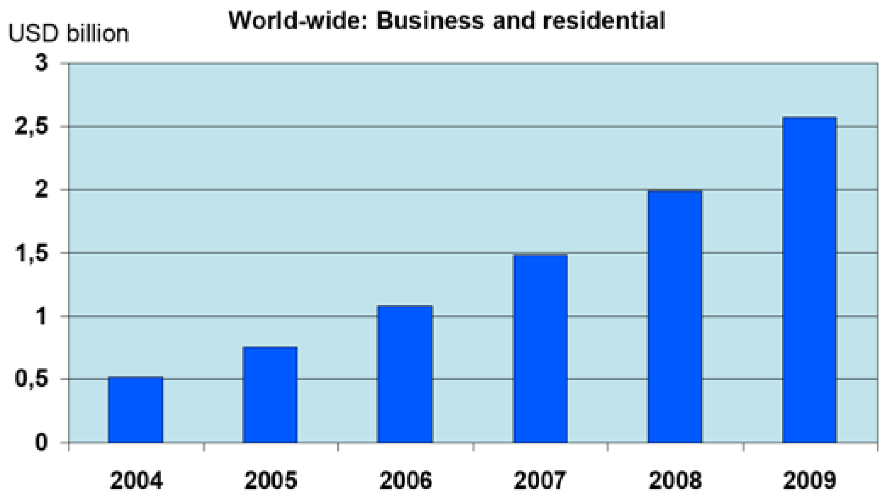


Figure 96 - Philips evolution of LED market shares for business and domestic sectors [Philips Lighting, 2006]

- Out of the ~€520 million in LED-based lighting sales in 2009, 45% was represented by packaged LEDs (Lumileds) and 55% by lamps and luminaires. In June 2011, packaged LEDs represented 6% of the global sales. The launch of a full range of retrofit LED light bulbs in 2009 enabled the company to benefit from growth in the residential market. However, with a 60 W incandescent equivalent bulb (winner of US L prize in 2011) still retailing for around €50-60, this market will be slow to pick up.
- **Seoul Semiconductor** is clearly growth-driven. Founded in 1987, Seoul Semiconductor has generated annual sales growth of 18%/year since 2002 and aims to become one of the top three LED manufacturers. For 2008, IMS Research ranked the company fourth behind Nichia, Osram and Lumileds. 2009 sales reached $357 million (2010 consensus forecast: US$620m). The main end market driver at present is TV backlighting. Strategic partnerships with Cree – white LED license and long term chip supply agreement; Toyoda Gosei – strategic business cooperation; Osram – white LED and visible housing patent and white LED cross license agreement; Nichia – cross-licence agreement.
- As a Toyota group auto parts supplier (42% owned by Toyota), **Toyoda Gosei** started developing gallium-nitride (GaN) LEDs in 1986, working with Nagoya University and Toyota Central R&D Labs. Utilising its macromolecule technologies, accumulated in the area of automobiles, the company developed blue LEDs (1991), green LEDs, purple LEDs and white LEDs (named "TG White Hi"), which offer a high level of brightness. In December 2009, Toyoda Gosei entered into a cross-licensing agreement with Sharp for nitride-based LEDs. A cross-licensing agreement was signed with Osram in 2007 to get access to its broad patent portfolio, covering technologies for industrial production of LEDs and laser-based on indium gallium nitride. Toyoda Gosei in turn provided access to a number of patents for blue LEDs.
- The **Zumtobel** Group is one of the few global players in the lighting industry. The group is positioned in Lighting Segment as European market leader in professional lighting. At the end of January 2010, Zumtobel announced that it is entering the LED-lamp business with the founding of LEDON Lamp GmbH. The product range will focus on "retrofit" lamps, LED lamps designed to look like and replace all conventional incandescent light bulbs (e.g. with E14 or E27 screw caps). Sales of these high-tech LED lamps will be through retail outlets (e.g. DIY stores) and sales partners across Europe. Given rising R&D costs, Zumtobel (which has spent €100m on LED applications since 2001) expect the European market to consolidate. The Zumtobel Group targets to gain market share, mainly from "Mittelstand" competitors and driven by strong growth rates in LED and services businesses. Figure 97 shows Zumtobel's sales revenue breakdown evolution for the next years, compared to 2008-09 period.

