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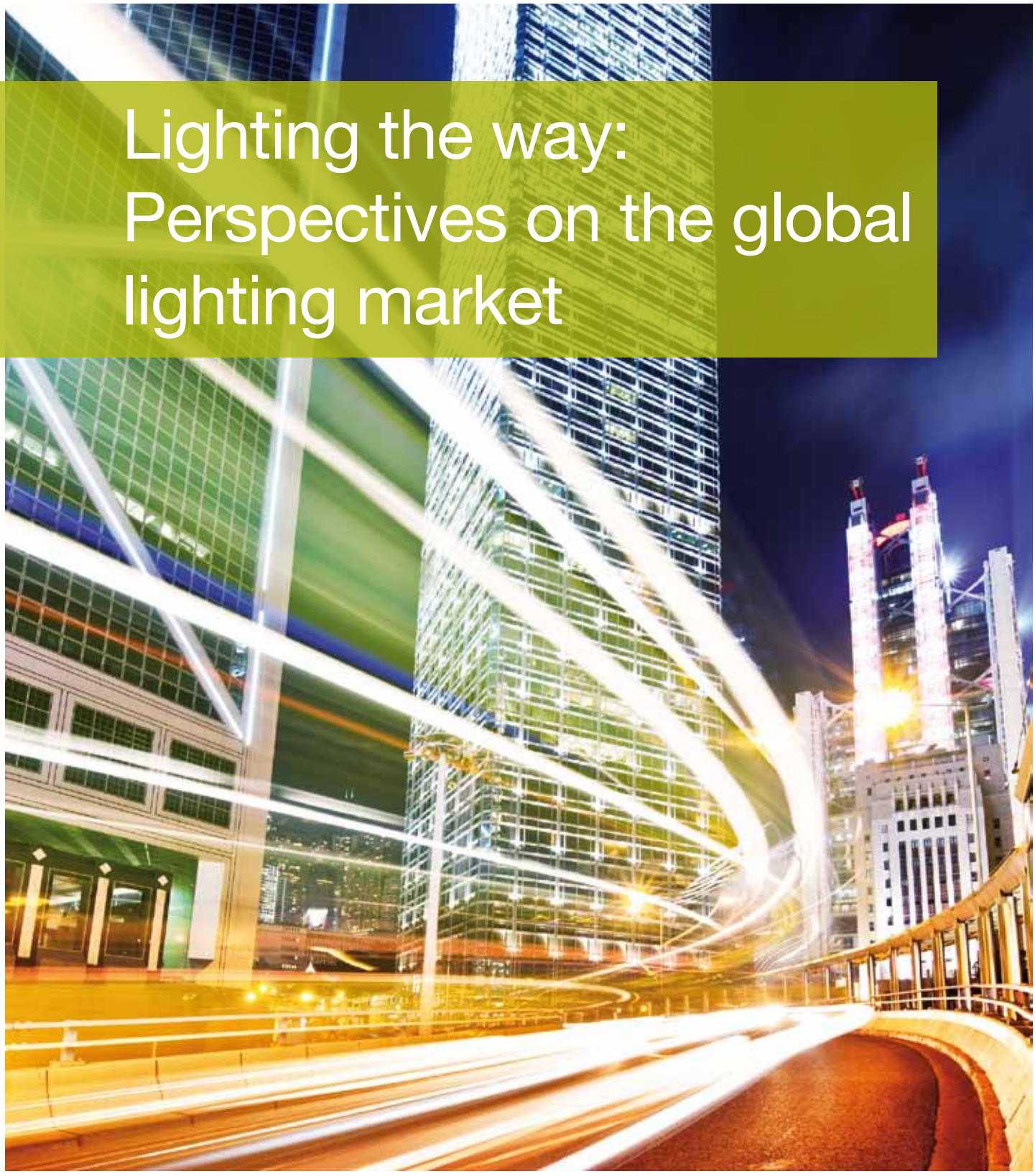
Lighting the way: Perspectives on the global lighting market



Lighting the way: Perspectives on the global lighting market

Foreword

The lighting market has been receiving much attention lately due to its high potential for CO_2 abatement and its many new entrants. However, no comprehensive report exists providing a holistic view across all the key sectors and applications, geographies, light source technologies and different stages of the value chain. In this context, McKinsey & Company was commissioned by Osram to draw up this market report with an independent perspective on the global lighting market and its likely evolution.

In order to develop a holistic overview of the global lighting market, including an estimate of LED market share going forward, McKinsey conducted a worldwide survey of lighting professionals as well as consumers from seven different countries (the US, Germany, Japan, China, Russia, Brazil, and India). McKinsey also developed a model allowing it to draw assumptions regarding the size of the global lighting market through to 2020, differentiated by application, geography, and light source technology. The market model is not based purely on this survey: it also factors in broad, deep research on hundreds of key parameters.

McKinsey has been working in this industry for many years, investing over USD 2 million on primary research through the McKinsey global LED Competence Center, with a network of more than 30 dedicated experts. This report incorporates the firm's accumulated industry insights together with synthesized data from external sources. The appendices contains details of the assumptions supporting the findings, and a full list of references.

This market forecast cannot offer any guarantees of a specific future path as many uncertainties underlie the industry's development. However, McKinsey's research reveals indications of the trends described, and we very much hope this report will be of assistance to decision makers in this industry.

Contents

Important notice

This market report has been prepared by McKinsey on the basis of public sources and certain information provided by McKinsey's Global Lighting Professionals and Consumer Survey, Pike Research Global Building Stock Database 2011, the IMS Research Quarterly GaN LED Supply and Demand Report, and other sources (please refer to the appendices for a full list). In preparing this market report, McKinsey has relied on the accuracy and completeness of the available information, and has not undertaken independent verification of the accuracy or completeness of such information.

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Executive summary

Projections reveal that the global lighting market will have revenues of approximately EUR 110 billion in 2020 – comparable to the global TV market. A number of megatrends underlie this expansion. Global population growth and urbanization are increasing the overall demand for lighting products. At the same time, resource scarcity and climate change are of increasing concern. Governments around the world are responding to this with greater regulation towards energy efficiency, and the lighting industry is addressing the issue by pursuing the development and enhancement of more energy-efficient lighting technologies.

"Population growth, resource scarcity, and climate change concerns are driving technological advances in the lighting industry."

Despite its large size and carbon abatement potential, the lighting industry has historically lacked transparency. This is due to its high complexity and fragmentation – driven by more than 10 major application areas and 6 key technologies – and the differences in deployment based on geography.

The advent of LED – only the fourth lighting technology in the history of humankind – is set to transform this industry. LED technology, however, has not yet achieved a competitive cost position in most applications. But heavy investment from various companies is cutting costs at a rate of 30 percent p.a., and LED is becoming a broadly affordable technology. The McKinsey model developed for this market report, including data gathered from lighting professionals and consumers around the world, reveals that LED's market share is likely to accelerate over the next decade, with revenue growth of 30 percent p.a. Figures suggest that global revenues from the LED lighting market will amount to almost EUR 65 billion by 2020 – close to 60 percent of the overall lighting market.

LED lighting – powered as it is by semiconductors – is very different from traditional light source technologies that use electrical filaments or plasma with bulky glass covers. This will lead to a fundamental disruption of the lighting industry along the entire value chain. New entrants from Asia, often with a background in other areas of semiconductor manufacturing, are ramping up capacity quickly. Entirely new possibilities of lighting using LED technology, such as dynamically changing light color temperature, or flexible designs as seen in cars, are challenging the standard interfaces that have been in place for decades. New growth opportunities are also emerging in the area of intelligent lighting systems

"The significant differences in LED technology vs other lighting technologies will lead to a fundamental disruption of the lighting industry along the entire value chain."

resulting from the greater controllability of LED-generated light, resulting in an expected EUR 7 billion in revenues in lighting systems control components in 2020. While the hype is mainly around LEDs, other green transition technologies such as CFL, HID, and halogen will also play an important role.

The three largest sectors in lighting are general lighting, automotive lighting, and backlighting. Backlighting has long been the major driver of the LED market, with its lower brightness requirements. However, while it will likely remain stable in market size across technologies at approximately EUR 4 billion until 2016, the backlighting market is expected to decline to around half of that by 2020, with brighter LEDs leading to a decreasing number of LEDs required, for example, per TV. In contrast, the automotive lighting market will continue to grow from its current revenue of EUR 13 billion to EUR 18 billion across technologies by 2020, driven mainly by the conversion of automotive headlamps to LED technology. The high design flexibility LEDs offer and the fact that automotive OEMs are embracing the technology worldwide is making them one of the most visible vanguards of LED technology today.

General lighting is the largest sector, accounting for approximately 75 percent of the total lighting market. It is also the most complex lighting market, with multiple applications and characteristics that vary substantially by geography. Residential lighting has the highest share, accounting for over 40 percent of the total general lighting market. Its LED penetration is slower, but thanks to its total market size, its worldwide revenues from LED are likely to be over EUR 20 billion by 2020. In terms of LED penetration, architectural lighting is the early adopter due to LED's technological edge in color control, with over 85 percent market share in 2020, although it is likely to remain limited in terms of market size. Hospitality, shop and outdoor LED applications are also all expected to see fast growth in market share to 70 percent or more by 2020 by utilizing the advantages of LED. In contrast, office and industrial applications will be slower movers due to the current high penetration of cost-competitive linear fluorescent lamps.

"General lighting, automotive lighting, and backlighting are the three largest sectors in lighting – with general lighting accounting for approximately 75 percent of the total lighting market."

"Architectural lighting is the early adopter due to LED's technological edge in color control, with 39 percent penetration as of today."

In terms of general lighting's geographical aspects, Asia is already the largest market in both the total general lighting market and LED general lighting market, with current revenues of close to EUR 20 billion and EUR 1.5 billion, respectively. Asia is strengthening its position due to its high economic growth, with China in the lead. China's general lighting market will be EUR 13 billion by 2016 (41 percent of Asia's and 17 percent of the global market), and its LED general lighting market will be EUR 11 billion by 2020 (42 percent of Asia's and 20 percent of the global revenues). In terms of the LED penetration rate,

"Asia is currently the largest market in general lighting and will likely strengthen its position to over 45 percent of the total market in 2020."

Europe and North America are likely to lead going forward, but Asia is expected to continue building on its number 1 position in terms of revenues due to the vast size of its general lighting market.

The final trend in general lighting discussed in this report is the industry's shift from light source replacement to new fixture installation, fueled by the trend towards light sources with longer lifetimes – particularly LEDs and other energy-efficient light sources, such as CFL. The resulting shift in profit pools has far-reaching implications for all industry players, driving the emergence of entirely new business constellations and strategies.

"The industry's focus will shift from light source replacement to new fixture installation thanks to longer-lifetime technologies."

Overview of the global lighting market

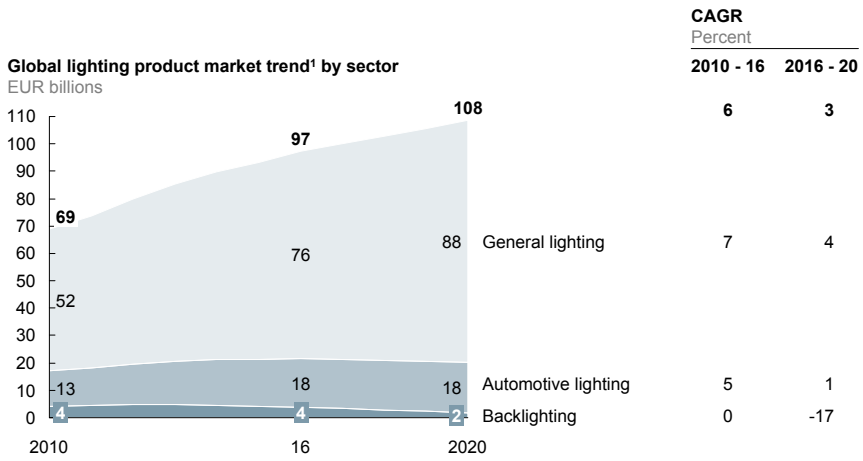
The global lighting market is currently undergoing a radical change, fueled by the exponential urban growth expected over the next decade, and the drive towards ever greater energy efficiency. Its great fragmentation, however, has led to little transparency. To provide greater clarity on this huge and very complex market, McKinsey has conducted the first large-scale research of the global lighting industry. The findings provide a clear picture of the status quo and a forecast through 2020, covering major applications and technologies, including light sources and light fixtures. This chapter outlines the scope of the study and the key drivers identified.

1.1 A poorly understood market, despite its size

The global lighting market is expected to have revenues of around EUR 110 billion in 2020, with 6 percent and 3 percent p.a. growth from 2010 - 16 and 2016 - 20, respectively (Exhibit 1) based on McKinsey's Global Lighting Market Model. Appendix 4 contains a description of the assumptions underlying the market model. These figures demonstrate that the size of the global lighting market is similar to that of the global TV market. It is important to note that this is calculated based on the producer price. If the model's calculations were based on retail price instead, factoring in both the wholesaler's and retailer's value added, this would almost double its size, making it comparable to the entire personal computer industry, including both laptops and desktops.[1]

Exhibit 1

The global lighting market is growing steadily, with general lighting being the major market segment



1 Total general lighting market (new fixture installation market with light sources and lighting system control components [full value chain] and light source replacement market), automotive lighting (new fixture installations and light source replacement), and backlighting (light source only: CCFL and LED package)
NOTE: Numbers may not sum due to rounding

SOURCE: McKinsey Global Lighting Market Model; McKinsey Global Lighting Professionals & Consumer Survey

Despite its vast size, the lighting market has received little attention in the past. Previous market reports have covered portions of the industry, such as light sources or LED packages. Very few have presented a comprehensive perspective that also includes the

lighting fixture market. This market report attempts to develop a holistic overview of the entire lighting market from several angles, including different applications, technologies, and geographies, encompassing both light sources and lighting fixtures.

The scope of McKinsey's market model includes general lighting at the light source, fixture and systems control component levels, automotive light sources and fixtures, and backlighting at the light source level. The fixture market size also covers electrical components such as ballasts. Light sources are defined as bulbs/tubes in traditional lighting, and as LED modules/light engines and LED lamps in LED lighting. Please refer to Appendix 3 for a definition of the value chain.

General lighting is the dominant market, with total market revenues of approximately EUR 52 billion in 2010, which represents close to a 75 percent share of the total lighting market. This is expected to rise to some EUR 88 billion by 2020 – approximately 80 percent of the total lighting market.

The general lighting market has two key drivers. The strong growth in construction investment in emerging countries is one. The second is the greater penetration of higher priced light source technology, including LED, which raises the average price of lighting products. The next section outlines the general contours of these major driving forces, while Chapter 3 provides a more granular perspective on the structure and development of the general lighting market. Our calculations of market size do not include OLED for general lighting, as the extent to which OLED will penetrate the general lighting market is still unclear. The price of OLEDs is higher, while their lifetime is shorter than non-organic LED lighting. Furthermore, OLED panels have yet to be manufactured in large sizes. Additional markets may open up for OLED in general lighting in the future when OLED overcomes issues such as its lifetime, especially for decorative lighting purposes. This would increase market size estimates even further. (Please refer to Appendix 1 for definitions of all the light source technologies covered.)

The **automotive lighting** market is steadily growing. The 2010 market size is estimated at EUR 13 billion, representing approximately 20 percent of the total lighting market. This is expected to climb to EUR 18 billion by 2020. More than 90 percent of automotive lighting is related to exterior lighting, with the major application being the headlamp market accounting for more than 70 percent of total automotive lighting. The trajectory of the automotive lighting market is similar to that of general lighting as its growth drivers are comparable: strong growth of the vehicle market in emerging countries (please see Section 1.2 for further details), and LED penetration. Another trend in the automotive lighting market is the shift from light source replacement to new lighting installation business. The driver for this is the evolution towards longer light source lifetimes, leading to a decrease in the replacement light source market.

The **backlighting** market is estimated to have had revenues of EUR 4 billion in 2010 at the light source level. This represents 6 percent of the total lighting market. This market report includes backlighting because the high penetration of LED in this market will greatly influence LED prices in other sectors, such as general lighting. The light sources analyzed were LED and CCFL (cold cathode fluorescent lamp). Currently, LED is already a major light source for small to midsize screen backlights, such as for mobile devices, laptops, monitors, and small-screen LCD TVs. It is also penetrating larger-size screen LCD TVs, where CCFL technology has mostly been used. OLED displays are already penetrating the mobile/ smart phone market, expanding OLED's market share as it

provides higher resolution than LCD displays. Even in large-screen TVs, OLEDs are expected to replace LEDs due to the aggressive investments of Korean companies. Our market report does not include the OLED market size in its model as OLED displays use self-light-emitting technology without the need for backlighting, eliminating the concept of a light source. The backlighting market (excluding OLED displays) will remain stable, with revenues of EUR 4 billion in 2016. The market is likely to decline after that as LED market share hits a ceiling, with brighter LEDs leading to a decreasing number of LEDs per TV, and OLED beginning to penetrate larger-screen TVs.

This report does not include other lighting applications within this sector, such as signal, sign display or medical lighting, machine vision lighting, or light sources for projectors, optical devices, sensors as well as other electronics equipment. These markets are relatively small as only the light source market can be included in these applications by their nature. They account for a total market share of under 10 percent[2], and this is expected to remain the case.

McKinsey global lighting professionals & consumer survey

McKinsey conducted a global lighting survey of both lighting professionals and consumers in June 2011, focusing on the general lighting market. The countries covered were the US, Germany, Japan, China, Russia, Brazil, and India. Over 650 respondents from the lighting professionals sector took part, including architects, lighting designers, and electrical engineers, and more than 1,000 respondents representing lighting products consumers who have made purchasing decisions on lighting fixtures and light bulbs/tubes in the past two years.

This survey asked questions that would indicate the evolution of the lighting industry, particularly focusing on the future market share of LED lighting.