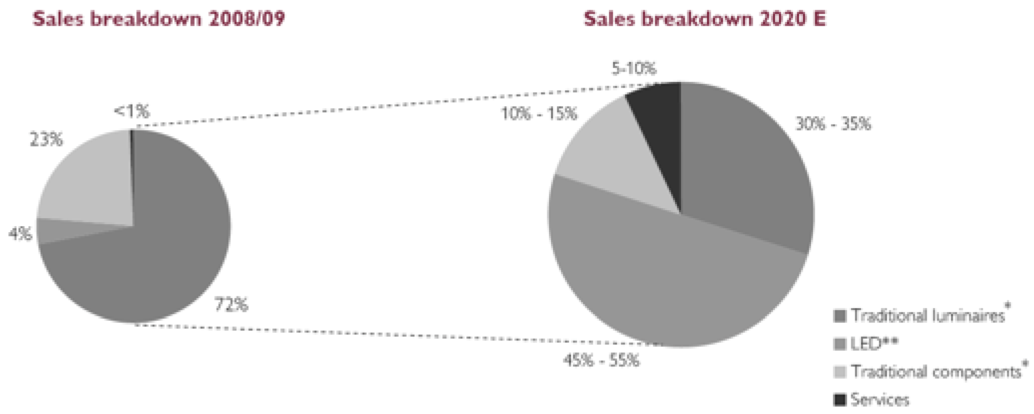


Figure 97 - Zumtobel's sales revenue breakdown evolution (*without LEDs, ** LED revenues with luminaires and components) [Ludwig A., Zumtobel, Capital Markets Day 2010]

In May 2009, Zumtobel and Philips signed an extensive worldwide cross-licensing agreement covering, in particular, driver and control technologies for changing intensity and colour of conventional and solid-state lighting systems. As a result of this agreement, Zumtobel has become a qualified supplier under the Philips LED-based luminaires licensing programme and customers of Zumtobel's OEM brands will be exempted from paying royalties to Philips.

15. Annex IV – REE production and availability

Further to the section on the availability of Rare Earth Elements (REE), this Annex covers the REE production and supply, as well as strategies to improve their availability.

REE Production and Supply

Despite their name, rare earth metals are relatively abundant in the earth's crust, but generally in concentrations too small to make mining economical (Figure 98). Therefore, the global supply relies on a small number of sources, found in concentrated deposits in order to make their mining economically viable. Table 9 shows the World REE oxide Production and Reserves in 2010, in which it can be seen that although China has half of the world's reserves, it totally dominates production.

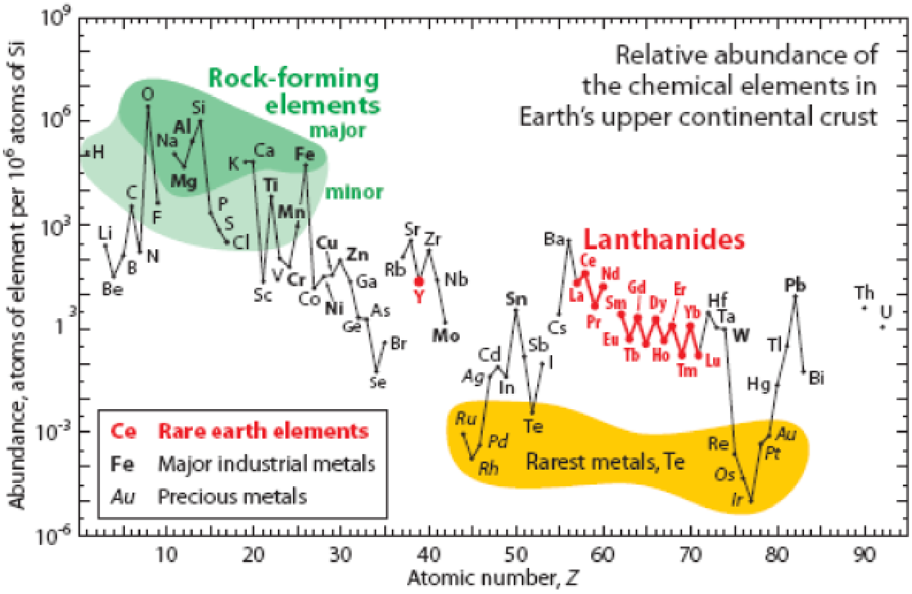


Figure 98 - Abundance of Elements in the Earth's Crust, showing the relative abundance of REE [Hard Assets Investor, 2011]

Concentrations in the lower single-digit percentages can be considered attractive, but they are nonetheless expensive to mine. Additionally, environmental impacts concerning mining activities, may pose limitations to mining those materials. In the past 30 years, the mining of these elements has increasingly been centred in China, because of lax environmental regulations and low costs of extraction that exist in that country (Robarge, 2011).

Table 9 - World REE oxide Production and Reserves – 2010 (Tonnes).

Country	Mine production (t)	Reserves (kt)
China	130,000	55,000
India	2,700	3,100
Brazil	550	48
Malaysia	350	30
Commonwealth of Independent States	n/a	19,000
United States	—	13,000
Australia	—	1,600
Other countries	n/a	22,000
World total (rounded)	130,000	110,000

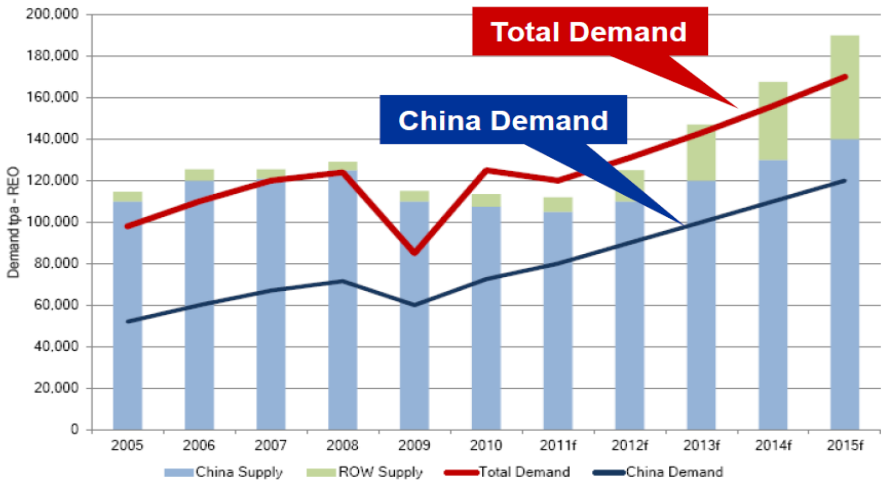


Figure 99 - Global Rare Earths Supply & Demand 2005-2015 (tonnes) [Spencer, et al., 2011]

China also has the lion's share of consumption, with apparently decreasing scope for exports (Figure 99). The EU, as can be seen in Figure 100, has strong dependence on imported REE. Currently the worldwide demand for rare-earth oxides is approximately 130 000 tons per year. China, the predominant supplier of these oxides, produces around 97% of this amount (Osram, 2011).