As an example of how this was conducted, the lighting professionals survey took four different approaches at estimating LED market share in new fixture installations. The first set of questions targeted levels of price acceptance in order to estimate LED market share, which was calculated using both the responses as well as the future lighting product price trend by technology. The second approach addressed levels of payback time acceptance. Payback time forecasts were conducted based on different lighting product price levels by country/light source technology, applying varying electricity prices. Major technology barriers by application were surveyed in the third category, including the timeline by which the barrier was expected to disappear. The last area surveyed concerned future LED market share based on respondents' expertise. These replies were then combined with the survey results on key purchasing decision criteria to develop estimates on LED market share by country and application.

1.2 Growth driven by various megatrends – especially energy efficiency

A number of megatrends are propelling the growth of the lighting market. One major trend is population growth, especially in developing countries. Secondly, rising incomes increase the amounts consumers are willing to spend on lighting. The third is urbanization, with usage of light being larger in urbanized areas than in rural areas.

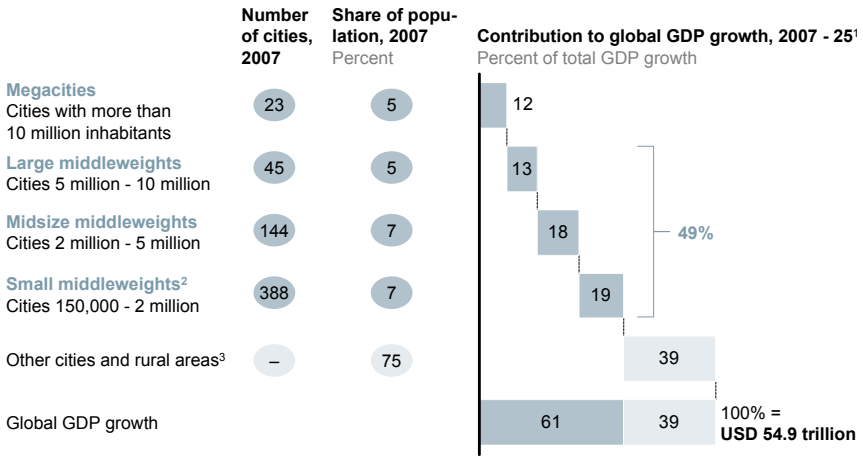
Lastly, due to concerns about scarce resources and climate change, demand for energy-efficient products has now become a global movement that is bringing about a gradual shift to higher prices in the lighting market.

Global population growth and rising incomes. The world's population is expected to grow from 6.9 billion in 2010 to 7.7 billion in 2020. This is a fundamental driver for growing lighting demand, both in residential but also in all other areas of lighting. The population growth mainly originates from Asia, with a 78 percent share in the 0.8 billion additional population between 2010 and 2020. The resulting shift in gravity will also be reflected in the geographic distribution of the lighting market and the corresponding need for products customized for these high growth markets.

Urbanization. The global economy is expected to grow by 3 - 4 percent p.a. from 2010 to 2020 in real terms. The major growth will be driven by initiatives in cities, which directly impact lighting market demand, especially general lighting. Recent McKinsey Global Institute (MGI) research has revealed that 600 urban centers – covering a fifth of the world's population – are expected to account for around 60 percent of worldwide GDP growth in 2025 (Exhibit 2). Urbanized cities use more light than rural areas, so the urbanization trend will be a strong driver of light usage going forward.

Exhibit 2

Global 600 cities will contribute 60 percent of global growth by 2025



1 Predicted real exchange rate
2 Smallest city in terms of 2007 population has 208,000 inhabitants (in South Korea)
3 Cities that do not belong to the City 600; small cities and towns and rural areas
NOTE: Numbers may not sum due to rounding

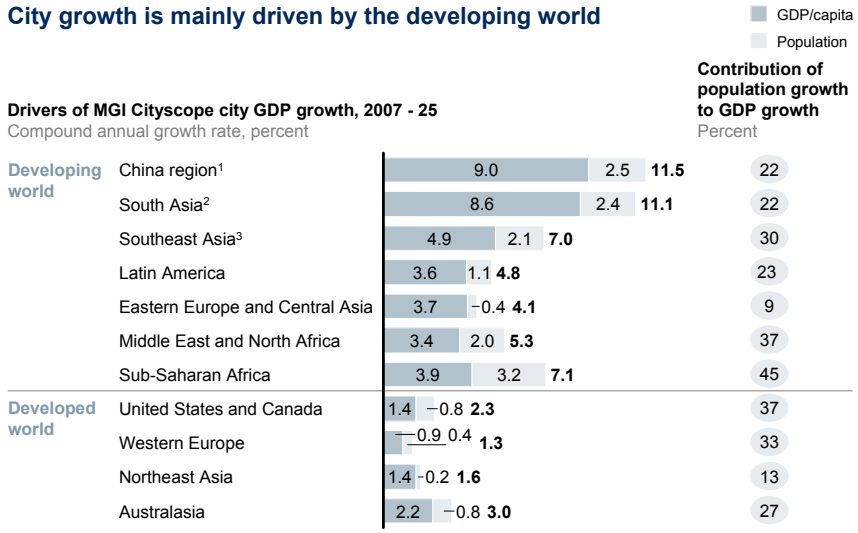
SOURCE: McKinsey Global Institute Cityscope 1.1

As for the population growth, the center of gravity for cities is shifting to developing regions. In 2007, the 380 developed region cities in the top 600 (by GDP) accounted for 50 percent of global GDP. By 2025, 136 new cities are expected to enter the top 600, all of them from the developing world, and overwhelmingly from China (100 new cities). These include cities such as Haerbin, Shantou, and Guiyang. But China is not the only economy that features in the shifting urban landscape. India will number 13 newcomers, including Hyderabad and Surat. Latin America will be the source of

eight cities, including Cancún and Barranquilla. Rapid growth in emerging cities is largely due to rising per capita GDP, whose contribution to GDP growth is much higher than that of population growth (Exhibit 3).

Exhibit 3

City growth is mainly driven by the developing world



1 Includes cities in China (including Hong Kong and Macau) and Taiwan
2 Includes cities in Afghanistan, Bangladesh, India, Pakistan, and Sri Lanka
3 Includes cities in Cambodia, Indonesia, Laos, Malaysia, Myanmar, P.N.Guinea, Philippines, Singapore, Thailand, and Vietnam
NOTE: Numbers may not sum due to rounding

SOURCE: McKinsey Global Institute Cityscope 1.1

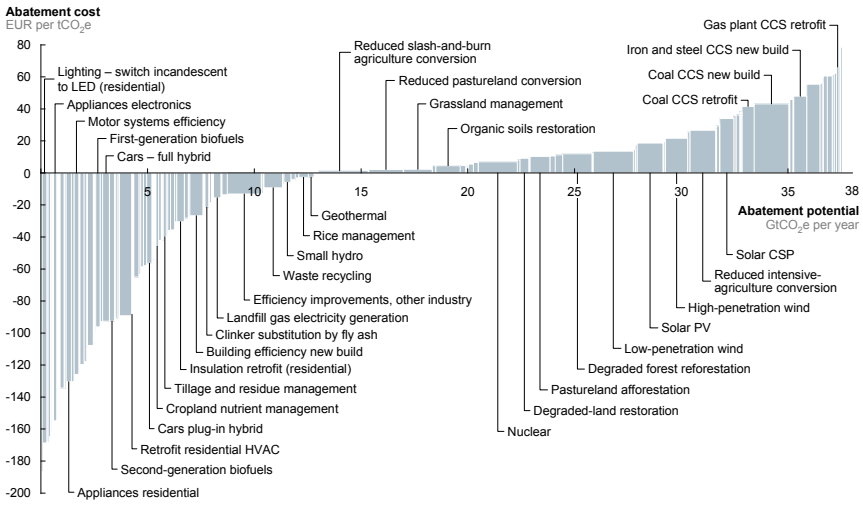
The automotive sector will expand as a result of this growth in the global economy, directly affecting the automotive lighting market. China has been the largest automotive vehicle market in the world since 2009, and the growth of automotive markets in other developing countries is higher than that in developed countries (approx. 6 percent p.a. in developing countries compared to approx. 2 percent p.a. in developed countries from 2010 - 20 on a unit basis.) However, the trend in automotive sales is moving towards smaller and lower price segments, which have a less pronounced effect on the automotive lighting market on a value basis.

Energy conservation and the global movement towards CO_2 abatement. Scarce resources and climate change are now two of the world's greatest concerns. Although there are several arguments on the scientific evidence, the implications ultimately equate to those driven by the global energy depletion issue, which is indisputable. McKinsey has been working on this topic for several years from the perspective of climate change, and has developed a global greenhouse gas (GHG) abatement cost curve that offers a very holistic perspective on GHG abatement activities. These initiatives are in essence very much the same as those required for energy conservation (Exhibit 4).

Analysis using the GHG abatement activities reveals that replacing current non-energy-efficient light sources with energy-efficient light sources will provide substantial economic benefit while at the same time reducing CO_2. In contrast, most other CO_2 abatement activities will have a negative economic impact. Replacing incandescent lighting with LED to reduce 1 t CO_2 per year in 2015 would provide an economic

Exhibit 4

GHG abatement cost curve is beyond business as usual in 2030



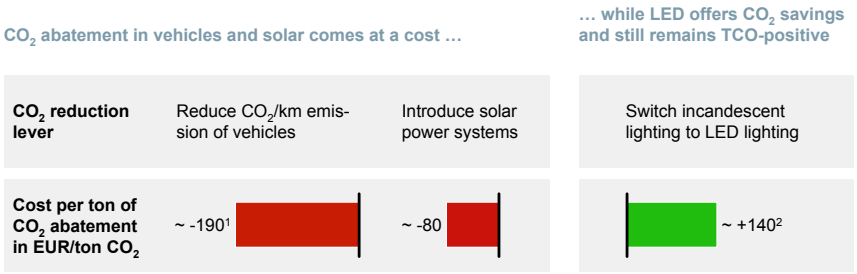
Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below EUR 80 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play

SOURCE: McKinsey GHG Abatement Cost Curve v2.1

benefit (calculated as total cost of ownership) of around EUR 140 per 1 t CO_2. Achieving the same CO_2 reduction by introducing solar power would cost around EUR 80 per 1 t CO_2 (Exhibit 5). Replacing traditional light sources would also require less capital

Exhibit 5

Switching to LED lighting is economically more attractive than other means of CO_2 abatement, but not yet in focus



1 Reduction of CO_2 in 2015 due to efficiency improvement of medium-duty vehicles in the range of 3.5 - 16 tons
2 Assumptions for 2015: price – LED ~ EUR 20, incandescent ~ EUR 0.6; luminous efficacy – LED 150 lumen per watt, incandescent 12 lumen per watt

SOURCE: European Commission; McKinsey GHG Abatement Cost Curve v2.1

investment than for solar power. The investment for substituting incandescent or CFL lighting with LED is a fifth of the investment for installing solar power, calculated on a t CO_2e p.a. basis, which means subsidizing LED is a more efficient investment than subsidizing solar power from a government perspective.

Replacing traditional lighting technology with energy-efficient technologies such as LED is therefore much easier and represents much sounder economics for reducing CO_2 emissions than other CO_2 reduction activities. By and large, populations have now adjusted to the fact that the average price of lighting products will increase. Energy efficiency is the driving force that will contribute most powerfully to the upcoming discontinuity in the lighting industry.

1.3 High fragmentation: lighting used in many different ways

In contrast to typical electronics products, the lighting industry is very fragmented and complex, as lighting is used in so many different ways. It needs to be viewed along four dimensions, all of which intersect, producing multiple variations (Exhibit 6).

Exhibit 6

The lighting industry is very fragmented and complex

Dimensions of the lighting industry

Applications	▪ **General lighting:** residential, office, shop, hospitality, outdoor, industrial, architectural ▪ **Automotive:** headlamps, DRLs, sidelights, rear lights, interior, etc. ▪ **Backlighting:** TVs, monitors, laptops, handhelds ▪ **Other industrials:** signal lighting, sign display lighting, medical lighting, projectors, machine vision lighting, etc.
Technologies	▪ **Non-green traditional:** incandescent, non-eco-friendly halogen, HID and LFL (CCG[1]-based) lighting ▪ **Green[2] traditional:** eco-friendly halogen, HID and LFL (ECG[3]-based) lighting, CFL, CCFL ▪ **Solid-state lighting:** LED lamps, LED light engines, OLED, infrared, laser
Geographies	▪ **Europe, North America, South America, Asia Pacific, Middle East, Africa** ▪ Developed countries (OECD), developing countries (non-OECD)
End-market structure	▪ **Building owners, tenants** ▪ **Lighting professionals:** architects, lighting designers, interior designers, electrical engineers, general contractors, electrical contractors, electrical wholesalers, etc.

1 Conventional control gear
2 Due to the broad range of different lighting products, green is defined per product group in line with typical energy efficiency standards within the industry, e.g., Energy Star for CFL light bulbs. At the minimum, all green products need to provide an 20% energy efficiency improvement vs. comparable non-green products.
3 Electronic control gear

SOURCE: McKinsey Global Lighting Market Model; McKinsey Global Lighting Professionals & Consumer Survey

The first – and most complex dimension – is applications. As explained in Section 1.1, the major sectors into which lighting falls are general lighting, automotive lighting, and backlighting. However, there are also many others, such as lighting for camera flashlights, machine vision, and projectors, or for traffic signals and signs. Even general lighting has several applications where lighting usage differs, such as residential lighting, shop lighting, and industrial lighting.

The second dimension by which lighting needs to be examined is light source technology. This field has seven main technologies: incandescent, halogen, LFL (linear fluorescent lamps), CFL (compact fluorescent lamps), HID (high-intensity discharge lamps), LED and OLED technology. Sub-technologies also need distinguishing, such as cold cathode fluorescent lamps (CCFL), metal halide, and high-pressure sodium.

A third key area is geography, especially in the general lighting arena. Electrical regulations differ by region/country, and voltage requirements also vary. Light preferences diverge by region/country, too. European consumers tend to prefer warm-colored light, which favors the halogen market, while those in Asian markets have less preference for warm light, giving the fluorescent lamp an advantage.

The fourth perspective is end market structure in general lighting. This industry involves multiple purchasing decision makers, whether architects, lighting designers, electrical engineers, building owners, or even government authorities. This makes marketing activities and channel structure particularly challenging.

Further complexities are created by the advent of LED. This totally different technology for emitting light is upending the role of the replacement business and transforming the landscape of the lighting industry value chain entirely, as the next chapter will go on to explain in greater detail.

The LED revolution

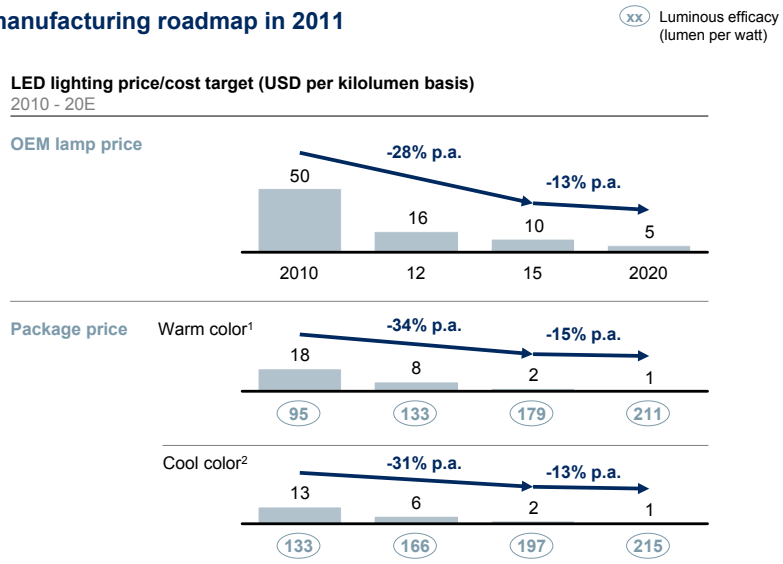
The lighting industry has been a conservative and relatively stable industry compared to other electronics industries. Human beings used fire as a light source for tens of thousands of years until the revolutionary invention of the light bulb in the 1870s. The fluorescent light bulb, another radical invention in the 1920s, proved more efficient and has a longer lifespan. LEDs evolved in the 1960s using the light emission properties of certain semiconductor materials. The full color spectrum they now offer combined with their low input power and improving price levels make them the clear fourth-generation candidate, set to disrupt the entire lighting market.

2.1 Prices falling: dramatic cost reduction trend

Theoretically, LEDs could become much cheaper than any other traditional lighting currently in use. According to the US Department of Energy's 2011 solid-state lighting manufacturing roadmap, the prices of LED OEM lamps and LED packages are predicted to drop by around 30 percent p.a. from 2010 - 15, and by 10 - 15 percent p.a. from 2015 - 20. Extrapolating these figures means they would be a fifth of their 2010 price by 2015, and a tenth of the 2010 price by 2020 (Exhibit 7). This cost reduction target is becoming increasingly aggressive every year due to the intensive focus of companies in the sector. The price forecast for a warm-color LED package for 2015 was USD 4 per kilolumen in 2009 and USD 3 per kilolumen in 2010, falling to USD 2 per kilolumen in the 2011 version of the DOE roadmap.[3]

Exhibit 7

LED manufacturing roadmap in 2011



1 2580 - 3710K, 80 - 90 CRI
2 4746 - 7040K, 70 - 80 CRI

SOURCE: Solid-state Lighting Manufacturing Roadmap 2011 (US Department of Energy)

There are two key drivers for reducing LED lighting costs. The first is improving the brightness of light generated (measured in lumen) in terms of the power consumed (measured in watt). This is commonly referred to as luminous efficacy (efficiency). The

second is reducing production costs per LED product. Several activities are under way to improve both of these dimensions.