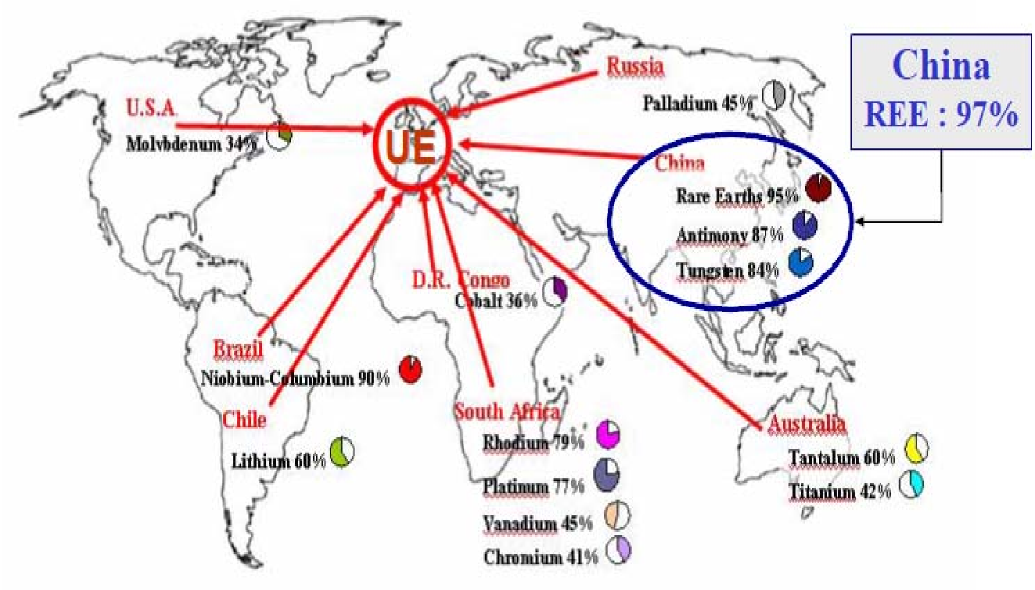


Figure 100 - EU imports dependency [Hocquard, 2010]

The Chinese Government has implemented new tariffs and mining regulations, which have restricted the trade in REE. The high demand and the expected supply shortages, additionally triggered by Chinese export restrictions, lead to a significant increase in rare-earth prices. In less than 12 months, costs of some rare-earth oxide materials, used in lighting products, have experienced increases ranging from 500 percent to more than 2000 percent, and they continue to climb, as shown in Figure 101 (GE Lighting, 2011).

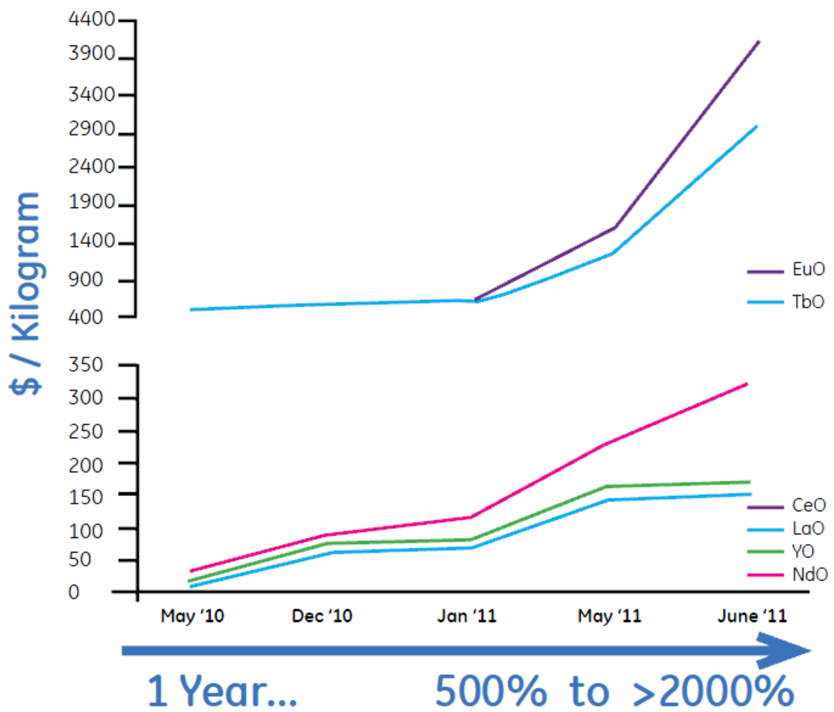


Figure 101 - Rare Earth Oxide Costs [GE Lighting, 2011]

STRATEGIES TO IMPROVE REE AVAILABILITY

A number of actions are underway to help to balance out this situation. The European Union, along with other governments, is working with China to ensure fair trade and cost levels. In conjunction with this strategy, more rare-earth mines are being re-opened and new mines being set up all over the world to ensure that the limited stocks are not solely exported from China. The present shortfall has also meant some stockpiling taking place. Although initial steps have been taken to help control the existing situation, it could take years to rectify with the long timescale of opening new mines, as well as the costs of the available materials being currently so volatile.

Other initiatives, currently being implemented, include the ability to recycle rare -earth metals as a more feasible and accessible option, to ensure that we reuse the materials already mined, rather than relying solely on raw materials (Industry News, 2011). Until now, there has been almost no recycling of rare earths. Only a few industrial recycling activities are currently implemented for rare earths, mainly because these processes are still quite complex and expensive, if direct re-use is not possible, and a physical and chemical treatment is necessary. Most of the recycling procedures are energy-intensive processes. The new higher prices might be a starting point to stimulate building up recycling systems for rare earth compounds (Schüler, et al., 2011).

Currently, there is an effort to conduct research and development in order to find substitutes for the rare-earth elements, but this is a difficult task due in part to their unique electronic structure and the unique properties of the 4f electron orbitals (K.A. Gschneidner, 2011).

16. Annex V – Glossary

- **AlGaAs -** One of the material systems for manufacturing LEDs that produce light in the red and amber portions of the visible light spectrum.
- **AllnGaP -** The preferred LED (Light Emitting Diode) chip technology containing aluminium, indium, gallium, and phosphorous to produce red, orange and amber-colours.
- **Ambient Operating Temperature -** The temperature environment in which the fixture will be operated. All life measurements reported by the LED device manufacturers are performed over a range of ambient temperatures. For a given luminaire, higher ambient temperatures will result in a shorter operating life; lower temperatures will allow the LED to operate even longer than anticipated.
- **Ambient Temperature (Ta) -** The air temperature surrounding the device.
- **Ballast -** A device that provides the circuit conditions necessary to start and operate electric discharge (fluorescent and high-intensity discharge) lamps.
- **Bin -** A restricted range of LED performance characteristics used to delimit a subset of LEDs near a normal LED performance.
- **Black Body / Black Body Radiator -** An object that absorbs all electromagnetic radiation falling on it. Because it reflects no light, a black body appears black. As a black body is heated to incandescence, it radiates light in a sequence of colours, from red to orange to yellow to white to blue, depending on its temperature. This colour sequence describes a curve within a colour space, known as the black-body curve.
- **Black Body Curve -** A curve within a colour space describing the sequence of colours emitted by a black-body radiator at different temperatures.
- **Candela (cd) -** The SI unit of luminous intensity. The term, retained from the early days of lighting, defines a standard candle of a fixed size and composition as a basis for evaluating the intensity of other light sources.
- **Chromaticity -** An objective specification of the quality of a colour, independent of its luminance, and as determined by its or saturation and hue.
- **CIE 1931 Colour Space -** A colour space created by the International Commission on Illumination (CIE) in 1931 to define the entire gamut of colours visible to the average viewer.
- **CIE Chromaticity Diagram -** A horseshoe-shaped line connecting the chromaticities of the spectrum of colours.

- **Colour Rendering -** A general expression for the effect of a light source on the colour appearance of objects.
- **Colour Rendering Index (CRI) -** A measure of how a light source renders colours of objects, compared to a "perfect" reference light source. CRI is given as a number from 0 to 100, with 100 being equivalent to the reference source.
- **Compact fluorescent lamp (CFL) -** A fluorescent lamp with bent tubes to reduce the size of the lamp. A CFL is constructed either with an integrated ballast, in which case it is designed to be directly interchangeable with a general lighting service lamp, or in a modular form where the ballast is supplied independently of the fluorescent tube.
- **Conduction -** Transfer of heat through matter by communication of kinetic energy from particle to particle. An example is the use of a conductive metal such as copper to transfer heat.
- **Convection -** Heat transfer through the circulatory motion in a fluid (liquid or gas) at a non-uniform temperature. Liquid or gas surrounding a heat source provides cooling by convection, such as air flow over a car radiator.
- **Correlated Colour Temperature (CCT) -** Correlated colour temperature; a measure of the colour appearance of a white light source. CCT is measured on the Kelvin absolute-temperature scale. White-lighting products are most commonly available from 2700K (warm white) to 5000K (cool white).
- **Die -** Chip: light emitting semiconductor.
- **Directional Light Source -** A light source that emits light only in the direction it is pointed or oriented.
- **Encapsulation -** A barrier structure on the OLED stack to protect the OLED device from moisture and oxygen.
- **Epoxy -** Organic polymer frequently used for a dome or lens, often prone to optical decay over time, resulting in poor lumen maintenance.
- **General lighting service (GLS) lamp -** Always used to refer to a standard incandescent light-bulb.
- **Glare -** The discomfort or sensation produced by luminance within the visual field that is significantly greater than the luminance to which the eyes are adapted.
- **Goniophotometer -** An apparatus for measuring the directional-light distribution characteristics of light sources, luminaires, media, and surfaces. Goniophotometry can be used to obtain total luminaire flux (lumens) and efficacy (lumens/watt), but not the colour metrics (chromaticity, CCT, and CRI).