Improving luminous efficacy (less energy use to achieve the same brightness). There are various opportunities to improve luminous efficacy along the value chain (please refer to Appendix 3 for a value chain definition). At an epitaxy level, one of the key drivers is greater sophistication of the critical production step, MOCVD (metal organic chemical vapor deposition), in which the light-emitting layers are created. Options include more efficient production handling and better choice of layer material, including the substrate material onto which the light-emitting layers are deposited. At a chip level, multiple activities to enhance luminous efficacy are currently underway, such as the recent introduction of laser liftoff/flip-chip technology and surface roughening, both of which increase the amount of light leaving the chip rather than being absorbed inside. Initiatives are being taken to increase the amount of light reaching the human eye at the package level, too. These range from changing the optical material or adding a remote phosphor light source to using reflectors. At a module level, LED driver design will continuously be refined to improve electrical efficiency, while enhancing secondary optics can reduce light loss.

Lower production costs (reduce production costs per product). The second OEM-related LED cost reduction lever, declining production costs, is being driven by a wide range of activities that both reduce material costs and improve production efficiency. Material costs are falling as the LED market expands due to economies of scale. Choice of material is another driver. One of the most expensive components of LED material costs today is the sapphire substrate. Using silicon (as in most other semiconductor applications) instead of sapphire substrate can significantly reduce substrate costs. Downsizing the LED package and thus the size of the entire light source (and potentially the fixture) is further reducing material costs. Another leverage point is that currently LED is still using 2- to 4-inch wafers, while other areas of the semiconductor industry are using 12-inch wafers, which can greatly improve the throughput of the MOCVD process. Integration of production steps – as is common in the semiconductor industry – is another major cost improvement option. For example, technologies are being explored that integrate the package and module step (chip on board). Please refer to Appendix 5 for explanations of the technological terminology.

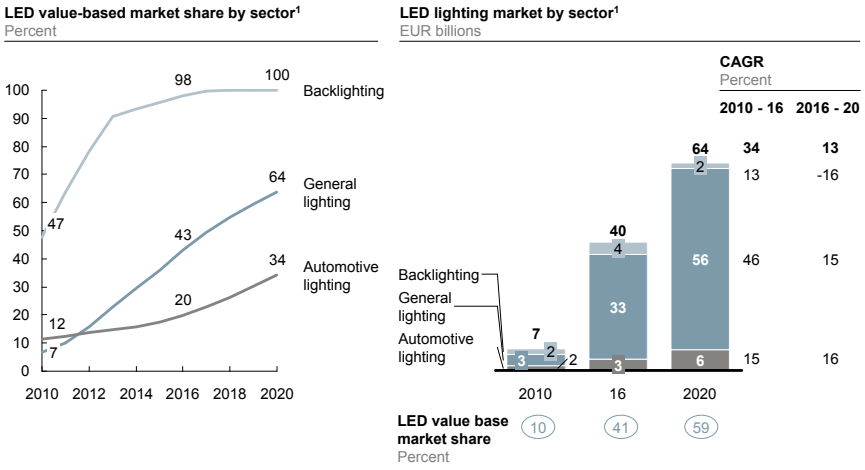
2.2 Penetration rising: growth of over 30 percent p.a.

The 2010 figure for the size of the LED lighting market in the general lighting, automotive lighting, and backlight sectors is estimated at around EUR 7 billion. This amounts to approximately 10 percent of the entire lighting market on a value basis. (LED market share is expressed on a value basis throughout this report unless specifically indicated otherwise). The McKinsey model calculates that LED lighting is expected to grow at a rate of around 35 percent p.a. from 2010 - 16, leading to a market share of approximately 40 percent by 2016, with revenues of some EUR 40 billion. After that, the growth is predicted to slow down to less than 15 percent p.a. from 2016 - 20, resulting in an LED market share of around 60 percent in 2020 and revenues of approximately EUR 65 billion.

LED penetrated the backlight market first and has now also made inroads into the automotive sector. However, the major market for LED going forward is expected to shift towards general lighting (Exhibit 8).

Exhibit 8

LED lighting market is expected to increase very rapidly in the coming 10 years



1 Total general lighting market (new fixture installation market with light sources and lighting system control components [full value chain] and light source replacement market), automotive lighting (new fixture installations and light source replacement), and backlighting (light source only: CCFL and LED package)

SOURCE: McKinsey Global Lighting Market Model; McKinsey Global Lighting Professionals & Consumer Survey

Successful deployment in the backlight market since the late 1990s. The LED market began opening up in the 1960s with low-brightness red indicators in several electronics products. As the technology developed, LED expanded into higher brightness and white-color applications, starting with mobile backlighting (around 1995) and backlighting for laptops (around 2005), gradually expanding to larger-screen backlighting (from 2009) and other brighter white-color applications. LED market share in the backlighting market was already 50 percent in 2010, thanks to aggressive investments by Korean and Taiwanese panel makers. The share of LED in the backlighting market is expected to peak soon, at close to 100 percent in 2016. The market is then likely to shift from LCD TV to OLED TV, which does not use backlighting.[4]

Growing use in the automotive sector. The 2010 market share of LED in the automotive sector was 12 percent, largely due to red LED applications, such as indicators and brake lights. LEDs are increasingly being used in DRLs (daytime running lamps), which are mandated for new car production in the EU from 2011 - 12, and which OEMs are now also using as a competitive edge in their design, such as in the Audi A8. LED also aims to penetrate the headlamp market, but technology barriers persist in this field as LED is still very expensive for ultra-high brightness applications: halogen and high-intensity discharge lamps (HID) have advantages at lower costs.

General lighting to be the key target. LED now penetrates general lighting, which is the mainstream of the lighting market. LED's market share was still low in 2010, at 7 percent. The key reason is that LED is still expensive for high-brightness applications. However, RGB color LEDs are already well accepted in architectural lighting as they have clear benefits over traditional lighting. White LED lighting is currently starting to ramp up, too. As a result of substantial cost reductions and the global movement toward energy

savings, LED's share of the general lighting market is expected to be 43 percent by 2016 and 64 percent by 2020. The details are covered in the next chapter.

2.3 Value chain transforming: disruption of industry structures

The penetration of LED technology just described is driving a far-reaching change to the industry's structure. This transformation is affecting every stage of the value chain, from upstream, where altered production methods are driving new capabilities and entrants, to downstream, where the fixtures market is expanding in multiple directions.

Upstream industry is experiencing a radical shift, with LED expected to capture a huge share of general lighting. LED production methods are very different from those used for traditional lamps, where electrical filaments or plasma with bulky glass covers are used. This is leading to the emergence of an entirely new industry and the upheaval of traditional industry structures.

Restricted to red and green low-brightness LEDs, the market was historically a very niche industry. The invention of blue LEDs in 1995 has led to a rapidly changing landscape over the last 15 years. From 1995 to 2005, the high-brightness white LED upstream industry was dominated by a handful of companies protected by their patents, following intensive IP-related battles between them.

From 2005 to 2010, the major LED application was backlighting for mobiles and laptops, necessitating continuous cost reduction. Several Taiwanese and Korean companies entered this market via licensing from the Big 5, gaining market share with their low-cost production capabilities. In 2010, as LED brightness increased and its costs started to fall, LED backlighting was introduced for large-screen LCD TVs. The top LCD panel manufacturers have begun to heavily invest in the upstream LED market, expecting high captive demand for LCD panels. They swiftly bought up MOCVDs and gained a large share of the LED upstream market within a very short time period.

Most upstream companies are now aiming to capture the general lighting oppor-tunity as LED upstream business in general lighting is expected to be significant. This is especially true once the LED package market in LCD TV backlighting stagnates, epi/chip/package production capacity will shift to general lighting. Currently incumbents are at an advantage in the general lighting market because high-power LED still needs more sophisticated technology and a wider variety of application know-how than backlighting. However, emerging multichip/chip-on-board technologies are opening up opportunities for start-ups and semiconductor manufacturers.

Midstream, LED is set to become the next standard in the general lighting light source market. In the traditional light source market, the three main players have maintained a significant share of 60 to 70 percent globally for several decades, despite partially outsourcing production to Chinese manufacturers.[5] Light source standards for light bulbs/tubes in this field are already well established, meaning the light sources produced by different companies are basically interchangeable. Traditional light sources have become a commodity – a volume game product – as a result, and the market tends to be oligopolistic, as is common in the world of commodities (whether the automotive tire industry, glass industry, or semiconductor DRAM industry). LED

lighting is uprooting these traditions on multiple fronts and realigning thinking on standards.

- ***LED as a light source is altering traditional standards.*** LED lighting is still just emerging as a new general lighting light source, but it is already clear that its profile will differ greatly from that of the traditional light source industry. The functionality of an LED module (light engine) is similar to that of lamps (light bulbs/tubes) in traditional lighting. Despite this, a standard for LED modules has not yet been set, although the LED retrofitting market for light bulbs and tubes is currently adapting to traditional light source standards as a default. This lack of standards in LED is due to LED's new value proposition, such as its long life and the compact/directional light source it offers. As a light source, an LED may have an even longer lifespan than the lighting fixture used for it, eliminating the need for light source replacement and leading to integration of fixture and light source. In traditional lighting, design customization is mainly for fixture designs that use a standard light bulb/tube, but fixtures can now be designed more flexibly using a compact/directional light source.

- ***New standards will depend on the directions the industry takes.*** Discussions on LED general lighting standardization have been initiated by several organizations (such as the Zhaga Consortium). The lack of standards is creating inefficiency in the industry. For example, module/light engine manufacturers cannot enjoy economies of scale, and fixture and module/light engine designers/engineers cannot design their products smoothly: extensive coordination among various parts suppliers is required.

  For example, Zhaga's objective is to define a light engine interface – differentiating light engine and module – from four different physical perspectives: mechanical, thermal, electrical, and photometric. Currently, the Zhaga Consortium has 140 members and is holding very active discussions on light engine standardization.

The degree of standardization will likely vary depending on the application. One model is that light engines are standardized products, where fixture designs are adjusted to the commonly available LED light engines, and end users can replace LED light engines themselves. The alternative is that light engines will be individually customized towards lighting fixture designs provided by the fixture manufacturers. In this scenario, the light engine business would be similar to today's consumer electronics business: light engine makers would need to align to fixture manufacturers' design activities.

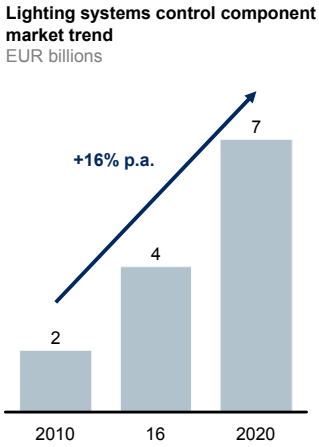
Downstream companies are exploring new growth opportunities beyond their current business domains. Many lighting companies, especially fixture companies, are seeking new growth opportunities through value chain expansion by entering the systems/solutions businesses, as the advent of LED and the recent energy efficiency movement are creating a new lighting systems/solutions market. Currently the lighting fixture market is regionally/locally fragmented. Some leading companies are also seeking growth opportunities through geographical expansion. However, major consolidation is unlikely, due to the underlying fragmentation of the market.

- ***Systems/solutions are a new downstream business opportunity.*** The systems/ solutions arena is expected to be a large market in the future as new solutions will be created for every type of application due to the advent of the new light source, LED. Current revenues in the lighting systems control component

market (excluding building systems, etc.)[6] are roughly estimated at EUR 2 billion. This is expected to grow to EUR 4 billion by 2016 and EUR 7 billion by 2020 (Exhibit 9). This calculation does not include new applications such as biolight systems, which represent upside potential in addition to the market growth figures presented in this report.

Exhibit 9

Lighting systems control component market is growing very rapidly



SOURCE: McKinsey Global Lighting Market Model; McKinsey Global Lighting Professionals & Consumer Survey

— *Companies.* Historically, the lighting systems/solution business has mainly been covered by traditional controller (switch) companies and lighting control systems companies. Many lighting companies, especially fixture companies, are now targeting this area as one of the largest untapped opportunities in the lighting industry. Many building solutions companies are also targeting the lighting systems business as part of their overall building solutions business.

— *Systems/solutions applications.* Several types of lighting systems are in use, such as the RGB dynamic color control system, mainly deployed for architectural lighting. Color temperature control systems are relatively new and have tended to be a niche market limited primarily to hospitality and studio lighting up to now. Dimming control systems have frequently been used in hospitality lighting and are now extending to every other form of general lighting to minimize energy usage. There is also a trend towards using lighting systems to regulate human, animal, and plant biorhythms. LED lighting has an advantage in all these arenas due to its better controllability compared to traditional lighting.

  ▪ *RGB color control systems.* As LED increases the functionality of RGB color control, such as dynamic color control with a short response time, it

is creating new applications: media façades and dynamic entertainment stage lights are just two examples. This control system is also used beyond general lighting, such as for outdoor large-screen sign displays, where LCD displays have difficulties achieving sufficient brightness.

- *Dimming systems have mainly been used in high-end hotels, convention rooms, etc., to change the spatial atmosphere.* These dimming systems combined with an automatic switch system (sometimes with a human sensor) are now also being used to improve energy efficiency. As the current efficiency of LFL lighting is good, switching to LED would provide limited energy savings. However, a large amount of energy is consumed when spaces/rooms are not in use: over 30 percent of lighting energy consumption is wasted.[7] There is huge potential for improvement by introducing automatic dimming control systems. Gas stations are generally very brightly lit at night whether or not customers are using them. When no one is there, a little light may be enough, and the automatic dimming system would increase the light intensity when a car comes into the station. Home/building energy management systems (HEMS/BEMS) are also being intensely debated, where lighting is controlled remotely using other electronic devices.

- *Biolight systems have several applications.* Plant growth lighting is used in plant factories and gardens to accelerate the growth of plants. Recent food shortage problems and the growing consumer awareness of risks of contamination or infection in fruits and vegetables are accelerating demand for plant factories. Animal barn light helps maintain barn animals' health, such as in chicken farms. Human biorhythm control mechanisms that deploy light have a wider range of applications. One is to improve people's work/study efficiency in offices and schools. Research into human biorhythms has revealed that light has a vast impact on human motivation and can be optimized to specific circumstances to enhance people's abilities. Light can also have a direct impact on human health. New lighting systems are expected to play a significant role in Scandinavian countries, which experience 24 hours of darkness in winter.

- ***Local lighting fixtures will remain a regionally fragmented market.*** Unlike typical electronics products, the general lighting fixture market is regionally segregated and fragmented. This is because purchasing decisions in the lighting fixture arena are not made by end users alone, in contrast to decisions on other electronics products. Many construction industry professionals are involved in the decision-making process, such as architects, lighting designers and electrical engineers, all of whom tend to be largely fragmented, local decision makers. Lighting fixture preferences also differ by region and country, as do electrical regulations. Local market access in the lighting fixture industry is therefore more important than for other electronics products.

  As the lighting fixture market is local, the landscape of fixtures players is fragmented from a global perspective even though there are relatively consolidated markets in some regions. In Europe, the fixture market is locally fragmented, with over 100 fixture companies. In the US, the lighting fixture market is relatively consolidated with four major companies. In Japan, local consolidation is even higher than in the US:

the top two companies have a large market share. China has many local companies, including OEM suppliers for overseas brands.

The lighting fixture market will remain a regionally fragmented market although there are some trends towards consolidation. For instance, some cross-border M&A activity has taken place in Europe and the US. A number of leading Japanese fixture companies are proactively expanding their business, mainly within Asia. Some leading Chinese companies are seeking global opportunities beyond their OEM businesses. However, due to the reasons described above, these trends will not lead the lighting fixture industry towards a globally consolidated world like the upstream LED industry and certain electronics sectors such as TV and PC, where a limited number of companies have a high global market share.

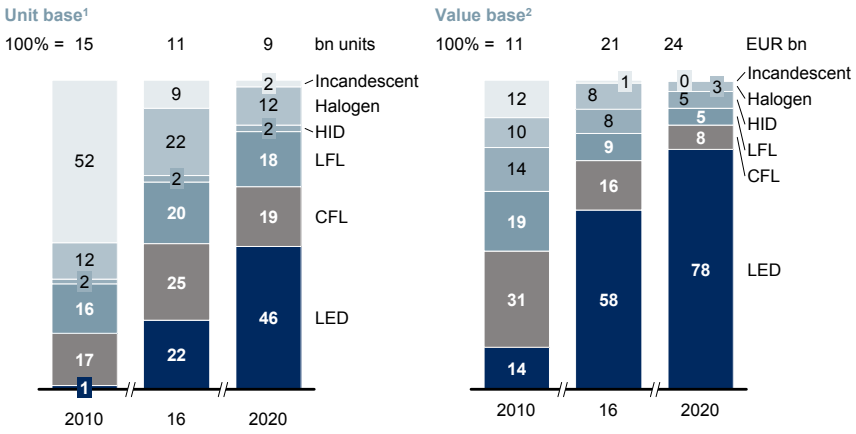
2.4 Technologies transitioning: energy efficiency rising throughout the lighting sector

The current major light source on a unit basis per year (in terms of sales) is incandescent, which has over 52 percent of the general lighting market (12 percent based on value). The second largest light source on a unit basis is the fluorescent lamp, which is already the largest based on value, with a share of over 50 percent. There are two fluorescent types: the linear fluorescent lamp (LFL), which is mainly used in the office segment, and the compact fluorescent lamp (CFL), which is used as a replacement light source for incandescent bulbs. LFL's current market share is around 16 percent on a unit basis (19 percent based on value), while CFL's is 17 percent (31 percent by value). CFL's growth has been significant over the past few years as many governments have been supporting CFL to restrict incandescent usage. Other light sources are halogen and HID. Halogen

Exhibit 10

Other non-LED green technologies will play an important role in the transition to LEDs

Light source technology market share trend in general lighting (lamp level)
Percent



1 Calculated based on number of light sources (lamps), incl. both new fixture installations and replacements; incl. LED modules/light engines
2 Total lamp and LED light engine market (incl. LED module)
NOTE: Numbers may not sum due to rounding

SOURCE: McKinsey Global Lighting Market Model; McKinsey Global Lighting Professionals & Consumer Survey

has a 12 percent market share (10 percent by value), but usage is concentrated in Europe and the US, where awareness of color quality is very high. HID, which is the most recent technology apart from LED, has a 2 percent market share (14 percent by value) (Exhibit 10).

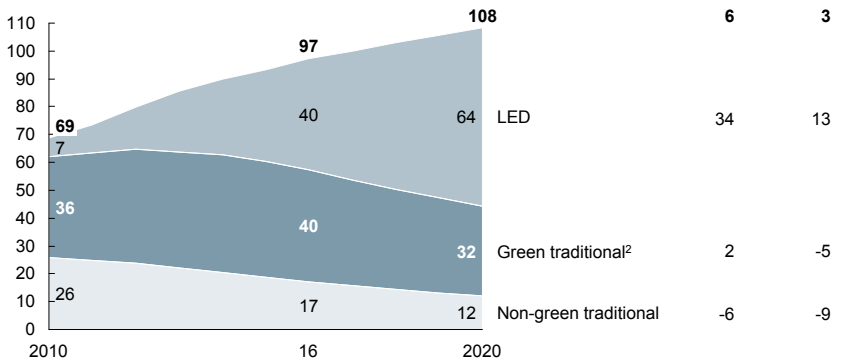
Although incandescent is today's key light source on a unit basis, it has the lowest energy efficiency. LED has a much better efficiency of 60 to 120 lumen per watt (at lighting fixture/lamp level) than incandescent at 10 to 19 lumen per watt, and continues to improve rapidly. However, it is not just LED that has better efficiency. Other non-LED technologies that have greater efficiency than incandescent are CFL at 40 to 70 lumen per watt, LFL at 35 to 87 lumen per watt (T8, for example), and HID at 50 to 115 lumen per watt (e.g., metal halide). Moreover, all traditional lighting technologies are improving their energy saving features as energy saving consciousness increases globally – and to compete with LED – by increasing their efficiency. For instance, while normal halogen's efficiency compared (lamp level) to incandescent's 60W is 11 to 12 lumen per watt, eco-friendly new halogen's efficiency is approximately 15 lumen per watt.[8]

The future technology split will shift towards a more energy-efficient mix, with non-LED green technologies playing a major role before transitioning to LED, especially through to 2016 (until LED gradually becomes more cost competitive). While the incandescent market – calculated on a unit base – will decrease from 52 to 9 percent from 2010 to 2016, the shares of other energy-efficient technologies will increase. CFL, for example, will rise from 17 to 25 percent over the same time scale, and halogen from 12 to 22 percent. These traditional eco light sources will also gain a greater share vis-à-vis the same technology (normal halogen versus eco-friendly halogen, for example) as their availability increases, even though their prices are higher than those of standard products.

Exhibit 11

Energy-efficient traditional technologies will play a significant role before LED transition in 3 - 4 years

Global lighting product market trend[1] by energy-efficient products
EUR billions



1 Total general lighting market (new fixture installations full value chain incl. lighting system control components, and light source replacements), automotive lighting (new fixture installations and light source replacement), and backlighting (light source only: CCFL and LED package)
2 Due to the broad range of different lighting products, green is defined per product group in line with typical energy efficiency standards within the industry, e.g., Energy Star for CFL light bulbs. At the minimum, all green products need to provide an 20% energy efficiency improvement vs. comparable non-green products.

SOURCE: McKinsey Global Lighting Market Model; McKinsey Global Lighting Professionals & Consumer Survey, Industry Experts

Moreover, this trend is not just for general lighting. Exhibit 11 shows the future estimate of the technology transition between non-green traditional lighting versus green traditional lighting, covering general lighting, automotive lighting and backlighting on a full value chain. This shows the importance of green traditional lighting in the overall lighting market before the transition to LED. Due to the broad range of different lighting products, green is defined per product group in line with typical energy efficiency standards within the industry, e.g., Energy Star for CFL light bulbs. At the minimum, all green products need to provide an 20% energy efficiency improvement vs. comparable non-green products.

Deep dive on the general lighting market going forward

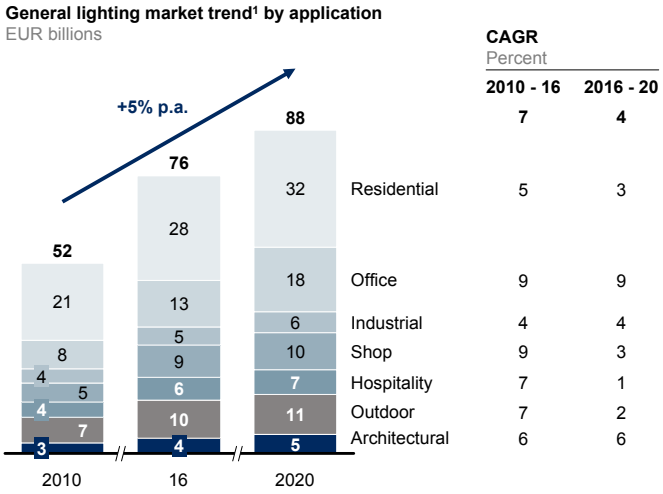
The big picture conveyed in the previous two chapters is based on detailed calculations for every segment, technology, and geography. As general lighting is the largest market, this chapter covers the individual applications in that field and presents the technology trends by geography for each of the regions surveyed. The uptake of LED mapped out over the next decade has radical implications for the sector's industry structure. Companies need to ensure that their strategies factor in these changes as constellations gradually shift towards more new fixture installation business.

3.1 Applications: architectural is the early LED adopter, with residential moving slowly but significantly

General lighting consists of seven applications. The first six – residential, office, shop, hospitality, industrial, and outdoor lighting – are defined by type of location and building. The seventh, architectural, is – in contrast – a functional application, the purpose of which is mainly decorative or to create mood. The market size and development trajectory of each application differs (Exhibit 12). Please refer to Appendix 2 for the definition of each application.

Exhibit 12

Residential is and will remain the largest market segment, followed by office and outdoor



1 Total general lighting market: new fixture installation market with light source and lighting system control component (full value chain) and light source replacement market
NOTE: Numbers may not sum due to rounding

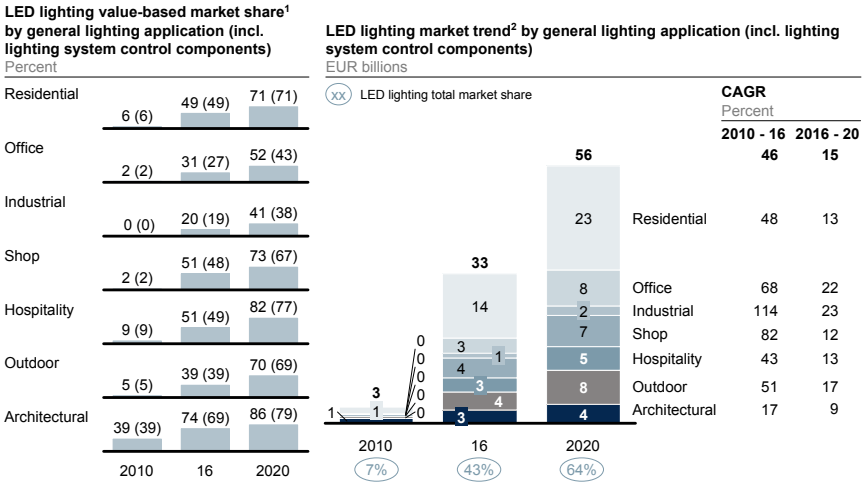
SOURCE: McKinsey Global Lighting Market Model; McKinsey Global Lighting Professionals & Consumer Survey

The applications market is determined by the number of installation locations and life cycle of fixtures. Since approximately 70 percent of buildings are currently residential, the huge number of lighting installation spots make residential the largest application overall.[9] Its market share is around 40 percent, although the average price of lighting products in residential is low relative to others. Office and outdoor follow with a market share of over 10 percent each – again due to their large number of lighting installation spots. Although shop and hospitality have fewer installation spots, their lighting fixture

replacement cycles are faster than for other applications, which increases their lighting market size.

Exhibit 13

Architectural is the early LED adopter, with residential moving slowly, but significantly

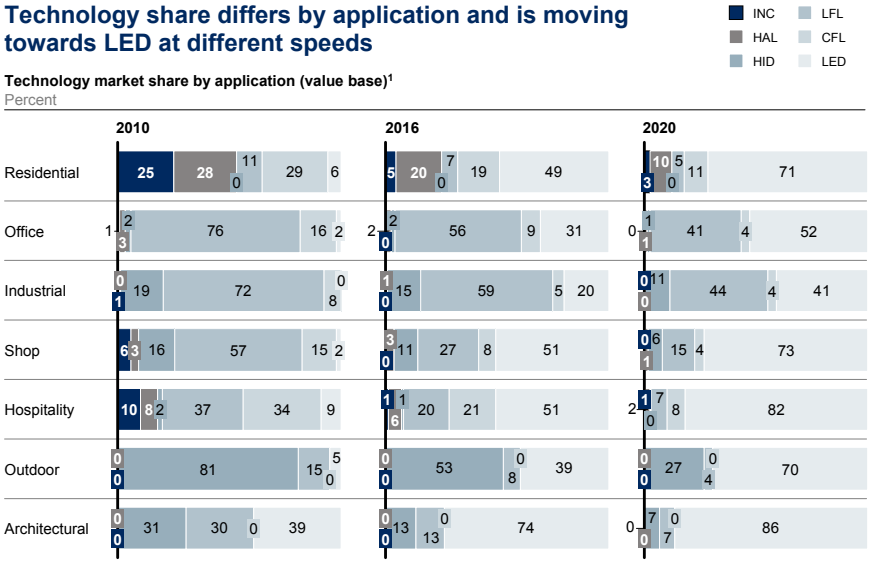


1 Total general lighting market: new fixture installation market with light source and light source replacement market
2 Total general lighting market: new fixture installation market with light source and lighting system control components (full value chain) and light source replacement market
NOTE: Numbers may not sum due to rounding

SOURCE: McKinsey Global Lighting Market Model; McKinsey Global Lighting Professionals & Consumer Survey

Exhibit 14

Technology share differs by application and is moving towards LED at different speeds



1 Total general lighting market: new fixture installation market with light sources (excl. lighting system control component) and light source replacement market
NOTE: Numbers may not sum due to rounding

SOURCE: McKinsey Global Lighting Market Model; McKinsey Global Lighting Professionals & Consumer Survey

LED market share and technology mix vary by application as each has differing key requirements and barriers. These range from technology requirements to mismatched incentives between purchasing decision makers and beneficiaries of energy savings (so-called principal-agent conflicts).[10] These different key requirements and barriers affect each application's LED market share, LED market size (Exhibit 13) and technology mix (Exhibit 14). Architectural lighting already has a value-based LED market share of almost 40 percent, while the other applications only have a single-digit LED market share as yet. Residential is slower where LED penetration is concerned, but is already the largest market thanks to its vast total lighting market size. The subsequent paragraphs provide details for each application.

- ***Architectural.*** Architectural lighting is the prime early adopter of LED. Market share in this application segment was estimated at almost 40 percent in 2010, and is expected to be 74 percent within just five years by 2016, and 86 percent by 2020. One of the biggest advantages of LED in the architectural field is its RGB color controllability. In traditional lighting, RGB code colors are controlled by color film filters (color wheels), which require high maintenance costs. Another important factor is that both the flexibility and speed of color control are limited in traditional lighting. LED has overcome these drawbacks and created new applications, such as media façades and some entertainment lighting. A further trend will be white LED market share. Although this is more expensive than RGB, LED symbolizes energy consciousness, and architectural lighting is widely defined as the high-end building lighting application that tends to use advanced technologies.

- ***Residential.*** Current light sources vary by region in the residential application. Incandescent has the largest share globally on a unit basis, while the shares of halogen and LFL are country-dependent. Europeans tend to use halogen, as they have a strong preference for warm-colored light, whereas Asians tend to use LFL, as their preferences on this are less pronounced.

  The major trend in residential applications today is the increasing share of CFL. People are shifting to CFL as awareness of life cycle costs grows. However, CFL's lower color quality is a barrier to its penetration in segments that are highly conscious of this feature, especially Europe.

  In terms of LED penetration, residential is much slower than architectural lighting. Current LED market share in residential is estimated at around 6 percent at present. The current major LED lighting market in residential is light source replacement as opposed to other segments, and this trend will likely continue through 2016. As its current price is far higher than that of other technologies, current LED market share is limited in this very price-sensitive segment. However, LED lighting is particularly making inroads into lamp retrofitting as its price declines, and the new fixture installation market is also expected to take off, which results in a forecast of almost 50 percent LED market share for 2016 and around 70 percent for 2020.

- ***Office.*** LFL currently has a large share in the office segment, except in high-end office buildings where more downlight-type lighting and warm color light sources are preferred. Other technologies differ by country and by the location where the lighting is installed. LFL is likely to maintain the highest market share even in

2016, as its cost performance will still be the best. LED also faces principal-agent conflicts in this segment (except in owner-occupied buildings), as the decision makers are generally not the beneficiaries of LED's low energy consumption. Current LED market share in the office segment – where LED is a slow mover – is estimated at around 2 percent and expected to grow to around 30 percent by 2016 and approximately 52 percent by 2020.

- ***Shop.*** This application consists of many subsegments, from supermarket (mainly LFL and CFL) to fashion clothing display lighting (mainly halogen and incandescent). Current halogen and incandescent users are sensitive to light quality, requiring high CRI (Color Rendering Index), color consistency and well-managed light distribution. LED is still at a disadvantage where these features are concerned. However, LED's light quality is improving: it already has a CRI of over 90. LED lighting is expected to eventually replace incandescent and halogen as a result of this combined with its other benefits, such as low energy consumption, lower heat generation, and greater design flexibility, once LED costs fall.

  LED is already better than LFL and CFL where many light quality features are concerned, but its current challenge versus these fluorescent lamps is cost. As the cost of LED declines, it is likely to penetrate the current fluorescent lamp segments as well in the shop segment by emphasizing its features of light quality and design flexibility, especially in the new fixture installation market. Moreover, LED's lower maintenance costs are also appreciated in this segment, especially at retail chains such as Starbucks and Walmart.

  Current LED market share in the shop segment is estimated at around 2 percent and is expected to grow to around 50 percent by 2016, increasing to almost 75 percent by 2020.

- ***Hospitality.*** The hospitality segment is complex. Mid- to high-end segments generally prefer warm light such as halogen and incandescent to obtain color quality and dimmability. However, lower-end segments of the hospitality application tend to use LFL, especially in Asia.

  LED market share varies by subsegment, from high-end hotel lighting to low-end restaurant lighting. Current LED market share in hospitality is estimated at close to 10 percent. It is expected to rise to around 50 percent by 2016 and over 80 percent in 2020. Similar to shop lighting, high-end segments in the hospitality application are sensitive to light quality. LED is still at a disadvantage in this respect. However, one aspect in its favor is that the high-end hospitality segment emphasizes light controllability (such as dimming) to change mood. This segment – hotel chains, for example – also tends to be an early adopter of new technology as, to take just one example, lighting is needed 24 hours a day in common areas. These features – in addition to LED's improved light quality – will help drive LED market share.

- ***Industrial.*** LFL and HID are the major technologies in the industrial segment at present. Current LED market share in industrial lighting is estimated at less than 1 percent. A key driver of LED penetration in this segment is total cost of ownership (TCO). LED can reduce lighting maintenance costs significantly, especially in high, hard-to-reach places (high-bay lighting) where replacement costs are much higher than in locations closer to ground level. However, in this

application LED needs to compete with HID and LFL, which have high energy efficiency and good cost performance, limiting LED market share in this segment. LED market share in industrial lighting is expected to be limited to around 20 percent in 2016 and approximately 40 percent in 2020.

- ***Outdoor.*** The current major light sources in the outdoor segment are HID and fluorescent lamps. HID is mainly used for wide-area lighting and LFL for narrow-area lighting. HID mainly consists of mercury vapor, metal halide, high-pressure sodium, and low-pressure sodium lamps. Sodium lamps are very cost efficient (their price is low, and they have a long life), but their color quality is considered poor.

  The major technology shifts in outdoor lighting are towards both HID and LED lighting. Within HID, white (high-CRI) HID is tending to gain share, while LED is increasing its share within white-color preference segments due to its longer lifetime and government support.

  Similar to industrial lighting, the key buying factor in this segment is TCO. Outdoor lighting is mostly installed at considerable heights, and the benefits of LED are greater than in the field of industrial lighting. Current LED market share in outdoor lighting is estimated at around 5 percent. It is expected to be close to 40 percent in 2016, rising to around 70 percent in 2020. Government initiatives are key to adoption. Governments are the chief owners of most outdoor lighting and are therefore the prime decision makers on LED installations. The current pressure on governments to reduce CO_2 emissions will push LED market share in this segment. However, LED needs to compete with HID, and LED will face difficulties in replacing very-high-brightness applications such as stadium lighting, where HID is expected to maintain its strong advantage.

3.2 Geographies: Asia leads the global LED general lighting market

Asia is already estimated to be the largest general lighting market with approximately 35 percent of the total market and is strengthening its position due to strong economic growth driven mainly by China. Asia's lighting market share is expected to be more than 45 percent by 2020. Europe and North America are likely to follow with a market share of approximately 25 percent and 20 percent, respectively, while the rest of the world will lag far behind these regions (Exhibit 15).