- **Halogen lamp -** A class of incandescent lamps containing a halogen gas that recycles tungsten (which would normally be deposited onto the bulb wall during lamp operation) back onto the filament surface.
- **Heat sink -** Thermally-conductive material attached to the printed circuit board on which the LED is mounted, in order to cool it through conduction.
- **High-intensity discharge (HID) lamp -** An electric discharge lamp in which the light-producing arc is stabilised by wall temperature and the arc tube has a bulb-wall loading in excess of 3 W per square centimetre. HID lamps include mercury vapour, metal halide and high-pressure sodium light sources.
- **High-pressure sodium lamp -** A type of high-intensity discharge lamp that contains pressurised sodium vapour.
- **Illuminance -** The amount of light (strictly, the luminous flux) incident on a surface/plane per unit area; measured in units of lux (lm/m^2).
- **Incandescence -** The emission of light through being heated, i.e. glowing.
- **InGaN -** The preferred LED (Light Emitting Diode) semiconductor material system containing indium, gallium and nitrogen to produce green-, blue- and white-coloured LED light sources.
- **Integrating Sphere -** A device used for a variety of optical, photometric, or radiometric measurements.
- **Junction temperature (T_j) -** Temperature within the LED. Direct measurement of T_j is impractical, but can be calculated based on a known case or board temperature and the materials' thermal resistance.
- **Kelvin Temperature -** Term and symbol (K) used to indicate the comparative colour appearance of a light source when compared to a theoretical black body. Yellowish incandescent lamps are 3000K. Fluorescent light sources range from 3000K to 7500K and higher.
- **Lamp or light source -** A generic term for a device created to produce optical radiation.
- **LED -** Light-emitting diode; a semiconductor device that emits light, be it ultraviolet, visible, or infrared.
- **LED Array or Module -** An assembly of LED packages and electrical interfaces that are intended to connect to the load side of a driver.
- **LED Die -** A small block of light-emitting semiconducting material on which a functional LED circuit is fabricated.
- **LED Driver -** A device comprising of a power source and LED control circuitry designed to operate a LED package, array, or lamp.

- **LED Lamp -** An assembly comprised of a LED array or LED packages and an ANSI standard base (non-integrated and integrated).
- **LED Light Engine -** An integrated assembly comprised of LED packages or arrays, LED driver, and other optical thermal, mechanical and electrical components. The device is intended to connect through custom connector.
- **LED Luminaire -** A complete lighting unit consisting of LED-based light emitting elements and a matched driver, together with parts to distribute light, to position and protect the lighting elements, and to connect the unit to branch circuit.
- **LED Package -** An assembly of one or more LED dies that includes wire bond.
- **Life performance curve -** A curve that presents the variation of a particular characteristic of a light source (such as luminous flux, intensity, etc.) throughout the life of the source. Also called lumen maintenance curve.
- **Light -** Radiant energy that is capable of exciting the retina and producing a visual sensation. The visible portion of the electromagnetic spectrum extends from about 380 nm to 770 nm.
- **Lumen -** The SI unit of luminous flux. The total amount of light emitted by a light source, without regard to directionality, is given in lumens.
- **Lumen depreciation -** The decrease in lumen output that occurs as a lamp is operated.
- **Lumen Maintenance -** The percentage of initial light output produced by a light source at some percentage of rated useful life (usually 100% for LED and 40% for source types characterized by sudden failure).
- **Luminaire -** A complete lighting unit consisting of a lamp or lamps and ballast(s) (when applicable) together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply.
- **Luminaire Design -** Luminaire design has a significant effect on LED operating life. In fact, two luminaires may show radically different operating lives in the same ambient, due to how well they are designed and how efficiently they remove heat from the LED.
- **Luminaire efficacy -** Total lumens provided by the luminaire divided by the total wattage drawn by the power supply/driver, expressed in lumens per watt (lm/W).
- **Luminous efficacy -** The total luminous flux emitted by the light source divided by the lamp wattage; expressed in lumens per watt (lm/W).
- **Lux (lx) -** The SI unit of illuminance; one lux is one lumen per square metre (lm/m^2).
- **MacAdam colour ellipse -** An elliptical region of chromaticity coordinates that is defined using a centroid, a tilt angle relative to a horizontal axis, and a defined level of variance. Such

a region defines what chromaticity coordinates can be acceptably associated with a target Correlated Colour Temperature.

- **Mercury vapour lamp -** a type of high-intensity discharge lamp that contains mercury vapour.
- **Metal halide lamp -** a type of high-intensity discharge mercury vapour lamp that contains metal halides.
- **Monochromatic -** for light, consisting of a single wavelength and having a very saturated colour.
- **OLED -** Organic Light Emitting Diode; semiconductor device for the generation of light containing organic semiconductor materials. Most common building blocks of an OLED device are the OLED stack which is embedded between the substrate and the encapsulation, and optionally optical out coupling structures.
- **OLED stack -** Core element of an OLED to generate light. It is a multi-layer structure with significant lateral dimensions where each layer has a special functionality. The two sandwiching layers at top and bottom are electrodes which need to be connected to an electrical power supply. At least one of the electrodes has to be transparent to enable light extraction to air.
- **Phosphor -** A coating of phosphorescent material which photons from a royal blue LED pass through causing those photons to exit with a different colour property.
- **Phosphor Conversion -** This is the process by which photons from a LED chip are converted to a different colour. White LEDs and some coloured LEDs are made using phosphor conversion.
- **Photometry -** The measurement of quantities associated with light, including luminance, luminous intensity, luminous flux, and illuminance**.**
- **Planckian Black Body Locus -** The line on the CIE Chromaticity Diagram that describes the colour temperature of an object when heated from approximately 1000K to more than 10,000K.
- **PN junction -** Area on a LED chip where the positively and negatively charged regions meet. When current is applied, the electrons move across the n region into the p region. The process of an electron moving through the p-n junction releases energy. The dispersion of this energy produces photons with visible wavelengths. In short, the area on a chip where light is produced.
- **Quality of light -** Pertains to the distribution of luminance in a visual environment. The term is used in a positive sense and implies that all luminances contribute favourably to visual

performance, visual comfort, ease of seeing, safety and aesthetics for the specific visual tasks involved.