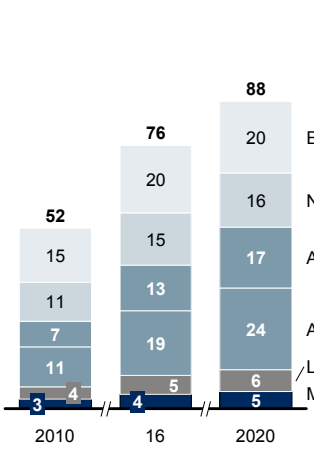
A key reason for this landscape is that growth of the general lighting market is highly correlated with local construction investment. Currently, Asia accounts for an approximate 35 percent share of global construction investment, followed by Europe's 27 percent and North America's 17 percent. Asia also has a higher growth rate than other regions, driven particularly by China and non-OECD Asia growing at a rate of 13 percent and 12 percent, respectively, from 2010 - 16. Growth in Western Europe over the same time period is expected to only be 2 percent (Exhibit 16).

The light source technology mix/LED market share in general lighting varies by region/country and is determined by factors such as government regulation, development of the economy, and light source preference. One of the major drivers for determining technology mix is regulation. A heavy focus on climate change issues is now

Exhibit 15

Asia is the largest lighting market and will strengthen its position going forward

General lighting market trend[1] by country/region
EUR billions



	CAGR Percent 2010 - 16	2016 - 20
	7	4
Europe	4	1
North America	5	1
Asia (China)	10	7
Asia (non-China)	8	6
Latin America	7	4
Middle East & Africa	7	4

1 Total general lighting market: new fixture installation market with light sources and lighting system control components (full value chain) and light source replacement market
NOTE: Numbers may not sum due to rounding

SOURCE: McKinsey Global Lighting Market Model; McKinsey Global Lighting Professionals & Consumer Survey

Exhibit 16

Fixture market will be supported by high construction investments in developing countries, especially in non-OECD Asia, incl. China

Construction investment trend[1] by country/region, 2005
EUR billions

Share (percent)
High growth rate

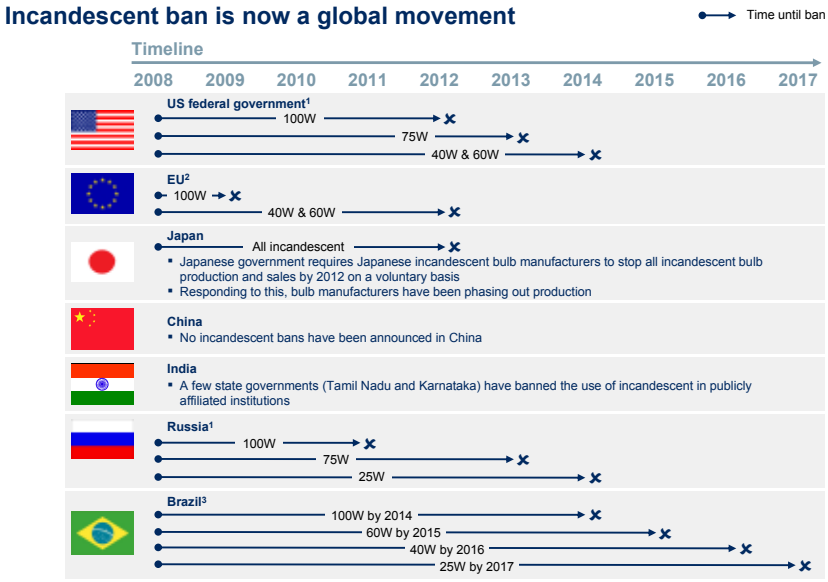
		2010		2016		2020		CAGR Percent 2010 - 16	2016 - 20
	North America	33	17	59	20	70	19	10	5
Europe	Western Europe	38	20	44	15	49	13	2	3
	Eastern Europe	13	7	21	7	26	7	8	6
Asia	OECD Asia Pacific	27	14	33	11	34	9	3	1
	China	12	6[3]	24	8[3]	35	9[3]	**13**	**10**
	Non-OECD Asia[2]	27	14	54	18	77	21	**12**	**9**
	Latin America	28	15	44	15	55	15	8	6
	Middle East & Africa	12	6	18	6	24	6	7	7
	Global	190	100	296	100	370	100	8	6

1 Capital expenditure (capex) includes investments made by establishments operating in that sector during the reference year, net of fixed assets sold on a real basis (not nominal)
2 Excl. China
3 China's share is significantly higher in nominal terms, 2010: 10%, 2016: 15%, 2020: 18%

SOURCE: Global Insight

driving regulation in each country/region. The current major light source worldwide, incandescent, is – after dominating for around 100 years – facing a phaseout in many regions due to government regulations. Its lifetime is shorter than that of any other technology and its efficiency is also lower, resulting in the global movement to ban incandescent usage (Exhibit 17). As incandescent currently accounts for a significant share of the overall lighting market, this phaseout is having a high (but varied) impact on each country's/region's overall technology mix.

Exhibit 17



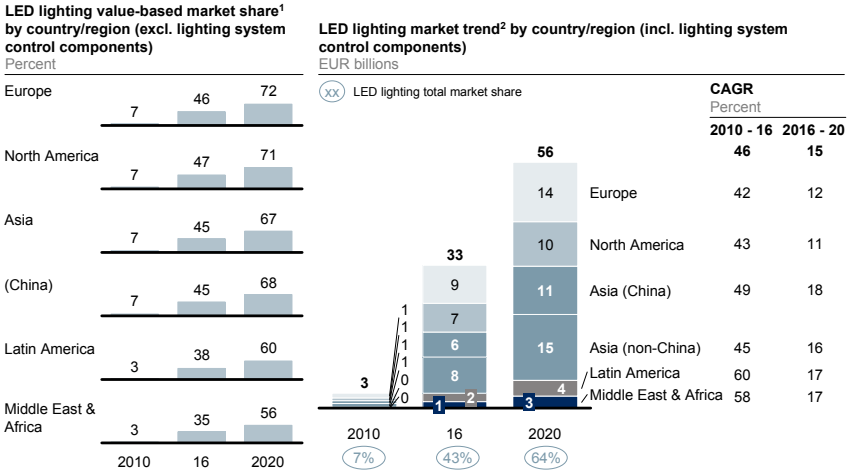
SOURCE: Press search; Credit Suisse analyst report; McKinsey analysis as of June 2011

Research indicates that the path to regional LED penetration might differ by country/region. Currently, LED market shares in North America, Europe, and Asia are similar, with each at around 7 percent. LED penetration in Asia is going to be behind that of Europe and North America for reasons inherent to the trajectory of developing countries, which include the lower price range of traditional lighting, more limited adoption of the incandescent ban, and lower electricity costs. However, the vast size of Asia's total general lighting market, which is currently more than 35 percent of the global general lighting market (with China accounting for around 15 percent), positions Asia as the largest LED general lighting market as well.

This position is expected to continue strengthening due to the heavy growth of its overall general lighting market, as outlined previously. The 2020 forecast for Asia's LED general lighting market is EUR 26 billion, followed by Europe with EUR 14 billion, and North America with EUR 10 billion (Exhibit 18).

Exhibit 18

Asia is leading the global LED general lighting market with 40 - 50 percent of the total market going forward



1 Total general lighting market: new fixture installation market with light sources and light source replacement market
2 Total general lighting market: new fixture installation market with light sources and lighting system control components (full value chain) and light source replacement market
NOTE: Numbers may not sum due to rounding

SOURCE: McKinsey Global Lighting Market Model; McKinsey Global Lighting Professionals & Consumer Survey

At a more granular level, trends differ by country/region, as described below.

- ***North America.*** At present, North America's LED market share is estimated at around 7 percent, with a market size of EUR 1 billion. This market is currently led by the new fixture installation market, especially in the non-residential segment, supported by several government initiatives such as the LEED (Leadership in Energy and Environmental Design) program in the US. Although the incandescent ban will come into effect starting in 2012, LED market share may grow more slowly in the light source replacement market. CFL and electricity prices are relatively low in most US states, which means the benefits of LED light bulbs are limited. However, LED market share is likely to increase as the price of LED lighting goes down, even in the residential and light source replacement segments. These factors will accelerate LED market share in North America, which is expected to rise to over 45 percent in 2016 and around 70 percent in 2020 on a value basis, including both new fixture installation and light source replacement.

- ***Europe.*** LED market share in Europe is currently estimated at around 7 percent, with a market size of around EUR 1 billion, similar to that of North America. The current major application of LED lighting in Europe is architectural lighting as European buildings tend to be decorated by colorful exterior lighting, where RGB-type LEDs have considerable advantages. The incandescent ban will be a key trigger for increasing LED market share, particularly white light. Europe has the fastest incandescent ban roadmap. Almost all incandescent lighting will be banned by 2012. However, Europeans are very light-quality-conscious, which could be a potential barrier. Halogen lighting is likely to benefit from the incandescent ban until LED overcomes its color quality issues. However, Europe's high electricity prices and tendency towards high energy awareness will push up LED's share of the

market, especially in Western Europe, while Eastern Europe lags behind. Europe's LED market share is expected to be over 45 percent by 2016 and over 70 percent by 2020.

- ***Asia.*** Currently, the Asian general lighting market is already the largest market in terms of both total general lighting and LED lighting. Furthermore, heavy demand for new construction and the increasing affordability of LED will strengthen Asia's position in the global lighting market. In terms of current LED market share, Asia's figures are similar to those of Europe and North America due to the Chinese government's strong support for LED street lighting and Japan's strong retrofit market. However, Asia's LED market share is expected to be lower than that of Europe and North America, at around 45 percent in 2016, rising to almost (but not above) 70 percent in 2020.[11]

  China plays a significant role in this region due to its large economic size and strong growth. LED's main market share in China is in outdoor and architectural lighting. The government intensely supports the installation of outdoor LED lighting, aspiring to achieve an LED share in this segment of 30 percent by 2015. The high demand for landmark buildings also favors architectural lighting. Total LED market share in the Chinese market is going to be lower than in the West due to several factors. Local governments strongly support CFL, and the price of CFL is relatively low, buoyed by local Chinese brands. This limits LED penetration in the residential segment, which is the largest application. (The average CFL price is USD 2 to 3 without government subsidies, and government subsidies for residential use are 50 percent of the price at present.) China's LED market share is currently estimated at around 7 percent. It is expected to be around 45 percent in 2016 and over 65 percent in 2020. However, thanks to the enormous size of its total lighting market, China is expected to account for 20 percent of the global LED general lighting market in 2020, with a market size of EUR 11 billion.

  Japan will be an early adopter in the retrofit market. One factor is the current high price of CFL lighting, which is six times that of China. The availability of highly energy-efficient LED bulbs is another: LED bulbs equivalent to 60W incandescent bulbs typically offered in Japan only consume 4 - 9W compared to 11 - 12W as is typical in Europe and the US. A further push comes from strong retailer and manufacturer promotion of LED, as well as recent energy saving requirements due to the Fukushima nuclear disaster. As a result of all these drivers, the LED retrofit market in Japan is already taking off. However, the current very high fluorescent market share – even in residential segments – will be a barrier to expansion of the total LED general lighting market in Japan.

- ***Rest of world.*** The rest of the world – Latin America, the Middle East, and Africa – accounts for a much smaller share than the other regions covered in the survey in terms of the size of both their total general lighting and LED general lighting markets. LED is nevertheless expected to gradually penetrate these regions depending on application, though the speed of uptake is likely to be slower than elsewhere. The LED market share is currently estimated at around 3 percent in each of these regions. It is expected to rise to 35 - 40 percent in 2016 and 55 - 60 percent in 2020. This is mainly driven by the growth of major cities and urbanization in Latin America and the Middle East, as mentioned in Chapter 1.

3.3 Structural shift: new installation business overtaking replacement

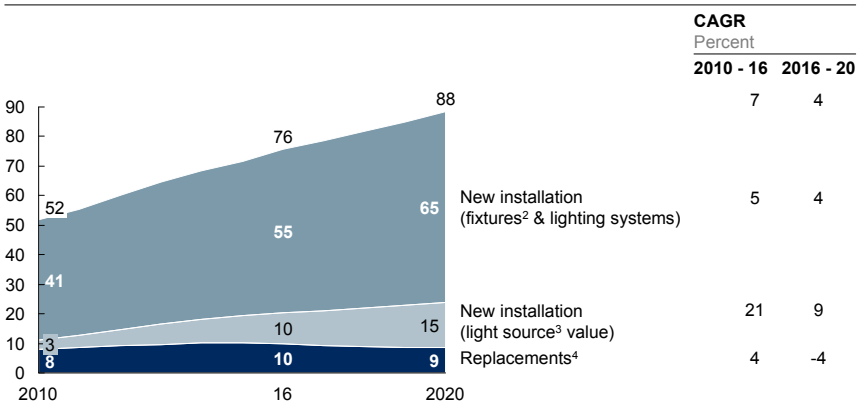
As outlined in the course of this report, a market shift is taking place from incandescent lighting, with a lifetime of only 1,000 hours (as standard light bulb example), to longer-life light sources such as fluorescent lamps and LED, which last more than 10 times longer than incandescent sources. (Please refer to Appendix 1 for technical descriptions of the different technologies.) This trend is shrinking the light source replacement market and transferring value creation to new fixture installation in the general lighting market (Exhibit 19).

The shift towards integrating light sources and fixtures in LED (due to the technology's long lifetime) is accelerating this trend. Even though an LED's lifetime – as a light source – is over 10 years, the new fixture installation market will not deteriorate to the same extent. This is because the lifetime of a fixture is not only determined by the durability of the lighting products in most applications, but also by the renovation cycle of each lighting application.

Exhibit 19

Value is steadily shifting to the fixtures market as the general lighting market grows

New installation and replacement market trend[1] in general lighting
EUR billions



1 Total general lighting market: new fixture installation market with light sources and lighting system control components (full value chain) and light source replacement market
2 Fixtures include electrical components (ballasts)
3 Light sources include traditional lamps and LED modules/light engines, incl. packages
4 Replacement light sources are defined as light bulbs/tubes in traditional lighting and LED modules/light engines in LED lighting
NOTE: Numbers may not sum due to rounding

SOURCE: McKinsey Global Lighting Market Model; McKinsey Global Lighting Professionals & Consumer Survey

The fixtures with the longest life are used for outdoor street lighting, with a replacement cycle that often exceeds two decades. But shop lighting fixtures tend to be replaced approximately every seven years due to renovation cycles.

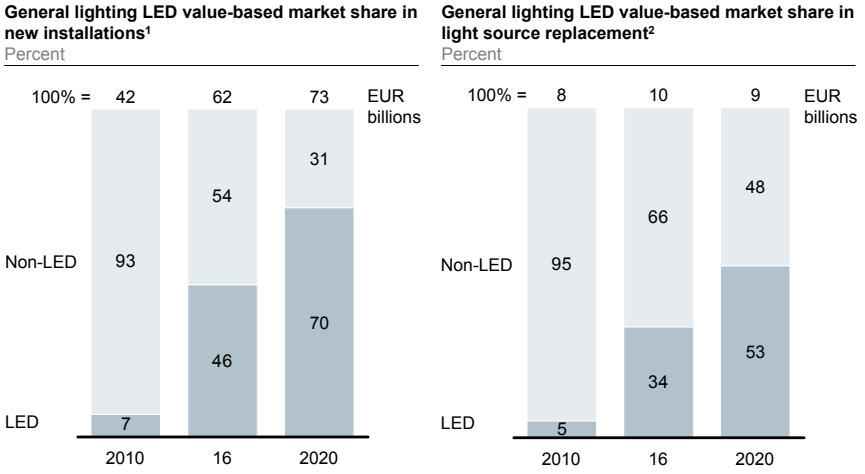
As a result of these changes, the development trajectory of new fixture installation in LED is rising faster than that of light source replacement. This is because the technological benefits of LEDs can be realized more readily in LED-embedded fixtures than by using LED replacement lamps, regardless of the high cost. For instance, one of the major benefits of LED lighting is its color controllability – especially valuable in architectural lighting, where it is difficult to use LEDs as replacement lamps. Other examples are high-bay lighting, ground-embedded lighting, or underwater lighting, where the cost of

replacing a light source is high, and users may prefer not to have to replace it at all. These are just early-adopter examples. LED replacement lamps can be used in new non-LED fixtures, too, especially when users are changing fixtures in their old building, which will also drive faster LED market share than light source replacement. Current LED market share in new fixture installation is estimated at around 7 percent. This figure is expected to rise to more than 45 percent in 2016 and to around 70 percent in 2020 (Exhibit 20).

This industry shift from the light source replacement business towards new lighting fixture installation is set to transform the industry supply chain going forward. The current light-bulb-centric supply chain – where a few global light source manufacturers supply their products to local markets – is at least temporarily losing its hold, with manufacturing sites

Exhibit 20

In general lighting, LED penetration started in new fixture installation, the LED retrofit market will follow



1 Value-based fixtures (incl. CCG/ECG) and light sources, excl. lighting system control components
2 Value-based light sources
NOTE: Numbers may not sum due to rounding

SOURCE: McKinsey Global Lighting Market Model; McKinsey Global Lighting Professionals & Consumer Survey

becoming more fragmented. As LED light engine standards are still unclear, it is difficult to predict the exact evolution of this future industry, but this structural shift in the supply chain has radical implications for all industry players and will require the development of entirely new business strategies.

Endnotes

1 Global TV and PC market from: iSupply, LED-backlit LCD-TV to hit worldwide market, IHS, June 2011; iSupply, PC market incl. Desktop PC, Notebook PC, Netbook PC, and tablet PC forecast 2010H2, IHS, 2010.

2 Estimated based on J.P. Morgan Cazenove, Electrical engineering and semiconductor equipment: Winners and losers in a radically changing lighting market driven by LED, March 2010, and Fuji Keizai, light source/lighting fixture market report 2010, February 2010.

3 US Department of Energy, Solid-state lighting LED manufacturing roadmap, 2011 (www.energy.gov); US Department of Energy, Solid-state lighting research and development: Multi year program plan, Prepared for: Lighting Research and Development Building Technologies Program, 2011 (www.energy.gov); US Department of Energy, Solid-state lighting multi-year program FY'09-FY'15, Prepared for: Lighting Research and Development Building Technologies Program, 2011 (www.energy.gov).

4 Haitz et al., The case for a national research program on semiconductor lighting, October 1999; Edwards, Samsung's series 7000 LED TV keeps you connected, BusinessWeek, 15 October 2009.

5 J.P. Morgan Cazenove, Electrical engineering and semiconductor equipment: Winners and losers in a radically changing lighting market driven by LED, March 2010.

6 Please refer to Appendix 3 for the definition of lighting systems control component.

7 Based on estimates by US Energy Information Administration and Lumina Technologies, Survey of 156 California commercial buildings energy use, August 1996.

8 Strategies Unlimited, The market for high-brightness LEDs in lighting, 2010. US Department of Energy, Solid-state lighting LED manufacturing roadmap, 2011, etc.

9 Pike Research, Global Building Stock Database, 2011.

10 Principal-agent conflicts are conflicts that arise when the decision-maker's (the agent) interests are not aligned with those delegating (the principal) the decision-making power. The principal hires an agent to perform tasks on his or her behalf, but cannot ensure that the agent performs the tasks precisely in the most optimal way for the principal.

11 This is because most of Asia is still developing economically, and an energy-efficient light source – fluorescent – is already popular in the region. There are several reasons for the popularity of fluorescent lighting. One, as already mentioned, is that Asians tend not to have a strong preference for warm-colored light. Others are their appreciation of fluorescent lighting's high energy efficiency, and of light sources – even in the residential segment – that have a long lifetime.

12 Based on US Department of Energy data at package level and calculated to lamp/lighting fixture level assuming 35 percent efficacy drop from package level to luminaire level.

Appendices

1. Definition of light source technologies

There are seven technologies in the light source arena: incandescent lamps, halogen lamps, linear fluorescent lamps (LFL), compact fluorescent lamps (CFL), high-intensity discharge (HID) lamps, light emitting diodes (LED) and organic light emitting diodes (OLED).

Incandescent lamps create light by heating a suitable material (usually metal filament wire) to a high temperature until it glows. The technology has a relatively low luminous efficacy (~ 10 - 19 lumen per watt) and a short lifetime (750 - 2,500 hours). The lamps have a high color quality (~ 97 CRI), are quick to switch on and are dimmable.

Halogen lamps are a type of incandescent lamp. They have a tungsten filament just like incandescent lighting, but the bulb is filled with halogen gas. Halogen results in a longer lifetime and a cleaner bulb wall for the light to shine through. Halogen lamps have a luminous efficacy of between 11 and 20 lumen per watt, and a lifetime of 2,000 - 3,500 hours. These lamps are characterized by high color quality (~ 99 CRI) and a fast turn-on time.

Linear fluorescent lamps (LFLs) are gas-discharge lamps that use electricity to excite mercury vapor. LFL has a relatively high luminous efficacy (~ 35 - 87 lumen per watt) and a lifetime of 7,500 - 20,000 hours with T8 as an example. LFLs take a couple of seconds to turn on. The luminous efficacy of LFLs is high, but the color quality is low (~ 52 - 90 CRI), and the color tends to be cold.

Compact fluorescent lamps (CFLs) contain a gas that produces invisible ultraviolet light (UV) when the gas is excited by electricity. The UV light hits the white fluorescent coating material inside the bulb and the coating changes it into visible light. CFLs have a luminous efficacy of 40 - 70 lumen per watt and a lifetime of ~ 10,000 hours. The color quality has traditionally not been as good as incandescent even though it is improving, and has already achieved CRIs in the low 80s. The turn-on time of CFLs is usually slow.

High-intensity discharge (HID) lamps are a type of arc lamp. The technology produces light by establishing an arc between two electrodes in a gas-filled tube, which causes a metallic vapor to produce radiant energy. A metal halide HID lamp, for instance, has high luminous efficacy and output (~ 50 - 115 lumen per watt) as well as a long lifetime (~ 3,000 - 20,000 hours), but relatively low color quality (~ 65 - 70 CRI). There are some other types of HID, such as mercury vapor lamps and high-pressure sodium lamps, and characteristics vary among these subtechnologies.

Light emitting diodes (LED) are a semiconductor light source. An LED is often very small (less than 1 mm^2), and integrated optical components may be used to shape its radiation pattern. LEDs have a relatively high luminous efficacy (~ 60 - 120 lumen per watt[12]) and a lifetime of 12,000 - 50,000 hours. The CRI is approximately 44 - 90. The technology is characterized by having tunable and flexible color and almost instant turn-on time.

Organic light emitting diodes (OLEDs) are LEDs where the emissive electroluminescent layer is a film of organic compounds emitting light in response to an electric current. OLEDs have an luminous efficacy of 25 - 75 lumen per watt and a lifetime between ~ 14,000 and 30,000 hours. OLED technology is still emerging.

2. Definition of general lighting applications

General lighting has been categorized into seven applications for the purposes of this market report. General lighting includes a residential application and six professional applications: office, hospitality, shop, industrial, architectural, and outdoor.

Residential. The residential application includes both permanently installed fixtures and portable plug-in fixtures. Permanent fixtures are usually purchased by home builders in large quantities via wholesalers and manufacturers' representatives. Permanent fixtures include recessed sconces and undercabinet lights. Portable fixtures are purchased by homeowners in retail stores, and include pendants, table lamps and floor lamps. Light sources vary by region in the residential segment, which is very price sensitive.

Office. The office application comprises lighting for office buildings, healthcare institutions and educational buildings as well as other buildings that are utilized for public or commercial purposes. This includes meeting rooms, workspaces, receptions, hallways/corridors, staircases, restrooms, and basements.

Industrial. This application consists of general lighting in production, assembly and storage spaces in factories and warehouses. It includes downlights, linear lights, spotlights, high/low bay lights and task lighting.

Shop. The shop application consists of display lighting, decoration as well as general shop floor area lighting. Different products – ranging from jewelry through to clothing, cosmetics, and food – require different types of lighting.

Hospitality. This lighting application includes general lighting for hotels, bars and restaurants. The hospitality application is often focused on decorative lighting and spans an entire spectrum from mood lighting to orientational lighting.

Outdoor. This application includes lighting for streets, highways, tunnel lights, and other public and non-public outdoor areas such as parking lots, low bays and area lighting in stadiums. Outdoor lighting has to fulfill three criteria: safety, security, and esthetics. Safety means adequate lighting for visibility, security is required as a deterrent to crime, and esthetics is important to create an inviting, intimate atmosphere. The cost of maintenance associated with outdoor applications is relatively high.

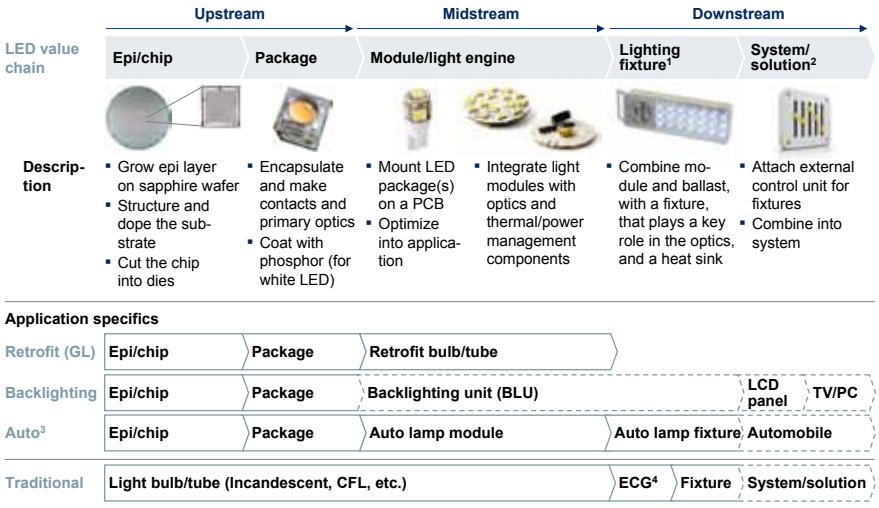
Architectural. This application is used for the illumination of building structures, with the artistic integration of light source and architectural elements. Architectural lighting can be both functional and decorative. In addition, architectural lighting can be applied both outdoors and indoors.

3. LED value chain definition

The LED lighting value chain consists of three steps: upstream, midstream, and downstream. The upstream value chain covers the epi/chip process and the LED packaging. Midstream is classified as the creation of modules/light engines. The downstream steps of the value chain comprise creating the LED lighting fixture and the final system or solution (Exhibit 21).

Exhibit 21

LED general lighting value chain (LED embedded-type fixture)



1 The same definition as luminaire
2 Fixtures have a minimum number of external control components, but a more sophisticated controller/system can be added to LED lighting
3 Exterior lighting example
4 Electronic control gear (ballasts)

SOURCE: Amadeus; Bloomberg; analyst reports; expert interviews; Strategies Unlimited; team analysis

Epi/chip. Epitaxy refers to the process of evolving a wafer (sapphire or SiC, for instance) by depositing epitaxial layers on the wafer using MOCVD. Creating the epitaxial layers is the most critical and capital-intensive step in LED manufacturing. After additional wafer processing to create the metal connection, the wafer is cut up ("diced") into chips. Although it can be used for different applications, the quality requirements (mainly efficacy) of the epi/chip differ by application.

Package. The package procedure involves encapsulating and protecting the epi/chip using package substrate and epoxy or silicone resin. White LED packages are coated with phosphor. The types of package differ by application.

Module (sometimes called light engine). Creation of a module (light engine) is the next step in the LED lighting value chain. The module (light engine) mainly consists of one or more LED packages, secondary optics, a heat sink and an electrical driver. The LEDs are mounted on a PCB (printed circuit board), and the modules (light engines) are integrated with optics and thermal/power management components to optimize the module (light engine) to each application.

For the backlighting application, the creation of a module (light engine) cannot be viewed as a discrete step. This is because backlighting units are produced directly from LED packages.

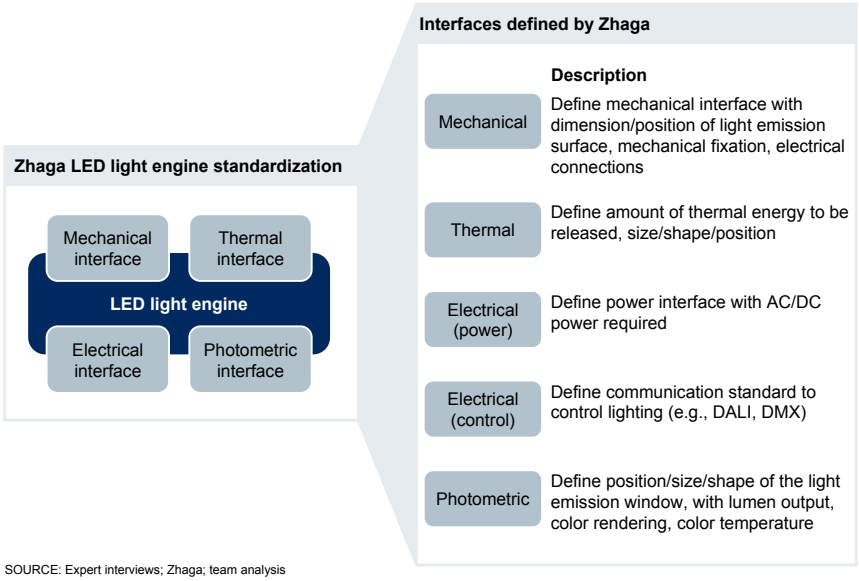
The distinction between “module” and “light engine” is not well defined yet. According to the Zhaga Consortium definition, a light engine is a wider idea than a module; “an LED light engine is the combination of an LED module and the associated control gear. A light engine can have an integrated control gear or a physically separated control gear.” – the Zhaga Consortium. To avoid confusion, this market report treats

"module" and "light engine" as the same definition especially in the market size calculation.

Exhibit 22 shows the Zhaga Consortium's concept of light engine standard setting, which is trying to define the interchangeability of light engine interfaces from the 4 points of view: mechanical interface, thermal interface, electrical interface, and photometric interface.

Exhibit 22

Zhaga defines interfaces for interchangeability (standard) of light engines



SOURCE: Expert interviews; Zhaga; team analysis

Lighting fixture (or luminaire). These exist in general lighting and automotive lighting, but not in backlighting. In this step of the value chain, module/light engine and ballast are combined with additional optics, heat sinks, and cases to combine them into a complete lighting product. The lighting fixture helps to optimize the optics, and also functions as a heat sink. Lighting fixture and luminaire are synonymously used terms.

System/solution. At the systems/solutions step of the value chain, the fixture is enhanced by attaching external lighting control units and providing fully integrated solutions.

Previously system controls consisted of a simple switch. Recently, lighting system controls have a number of advanced features, such as enhanced RGB color changeability, dimming, and color temperature control.

The market size calculation in this market report covers lighting systems control components; i.e.,

- Lighting control sensors, including sensors on the wall and ceiling
- Lighting controllers, which connected to sensors and electronic lighting ballasts and range from standard systems to advanced LCD panels

- Other lighting system control components are, e.g., master controllers connecting multiple control panels and integrated software as well as network communications and interfaces to building management systems.

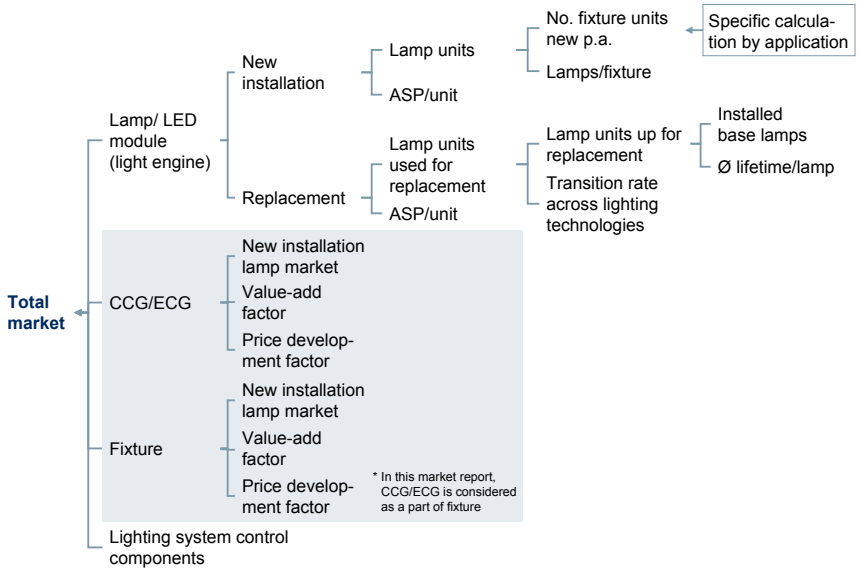
Services pertaining to lighting solutions for buildings, e.g., planning, installation, and labor, as well as lamp replacement services and energy management services, are not included in the lighting systems control components in this market report. Theatrical lighting (programmed specifically for entertainment), wiring conduits, and building management systems are also excluded.

4. McKinsey's global lighting market model (market model approach)

McKinsey's market model was designed to capture the full lighting market for general lighting, automotive lighting, and backlighting. The model is differentiated by application, main lighting technologies, geographies, and value chain steps. The model structure and logic are consistent across all applications. The model follows an end-market-oriented approach, allocating a unit (fixture, car, device) to the region where it is ultimately sold. The modeling included both annual new installation business on a total systems level (from lamp through to fixture and lighting systems control) as well as annual replacement business on a lamp level. Further detail is not provided on other replacement business with other components in the course of the lifetime of a fixture (e.g., CCG/ECG or LED module/light engine) given its limited contribution to the overall market size. For simplicity, our model assumes continued stable development of the global economy. Exhibit 23 illustrates the basic structure of the model on the level of the three main applications: general lighting, automotive, and backlighting.

Exhibit 23

Basic model structure (simplified view)



SOURCE: McKinsey

This market model calculation assumes a currency rate of EUR 1 = USD 1.35.

- ***General lighting.*** For general lighting, annual new fixture installation as well as the installed base of fixtures are derived from global real estate, road, and infrastructure statistics. Regionally differentiated illumination intensity metrics were applied to these fundamental model drivers, e.g., required lumen per m^2 of office space. This determines the relevant need for illumination in terms of lumen demand. Table 1 gives an overview of the fundamental inputs to the model derived from use cases and expert interviews.

Table 1

FUNDAMENTAL INPUTS TO GENERAL LIGHTING									
	Illumination intensity			**Standard luminaire**			**Other metric**		
General lighting application		**MIN**	**MAX**		**MIN**	**MAX**		**MIN**	**MAX**
Residential	lm/sqm	100	150	lm/unit	1,000	1,200			
Office	lm/sqm	150	400	lm/unit	4,500	6,500			
Industrial	lm/sqm	200	350	lm/unit	3,000	5,000			
Shop	lm/sqm	200	300	lm/unit	2,500	3,500			
Hospitality	lm/sqm	200	350	lm/unit	1,500	2,000			
Outdoor							unit/km	5	16
Architectural							sqm/unit	8	20

Note: Min/Max across regions, between 2010 - 2020

A standard fixture is then defined that is comparable across lighting technologies in terms of lumen output, e.g., 6,500 lumen output for a standard office fixture. This lumen value (i) determines the installed base of fixtures required to illuminate the globally available office space, and (ii) forms the basis for determining the required number of light sources per fixture. The unit number of new installation fixtures p.a. is driven by (a) changes in the underlying real estate, road, and infrastructure statistics, (b) development in the illumination intensity metric (e.g., emerging regions with lower lumen/m^2 ratios compared to developed regions, but with a narrowing gap and increasing wealth in these economies), and (c) by the typical lifetime of a fixture, determined by technical limitations as well as other factors such as changing design preferences. The average number of fixtures per km of road was used as a proxy for the outdoor segment. A ratio of m^2 of building space/number of fixtures was applied for the architectural segment. Table 2 summarizes the underlying assumptions on average fixture lifetimes by application.