- **Radiation -** Energy transmitted through electromagnetic waves. Examples: heat radiated by the sun and by incandescent lamps.
- **Rated lamp life -** The life value assigned to a particular type of lamp. This is commonly a statistically determined estimate of average or median operational life. For certain lamp types, other criteria than failure to light, can be used; for example, the life can be based on the average time until the lamp type produces a given fraction of initial luminous flux.
- **Restriction of Hazardous Substance (RoHS) -** Directive 2002/95/EC restricts the use of hazardous materials found in electrical and electronic products from 1 July, 2006. RoHS focuses initially on six substances (Lead (Pb); Mercury (Hg); Cadmium (Cd); Hexavalent Chromium (Cr VI); Polybrominated Biphenyls (PBB); Polybrominated Diphenyl Ether [PBDE]) found in many electrical and electronic products.
- **RGB White -** A method of producing white light by combining the output from red, green, and blue LEDs.
- **Semiconductor -** A material whose electrical conductivity is between that of a conductor and an insulator; the conductivity of most semiconductors is temperature dependent.
- **Source efficacy -** The luminous flux emitted by a light source divided by the nominal light source wattage (not including driver); expressed in lumens per watt (lm/W).
- **Spectral power distribution -** A representation of the radiant power emitted by a light source as a function of a wavelength.
- **Spectroradiometer -** An instrument for measuring radiant flux (visible and non-visible) as a function of wavelength. Visible radiation measurements can be converted into luminous intensity (candela) and flux (lumens).
- **SSL -** Solid-state lighting; umbrella term for semiconductors used to convert electricity into light.
- **Steradian -** The SI unit of solid angle, equal to the angle at the centre of a sphere subtended by a part of the surface equal in area to the square of the radius.
- **Substrate -** For light emitting diodes, the material on which the devices are constructed.
- **Target D_{uv} -** For a source's measured chromaticity coordinates (as plotted on the CIE 1976 (u', v') diagram), the maximum allowable distance from the Planckian (blackbody) locus. This distance is specified for each nominal CCT defined in ANSI C78.377-2008, and relates to the relative "whiteness" of a light source's appearance.

- **Thermal management -** Controlling the operating temperature of the product through design, examples includes heat sinks and improved airflow.
- **Warm White -** The unit of electrical power as used by an electrical device during its operation. Many lamps come with rating in watts to indicate their power consumption.
- **Waste Electrical & Electronic Equipment (WEEE**) **-** Directive 2002/96/EC which mandates the treatment, recovery and recycling of electric and electronic equipment. All applicable products in the EU market after 13 August 2006 must pass WEEE compliance and carry the underlined Wheelie Bin symbol.

Sources: Mor, 2010; Grabowski, 2009; Comparing White Light LEDs to Conventional Light Sources, 2008; US Department of Energy, 2009; Ruud Lighting, Inc. (BetaLED), 2010; IEA, 2006; Philips Lumileds, 2011; LED Group, 2011.

17. Annex VI - List of Abbreviations

ANSI: American National Standards Institute
ASP: Average Sale Price
CAGR: Compound Annual Growth Rate
CFL: Compact Fluorescent Lamp
CIE: International Commission on Illumination
DoE: Department of Energy
EEAP: Energy Efficiency Action Plan 2007-2012
EU: European Union
FCC: Federal Communications Commission
FE: Front-End
FP7: 7th Framework Programme
FL: Linear Fluorescent Tube
GDP: Gross Domestic Product
GE: General Electric
HB LED and UHB LED: High-Brightness and Ultra-High-Brightness Light Emitting Diode
IESNA: Illuminating Engineering Society of North America
IEC: International Electrotechnics Committee
INR: Indian Rupee
IP: Intellectual Property
JPY: Japanese Yen
KET: Key Enabling Technology
LCD TV: Liquid Cristal Display TV set
LED: Light Emitting Diode
MYPP: Multi-Year Programme Plan
MOA: Market Opportunity Analysis
MOCVD: Metal Organic Chemical Vapour Deposition
MYPP: Multi-Year Programme Plan
NEMA: National Electrical Manufacturers Association
NFPA: National Fire Protection Association
OEM: Original Equipment Manufacturing
PIDA: Taiwan's Photonics Industry Technology & Development Association.
PC: Personal Computer
QE: Quantum Efficiency
R&D: Research and Development
RMB: Chinese Renminbi
ROW: Rest of the World
SEK: Swedish Crown
SME: Small-Medium Enterprise
SSL: Solid State Lighting
TWN: Taiwan
UL: Underwriters Laboratories, Inc.
YAG: Yttrium Aluminium Garret

Currency rates used (July 2011 values)

1 JPY = 0.009 €
1 US$ = 0.688 €
1 RMB = 0.106 €
1 SEK = 0.11 €
1 INR = 0.016 €

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Abstract: Solid State Lighting is a promising technology with high growth potential in Europe. This document presents the SSL technology and European market. It then focuses on the strengths and weaknesses of the European market for SSL. It explores the potential of SSL for energy efficiency and also better lighting and addresses the obstacles to its development and ways to overcome these obstacles, including innovation.

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