Table 2

GENERAL LIGHTING APPLICATION – LIFETIME OF LUMINAIRE		Average	MIN	MAX
Residential	Years	10	8	12
Office	Years	12	10	14
Industrial	Years	14	13	15
Shop	Years	7	7	7
Hospitality	Years	8	8	8
Outdoor	Years	22	15	30
Architectural	Years	10	10	10

Note: Avg/Min/Max across regions, between 2010 - 2020

Table 3 provides an overview of key model outputs. The summary only shows the most relevant data cuts along the different model dimensions. Value-added factors for extrapolating the size of the related ballast and fixture market from the lamp/LED module (light engine) market are based on product teardowns and expert interviews.

Table 3

GENERAL LIGHTING												
Annual new installation	**Unit**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
# Fixtures	mn pcs	1,682	1,766	1,845	1,925	2,007	2,093	2,178	2,273	2,374	2,481	2,594
Residential	mn pcs	1,290	1,342	1,393	1,447	1,504	1,563	1,626	1,692	1,762	1,835	1,913
Office	mn pcs	107	113	121	128	135	142	149	157	165	174	183
Industrial	mn pcs	39	44	45	46	47	49	51	52	53	55	57
Shop	mn pcs	89	95	100	105	109	114	121	127	132	138	144
Hospitality	mn pcs	83	87	91	96	100	104	97	99	102	104	107
Outdoor	mn pcs	23	22	26	26	26	26	28	28	29	29	29
Architectural	mn pcs	51	62	70	77	86	95	106	118	131	145	161
Technology mix	%	100	100	100	100	100	100	100	100	100	100	100
Incandescent	%	22	20	18	13	9	7	5	4	4	4	3
Halogen	%	18	18	18	18	18	17	15	13	11	9	8
HID	%	2	2	2	2	2	2	1	1	1	1	1
LFL	%	24	24	23	22	21	19	18	16	14	13	12
CFL	%	32	31	30	29	28	26	23	22	19	17	14
LED lamp	%	1	2	4	6	8	9	11	11	11	10	8
LED module	%	2	3	5	9	14	20	27	33	40	46	54
# Lamps / LED modules	mn pcs	2,913	3,075	3,245	3,431	3,609	3,802	3,998	4,205	4,383	4,545	4,661
Incandescent	mn pcs	794	766	698	550	399	314	219	207	195	199	181
Halogen	mn pcs	614	660	697	728	737	719	679	591	525	473	407
HID	mn pcs	43	44	46	45	43	40	37	33	29	26	22
LFL	mn pcs	636	673	685	687	682	659	630	594	562	521	489
CFL	mn pcs	696	722	725	725	728	704	653	616	564	509	436
LED lamp	mn pcs	44	74	155	242	311	377	466	506	515	511	447
LED module	mn pcs	85	135	238	455	709	988	1,314	1,657	1,993	2,307	2,678
ASP per lamp / module1	EUR / unit	1.15	1.34	1.66	2.03	2.22	2.36	2.61	2.80	2.94	3.06	3.20
Incandescent	EUR / unit	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.18	0.19	0.19
Halogen	EUR / unit	0.53	0.55	0.57	0.58	0.59	0.59	0.59	0.58	0.58	0.58	0.57
HID	EUR / unit	7.37	7.15	7.02	6.84	6.70	6.50	6.32	6.10	5.87	5.66	5.45
LFL	EUR / unit	0.90	0.88	0.86	0.85	0.83	0.82	0.81	0.80	0.80	0.79	0.79
CFL	EUR / unit	1.28	1.24	1.21	1.19	1.16	1.12	1.07	1.04	1.00	0.96	0.92
LED lamp	EUR / unit	8.12	6.12	5.04	4.38	3.92	3.40	3.36	3.34	3.25	3.04	2.93
LED module	EUR / unit	8.90	10.22	9.60	7.99	6.49	5.69	5.30	5.05	4.86	4.76	4.65
Total new installation market	EUR mn	43,915	46,635	50,931	55,014	58,332	61,307	65,620	69,331	72,826	76,113	79,561
Lamp / module level	EUR mn	3,354	4,129	5,383	6,962	8,019	8,972	10,416	11,768	12,880	13,902	14,925
CCG / ECG level	EUR mn	3,582	3,957	4,463	5,226	5,980	6,702	7,525	8,342	9,205	9,999	11,052
Fixture level, excl. CCG / ECG	EUR mn	35,452	36,803	39,085	40,526	41,680	42,562	44,114	45,068	45,888	46,521	46,886
Lighting control system level	EUR mn	1,526	1,745	2,000	2,300	2,654	3,071	3,565	4,153	4,854	5,692	6,698
Annual replacement business												
Installed base Fixtures	mn pcs	12,822	13,231	13,678	14,150	14,649	15,174	15,726	16,299	16,903	17,540	18,214
Incandescent	mn pcs	6,723	6,425	6,144	5,865	5,546	5,187	4,825	4,452	4,112	3,801	3,523
Halogen	mn pcs	763	989	1,211	1,429	1,638	1,831	1,996	2,127	2,202	2,237	2,243
HID	mn pcs	452	464	475	485	492	496	496	492	485	474	461
LFL	mn pcs	3,344	3,398	3,467	3,531	3,594	3,651	3,690	3,704	3,696	3,671	3,621
CFL	mn pcs	1,385	1,762	2,115	2,430	2,710	2,964	3,173	3,326	3,439	3,503	3,524
LED lamp	mn pcs	27	46	79	149	254	383	530	705	880	1,039	1,180
LED module	mn pcs	128	147	185	261	414	662	1,015	1,493	2,089	2,815	3,663
Installed base lamps / modules	mn pcs	24,339	25,021	25,812	26,781	27,925	29,239	30,788	32,645	35,064	37,718	40,610
Incandescent	mn pcs	12,255	10,094	7,975	5,964	4,144	2,617	1,349	456	181	25	1
Halogen	mn pcs	1,978	2,739	3,445	3,992	4,308	4,323	4,100	3,731	3,252	2,745	2,227
HID	mn pcs	487	500	511	519	525	526	521	511	496	477	453
LFL	mn pcs	5,427	5,556	5,675	5,781	5,851	5,875	5,847	5,762	5,611	5,385	5,093
CFL	mn pcs	3,737	5,394	6,943	8,345	9,524	10,407	11,019	11,304	11,304	11,107	10,714
LED lamp	mn pcs	109	237	498	919	1,532	2,379	3,379	4,452	5,600	6,829	8,059
LED module	mn pcs	346	502	765	1,261	2,043	3,112	4,572	6,429	8,620	11,151	14,063
Lamps up for replacement	mn pcs	11,629	10,717	9,945	9,178	8,464	7,701	6,852	5,978	5,277	4,810	4,366
Incandescent	mn pcs	8,589	6,785	5,343	4,040	2,982	2,072	1,308	674	228	91	13
Halogen	mn pcs	744	1,364	1,800	2,135	2,314	2,335	2,170	1,898	1,672	1,424	1,184
HID	mn pcs	187	193	198	204	208	211	211	210	206	200	192
LFL	mn pcs	1,693	1,677	1,664	1,648	1,630	1,606	1,574	1,536	1,488	1,429	1,358
CFL	mn pcs	416	699	940	1,152	1,331	1,478	1,588	1,660	1,683	1,666	1,620
LED lamp	mn pcs	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LED module	mn pcs	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Lamps used for replacement	mn pcs	11,631	10,717	9,945	9,180	8,470	7,710	6,864	5,996	5,304	4,847	4,409
Incandescent	mn pcs	6,830	5,181	3,795	2,655	1,857	1,244	760	389	146	55	7
Halogen	mn pcs	1,116	1,670	2,063	2,254	2,237	2,015	1,685	1,380	1,121	903	713
HID	mn pcs	187	193	198	204	208	210	209	206	200	192	183
LFL	mn pcs	1,693	1,677	1,657	1,637	1,598	1,560	1,512	1,447	1,346	1,229	1,106
CFL	mn pcs	1,772	1,933	2,111	2,219	2,210	2,121	2,039	1,842	1,644	1,491	1,322
LED lamp	mn pcs	32	63	121	210	354	551	646	715	820	940	1,035
LED module	mn pcs	0	0	0	2	6	9	12	18	28	37	43
Lamp replacement market	EUR mn	7,872	8,609	9,326	9,754	10,313	10,431	10,113	9,457	9,142	8,962	8,600
Total												
Total General Lighting market	EUR mn	51,787	55,244	60,257	64,769	68,645	71,738	75,732	78,787	81,968	85,075	88,161
Europe	EUR mn	15.354	15.668	17.223	18.144	18.757	19.116	19.605	19.903	20.127	20.320	20.450
North America	EUR mn	11.421	11.935	12.804	13.618	14.205	14.576	14.979	15.188	15.345	15.512	15.654
Asia, incl. China	EUR mn	18.709	21.009	23.095	25.314	27.515	29.498	31.589	33.687	36.034	38.382	40.837
Latin America	EUR mn	3.567	3.669	3.954	4.294	4.571	4.795	5.393	5.655	5.922	6.157	6.374
Middle East & Africa	EUR mn	2.735	2.963	3.181	3.399	3.597	3.753	4.165	4.355	4.540	4.704	4.846

1 Assumption on average market price from McKinsey research; same for new installations and replacement business

- ***Application deep dive.*** The model differentiates seven distinctive applications. For each of these applications, a current and forward-looking technology split is presented as well as a split into new installation and replacement business. Table 4 contains further detail.

Table 4

APPLICATION DEEP DIVE														
			Unit	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Residential	Total market		EUR mn	21,009	21,710	22,983	24,816	26,165	27,144	28,487	29,381	30,190	30,965	31,850
	excl. lighting system control components		EUR mn	21,009	21,710	22,983	24,816	26,165	27,144	28,487	29,381	30,190	30,965	31,850
	Technology share	Incandescent	%	25	23	20	14	10	7	5	4	3	3	3
		Halogen	%	28	28	27	26	25	23	20	17	14	12	10
		HID	%	0	0	0	0	0	0	0	0	0	0	0
		LFL	%	11	11	10	9	9	8	7	7	6	6	5
		CFL	%	29	29	28	26	24	21	19	17	15	13	11
		LED	%	6	9	15	24	33	40	49	56	62	67	71
	New installation market		EUR mn	17,636	18,063	18,980	20,485	21,795	22,823	24,419	25,644	26,849	27,852	29,013
	Light source replacement market		EUR mn	3,373	3,646	4,003	4,331	4,371	4,322	4,068	3,737	3,341	3,113	2,837
	Lighting system control component market		EUR mn	0	0	0	0	0	0	0	0	0	0	0
Office	Total market		EUR mn	7,753	8,449	9,308	10,103	10,965	11,804	12,720	13,914	15,086	16,404	17,795
	excl. lighting system control components		EUR mn	7,059	7,637	8,356	8,984	9,648	10,251	10,883	11,739	12,503	13,332	14,133
	Technology share	Incandescent	%	1	1	0	0	0	0	0	0	0	0	0
		Halogen	%	3	3	3	3	3	3	2	2	2	1	1
		HID	%	2	2	2	2	2	2	2	2	1	1	1
		LFL	%	76	73	70	67	63	59	56	52	49	45	41
		CFL	%	16	15	13	12	11	10	9	7	6	5	4
		LED	%	2	6	12	16	21	26	31	37	42	47	52
	New installation market		EUR mn	6,147	6,646	7,290	7,891	8,448	9,020	9,587	10,352	11,044	11,815	12,576
	Light source replacement market		EUR mn	912	991	1,066	1,093	1,200	1,230	1,296	1,386	1,459	1,518	1,556
	Lighting system control component market		EUR mn	694	812	952	1,119	1,317	1,554	1,837	2,176	2,583	3,072	3,662
Industrial	Total market		EUR mn	3,891	4,254	4,383	4,501	4,633	4,698	4,889	5,054	5,263	5,443	5,625
	excl. lighting system control components		EUR mn	3,699	4,042	4,149	4,243	4,347	4,379	4,535	4,659	4,821	4,946	5,065
	Technology share	Incandescent	%	1	0	0	0	0	0	0	0	0	0	0
		Halogen	%	0	1	1	1	1	1	1	1	1	0	0
		HID	%	19	17	17	16	16	15	15	14	13	12	11
		LFL	%	72	70	69	67	64	62	59	56	52	48	44
		CFL	%	8	7	7	6	5	5	5	5	4	4	4
		LED	%	0	4	7	10	14	16	20	24	30	35	41
	New installation market		EUR mn	2,867	3,185	3,278	3,389	3,447	3,490	3,625	3,711	3,804	3,891	4,009
	Light source replacement market		EUR mn	831	857	871	854	900	889	910	948	1,016	1,055	1,056
	Lighting system control component market		EUR mn	192	212	234	259	286	318	354	395	443	497	560
Shop	Total market		EUR mn	5,221	6,002	6,730	7,491	7,981	8,321	8,909	9,381	9,677	9,936	10,153
	excl. lighting system control components		EUR mn	5,052	5,804	6,496	7,214	7,652	7,927	8,436	8,810	8,985	9,093	9,122
	Technology share	Incandescent	%	6	4	2	1	1	1	0	0	0	0	0
		Halogen	%	3	5	5	5	4	4	3	3	2	2	1
		HID	%	16	16	15	14	13	12	11	9	8	7	6
		LFL	%	57	53	48	41	36	32	27	23	20	17	15
		CFL	%	15	14	12	11	10	9	8	6	6	5	4
		LED	%	2	9	17	29	36	43	51	58	64	68	73
	New installation market		EUR mn	4,248	4,775	5,367	6,082	6,411	6,667	7,131	7,441	7,659	7,795	7,878
	Light source replacement market		EUR mn	804	1,029	1,129	1,132	1,241	1,260	1,305	1,368	1,326	1,297	1,243
	Lighting system control component market		EUR mn	169	198	234	277	329	394	473	571	692	843	1,031

Table 4 continued

			Unit	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Hospitality	Total market		EUR mn	4,159	4,558	5,065	5,494	6,069	6,557	6,331	6,117	6,320	6,508	6,638
	excl. lighting system control components		EUR mn	4,075	4,456	4,943	5,349	5,895	6,349	6,081	5,817	5,960	6,076	6,119
	Technology share	Incandescent	%	10	8	5	3	2	1	1	1	1	1	1
		Halogen	%	8	11	12	12	11	9	6	4	3	3	2
		HID	%	2	2	2	2	2	1	1	1	1	1	0
		LFL	%	37	33	32	31	28	24	20	18	14	11	7
		CFL	%	34	32	31	29	26	23	21	18	15	11	8
		LED	%	9	13	18	22	31	41	51	58	66	74	82
	New installation market		EUR mn	3,160	3,393	3,733	4,036	4,357	4,673	4,606	4,877	5,087	5,251	5,367
	Light source replacement market		EUR mn	915	1,064	1,211	1,313	1,538	1,676	1,475	940	874	825	751
	Lighting system control component market		EUR mn	85	101	121	145	174	209	250	300	360	432	519
Outdoor	Total market		EUR mn	6,893	6,948	8,245	8,660	9,010	9,288	10,226	10,531	10,772	10,895	10,916
	excl. lighting system control components		EUR mn	6,834	6,884	8,175	8,584	8,927	9,197	10,127	10,422	10,652	10,764	10,772
	Technology share	Incandescent	%	0	0	0	0	0	0	0	0	0	0	0
		Halogen	%	0	0	0	0	0	0	0	0	0	0	0
		HID	%	81	80	77	73	68	61	53	45	38	32	27
		LFL	%	15	14	13	12	11	9	8	7	6	5	4
		CFL	%	0	0	0	0	0	0	0	0	0	0	0
		LED	%	5	7	10	16	22	30	39	48	56	63	70
	New installation market		EUR mn	5,900	5,970	7,245	7,671	7,981	8,260	9,184	9,457	9,635	9,715	9,717
	Light source replacement market		EUR mn	935	914	930	913	945	937	943	965	1,018	1,049	1,055
	Lighting system control component market		EUR mn	59	64	70	76	83	91	99	109	120	131	144
Architectural	Total market		EUR mn	2,861	3,324	3,543	3,702	3,822	3,926	4,170	4,409	4,660	4,924	5,185
	excl. lighting system control components		EUR mn	2,533	2,967	3,153	3,277	3,358	3,420	3,618	3,807	4,004	4,208	4,404
	Technology share	Incandescent	%	0	0	0	0	0	0	0	0	0	0	0
		Halogen	%	0	0	0	0	0	0	0	0	0	0	0
		HID	%	31	27	23	19	17	15	13	12	10	9	7
		LFL	%	30	26	22	18	16	15	13	11	10	9	7
		CFL	%	0	0	0	0	0	0	0	0	0	0	0
		LED	%	39	47	55	62	67	70	74	77	80	83	86
	New installation market		EUR mn	2,430	2,858	3,038	3,159	3,239	3,303	3,503	3,695	3,895	4,103	4,303
	Light source replacement market		EUR mn	103	109	115	118	119	117	115	112	109	105	100
	Lighting system control component market		EUR mn	328	358	390	425	464	506	551	602	656	716	781

- ***Regional split.*** The model differentiates into key lighting market regions, namely Europe, North America, Asia, China separately, Latin America, and Middle East & Africa. Again, the same level of granularity is presented as in the application deep dive. Application splits across regions are also included. Tables 5 and 6 provide further detail.

Table 5

REGION DEEP DIVE														
			Unit	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Europe	Total market		EUR mn	15.354	15.668	17.223	18.144	18.757	19.116	19.605	19.903	20.127	20.320	20.450
	excl. lighting system control components		EUR mn	14,720	15,001	16,460	17,286	17,790	18,028	18,386	18,535	18,597	18,625	18,607
	Technology share	Incandescent	%	14	13	11	7	5	3	2	1	1	1	0
		Halogen	%	16	17	16	16	15	14	13	10	9	8	6
		HID	%	15	15	18	16	16	14	12	11	9	8	6
		LFL	%	26	25	23	21	19	18	16	15	14	12	11
		CFL	%	21	20	18	17	15	13	10	9	7	6	5
		LED	%	7	10	15	23	30	38	46	54	60	66	72
	New installation market		EUR mn	11,775	11,836	13,094	13,811	14,235	14,517	15,074	15,505	15,806	15,972	16,146
	Light source replacement market		EUR mn	2,946	3,165	3,366	3,475	3,555	3,511	3,312	3,030	2,791	2,653	2,461
	Lighting system control component market		EUR mn	634	667	763	858	967	1.088	1.219	1.368	1.531	1.695	1.844
North America	Total market		EUR mn	11.421	11.935	12.804	13.618	14.205	14.576	14.979	15.188	15.345	15.512	15.654
	excl. lighting system control components		EUR mn	10,905	11,351	12,150	12,874	13,362	13,621	13,900	13,972	13,978	13,981	13,925
	Technology share	Incandescent	%	15	13	11	8	5	4	3	2	1	1	1
		Halogen	%	17	18	18	17	17	15	14	11	9	8	6
		HID	%	10	9	10	9	9	8	7	6	5	5	4
		LFL	%	33	32	29	27	25	23	21	19	17	15	14
		CFL	%	19	18	16	15	13	11	9	8	7	6	4
		LED	%	7	9	15	24	31	39	47	54	60	65	71
	New installation market		EUR mn	8,763	9,018	9,625	10,252	10,625	10,878	11,296	11,578	11,757	11,845	11,920
	Light source replacement market		EUR mn	2,142	2,332	2,525	2,622	2,737	2,742	2,604	2,394	2,222	2,136	2,005
	Lighting system control component market		EUR mn	516	584	654	744	843	955	1.079	1.216	1.367	1.531	1.729
Asia, incl. China	Total market		EUR mn	18.709	21.009	23.095	25.314	27.515	29.498	31.589	33.687	36.034	38.382	40.837
	excl. lighting system control components		EUR mn	18,375	20,563	22,568	24,681	26,748	28,559	30,425	32,240	34,221	36,088	37,927
	Technology share	Incandescent	%	9	8	6	5	3	2	1	1	1	1	1
		Halogen	%	9	9	9	9	8	7	6	5	4	4	3
		HID	%	18	17	15	14	12	11	9	8	7	6	5
		LFL	%	38	37	35	32	30	28	25	23	21	19	17
		CFL	%	18	18	17	16	15	14	13	11	10	8	7
		LED	%	7	12	18	25	31	38	45	51	57	62	67
	New installation market		EUR mn	16,413	18,342	20,087	22,018	23,787	25,455	27,318	29,303	31,214	33,043	34,903
	Light source replacement market		EUR mn	1,962	2,221	2,481	2,664	2,961	3,104	3,107	2,937	3,007	3,045	3,023
	Lighting system control component market		EUR mn	335	446	528	633	767	939	1.164	1.447	1.812	2.294	2.910
China	Total market		EUR mn	7.271	8.408	9.320	10.269	11.223	12.092	13.026	13.977	15.040	16.131	17.272
	excl, lighting system control components		EUR mn	7,131	8,221	9,098	10,002	10,899	11,695	12,532	13,363	14,270	15,154	16,032
	Technology share	Incandescent	%	8	7	5	4	3	2	1	1	1	1	1
		Halogen	%	8	8	8	8	7	6	5	5	4	3	3
		HID	%	17	15	14	12	11	10	9	8	6	6	5
		LFL	%	42	40	38	35	32	30	27	24	22	20	18
		CFL	%	18	17	17	16	15	14	12	11	9	8	7
		LED	%	7	12	18	25	31	38	45	51	57	62	68
	New installation market		EUR mn	6,109	7,104	7,867	8,703	9,463	10,194	11,029	11,934	12,797	13,649	14,529
	Light source replacement market		EUR mn	1,022	1,117	1,231	1,298	1,437	1,501	1,504	1,428	1,473	1,505	1,504
	Lighting system control component market		EUR mn	140	187	222	267	324	397	493	614	770	976	1.240

Table 5 continued

			Unit	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Latin America	Total market		EUR mn	3.567	3.669	3.954	4.294	4.571	4.795	5.393	5.655	5.922	6.157	6.374
	excl. lighting system control components		EUR mn	3,546	3,644	3,925	4,260	4,532	4,750	5,341	5,594	5,851	6,072	6,270
	Technology share	Incandescent	%	13	12	10	8	6	5	3	3	3	4	4
		Halogen	%	13	13	13	12	11	10	8	7	6	5	4
		HID	%	23	21	20	18	17	16	17	15	13	11	9
		LFL	%	28	27	25	24	22	21	18	17	15	14	13
		CFL	%	20	21	20	19	19	18	15	14	13	11	10
		LED	%	3	6	11	19	25	31	38	44	50	55	60
	New installation market		EUR mn	3,107	3,170	3,416	3,724	3,962	4,173	4,758	5,011	5,254	5,475	5,684
	Light source replacement market		EUR mn	440	474	509	536	570	577	584	583	596	597	586
	Lighting system control component market		EUR mn	21	24	29	33	39	45	52	61	72	84	105
Middle East & Africa	Total market		EUR mn	2.735	2.963	3.181	3.399	3.597	3.753	4.165	4.355	4.540	4.704	4.846
	excl, lighting system control components		EUR mn	2,715	2,939	3,153	3,366	3,559	3,709	4,114	4,294	4,468	4,618	4,735
	Technology share	Incandescent	%	9	7	6	5	3	3	2	2	2	2	2
		Halogen	%	9	9	8	8	7	7	6	5	4	4	3
		HID	%	21	20	19	18	17	16	17	15	12	11	9
		LFL	%	42	41	39	37	35	33	30	27	26	24	23
		CFL	%	16	16	15	14	14	13	11	10	9	8	7
		LED	%	3	7	12	18	24	29	35	41	47	52	56
	New installation market		EUR mn	2,332	2,523	2,708	2,909	3,069	3,213	3,608	3,782	3,942	4,086	4,211
	Light source replacement market		EUR mn	383	417	445	457	490	496	506	512	527	531	525
	Lighting system control component market		EUR mn	21	24	28	32	38	44	51	60	72	87	111

Table 6

REGION vs APPLICATION													
		Unit	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Europe	Total market	EUR mn	15.354	15.668	17.223	18.144	18.757	19.116	19.605	19.903	20.127	20.320	20.450
	excl. lighting system control components	EUR mn	14,720	15,001	16,460	17,286	17,790	18,028	18,386	18,535	18,597	18,625	18,607
	Residential	EUR mn	7,473	7,525	7,756	8,176	8,371	8,425	8,535	8,553	8,486	8,440	8,430
	Hospitality	EUR mn	914	978	1,058	1,114	1,192	1,243	1,247	1,172	1,188	1,202	1,202
	Outdoor	EUR mn	1,811	1,904	2,722	2,850	2,939	3,024	3,146	3,216	3,262	3,274	3,248
	Office	EUR mn	1,635	1,637	1,774	1,855	1,933	1,986	2,043	2,134	2,196	2,263	2,312
	Architectural	EUR mn	616	607	633	637	629	616	624	631	638	644	650
	Shop	EUR mn	1,107	1,208	1,334	1,453	1,510	1,527	1,567	1,591	1,562	1,526	1,479
	Industrial	EUR mn	1,165	1,141	1,182	1,202	1,217	1,207	1,224	1,239	1,264	1,277	1,285
North America	Total market	EUR mn	11.421	11.935	12.804	13.618	14.205	14.576	14.979	15.188	15.345	15.512	15.654
	excl. lighting system control components	EUR mn	10,905	11,351	12,150	12,874	13,362	13,621	13,900	13,972	13,978	13,981	13,925
	Residential	EUR mn	5,338	5,430	5,741	6,215	6,479	6,642	6,818	6,867	6,825	6,814	6,812
	Hospitality	EUR mn	930	990	1,064	1,106	1,198	1,262	1,261	1,180	1,191	1,197	1,188
	Outdoor	EUR mn	546	560	813	846	875	896	929	948	961	963	955
	Office	EUR mn	1,262	1,352	1,422	1,479	1,530	1,560	1,592	1,650	1,685	1,723	1,746
	Architectural	EUR mn	359	347	351	348	337	324	318	311	304	296	287
	Shop	EUR mn	1,240	1,394	1,507	1,645	1,708	1,726	1,770	1,802	1,788	1,764	1,720
	Industrial	EUR mn	1,229	1,278	1,252	1,234	1,235	1,211	1,213	1,214	1,225	1,223	1,217
Asia, incl. China	Total market	EUR mn	18.709	21.009	23.095	25.314	27.515	29.498	31.589	33.687	36.034	38.382	40.837
	excl. lighting system control components	EUR mn	18,375	20,563	22,568	24,681	26,748	28,559	30,425	32,240	34,221	36,088	37,927
	Residential	EUR mn	5,576	5,999	6,545	7,225	7,895	8,481	9,291	9,944	10,672	11,330	12,067
	Hospitality	EUR mn	2,087	2,326	2,635	2,926	3,280	3,601	3,337	3,234	3,338	3,424	3,469
	Outdoor	EUR mn	3,085	3,054	3,210	3,355	3,511	3,624	3,773	3,888	3,973	4,019	4,036
	Office	EUR mn	3,029	3,458	3,860	4,258	4,695	5,131	5,608	6,202	6,766	7,383	8,005
	Architectural	EUR mn	1,392	1,826	1,970	2,087	2,185	2,272	2,462	2,644	2,834	3,033	3,224
	Shop	EUR mn	2,263	2,678	3,051	3,458	3,734	3,945	4,331	4,613	4,817	4,981	5,106
	Industrial	EUR mn	943	1,223	1,296	1,372	1,447	1,505	1,624	1,716	1,821	1,919	2,020
China	Total market	EUR mn	7.271	8.408	9.320	10.269	11.223	12.092	13.026	13.977	15.040	16.131	17.272
	excl. lighting control system	EUR mn	7,131	8,221	9,098	10,002	10,899	11,695	12,532	13,363	14,270	15,154	16,032
	Residential	EUR mn	1,836	2,039	2,253	2,518	2,785	3,027	3,356	3,633	3,943	4,233	4,557
	Hospitality	EUR mn	1,002	1,109	1,248	1,379	1,541	1,690	1,558	1,505	1,546	1,584	1,605
	Outdoor	EUR mn	1,010	1,043	1,091	1,122	1,172	1,194	1,234	1,271	1,313	1,341	1,353
	Office	EUR mn	1,264	1,442	1,641	1,820	2,034	2,252	2,494	2,795	3,068	3,380	3,698
	Architectural	EUR mn	570	774	832	877	913	945	1,025	1,100	1,179	1,262	1,342
	Shop	EUR mn	989	1,187	1,364	1,567	1,692	1,790	1,998	2,137	2,240	2,319	2,380
	Industrial	EUR mn	459	627	669	719	762	796	869	921	980	1,035	1,098
Latin America	Total market	EUR mn	3.567	3.669	3.954	4.294	4.571	4.795	5.393	5.655	5.922	6.157	6.374
	excl. lighting system control components	EUR mn	3,546	3,644	3,925	4,260	4,532	4,750	5,341	5,594	5,851	6,072	6,270
	Residential	EUR mn	1,799	1,893	2,022	2,206	2,359	2,482	2,657	2,778	2,912	3,034	3,154
	Hospitality	EUR mn	69	83	94	102	112	121	118	116	122	127	131
	Outdoor	EUR mn	885	830	873	945	992	1,028	1,394	1,456	1,515	1,553	1,575
	Office	EUR mn	470	479	536	575	616	654	685	735	781	830	878
	Architectural	EUR mn	56	67	71	73	74	75	77	79	82	84	87
	Shop	EUR mn	176	196	225	247	264	274	290	303	308	309	306
	Industrial	EUR mn	91	97	106	111	115	117	121	125	130	135	139
Middle East & Africa	Total market	EUR mn	2.735	2.963	3.181	3.399	3.597	3.753	4.165	4.355	4.540	4.704	4.846
	excl. lighting system control components	EUR mn	2,715	2,939	3,153	3,366	3,559	3,709	4,114	4,294	4,468	4,618	4,735
	Residential	EUR mn	822	862	919	994	1,061	1,115	1,188	1,239	1,296	1,347	1,388
	Hospitality	EUR mn	75	80	93	102	112	122	118	115	121	125	128
	Outdoor	EUR mn	507	536	557	588	610	625	885	914	941	955	958
	Office	EUR mn	663	711	764	817	873	920	956	1,018	1,074	1,134	1,192
	Architectural	EUR mn	110	119	129	133	134	134	138	142	146	151	155
	Shop	EUR mn	267	327	379	410	436	455	477	501	510	514	511
	Industrial	EUR mn	272	303	312	323	333	339	353	366	380	392	404

- ***Automotive.*** For the automotive sector, the model builds on annual new car, light and heavy commercial vehicle sales, plus heavy motorcycle unit sales, as well as the installed vehicle base. The model differentiates various application areas for light in a car, i.e., main front lighting (high/low beam and advances in front lighting systems), DRLs and foglights, turning lights, rear lights (tail, CHMSL, etc.), and interior lighting, including backlighting. Automotive front lighting is the most important application, and Table 7 provides further details.

Table 7

AUTOMOTIVE												
	Unit	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Total Automotive lighting market	EUR mn	13,154	13,899	14,934	15,819	16,561	17,132	17,599	17,853	18,042	18,251	18,442
Front / Headlamp	EUR mn	9,383	9,915	10,636	11,250	11,756	12,172	12,487	12,675	12,801	12,935	13,051
DRL / Fog	EUR mn	997	1,087	1,221	1,341	1,446	1,521	1,592	1,634	1,680	1,727	1,781
Side	EUR mn	287	302	322	346	380	398	415	427	439	452	464
Rear	EUR mn	1,861	1,959	2,096	2,206	2,293	2,354	2,419	2,439	2,456	2,478	2,495
Interior	EUR mn	625	636	660	675	685	687	686	677	666	659	650
Total Automotive light source market incl. ECG	EUR mn	3,084	3,377	3,645	3,901	4,140	4,394	4,743	5,097	5,390	5,678	5,959
Front lighting – Detailed view												
# annual new vehicle sales	mn pcs	76	80	87	92	97	101	104	106	108	111	113
Europe	mn pcs	18	19	20	21	22	22	23	23	23	23	24
North America	mn pcs	15	16	18	19	20	21	21	21	21	21	21
Asia	mn pcs	32	34	37	39	42	44	46	48	49	50	52
Middle East & Africa	mn pcs	5	5	5	6	6	6	6	6	7	7	7
Latin America	mn pcs	5	6	6	6	7	7	7	8	8	8	9
Technology mix	%	100	100	100	100	100	100	100	100	100	100	100
Incandescent	%	0	0	0	0	0	0	0	0	0	0	0
Halogen	%	88	85	83	82	80	78	76	73	69	65	60
HID	%	12	15	16	17	17	18	19	19	20	20	19
LED	%	0	1	1	2	2	4	6	8	12	16	21
Content per vehicle lamp level												
Incandescent	EUR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Halogen	EUR	4,36	4,26	4,22	4,17	4,12	4,09	4,06	4,03	3,99	3,96	3,94
HID	EUR	24,32	21,97	21,10	20,26	19,46	18,70	18,05	17,43	16,82	16,23	15,65
LED	EUR	144,98	136,71	122,98	107,37	88,24	76,32	66,77	59,09	52,28	46,78	41,85
Total new installation market	EUR mn	8,809	9,327	10,028	10,611	11,078	11,442	11,686	11,794	11,933	12,081	12,209
Lamp / module level	EUR mn	552	625	728	830	926	1,049	1,227	1,431	1,656	1,878	2,106
CCG / ECG level	EUR mn	407	525	605	684	750	818	893	968	1,053	1,122	1,178
Fixture level	EUR mn	7,850	8,176	8,696	9,098	9,403	9,575	9,567	9,396	9,224	9,081	8,926
Annual lamp replacement market	EUR mn	574	588	608	639	678	730	800	881	868	854	842
Incandescent	EUR mn	0	0	0	0	0	0	0	0	0	0	0
Halogen	EUR mn	542	550	563	586	619	666	728	808	789	770	753
HID	EUR mn	33	38	45	53	60	64	73	73	79	84	89
LED	EUR mn	0	0	0	0	0	0	0	0	0	0	0

- ***Backlighting.*** The following applications are addressed in the backlighting segment: TVs, monitors, portable PCs, including tablets and netbooks, as well as mobile and smart phones. The main backlighting technologies focused on are CCFL and LED. OLED is considered for the total LCD TV market size trend calculation, but the OLED backlighting market is not sized given that OLED qualifies as display rather than backlighting technology. For LED in backlighting, the model solely focuses on LED packages.

  Component replacement was not considered relevant. Table 8 summarizes the main backlighting model outputs.

Table 8

BACKLIGHTING												
	Unit	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Devices												
LCD TVs	mn pcs	182	207	226	242	257	267	277	289	300	312	325
Monitors	mn pcs	200	210	218	225	232	239	246	253	261	269	277
Portable PCs	mn pcs	198	229	259	290	316	342	362	380	399	419	440
Handhelds	mn pcs	1,306	1,371	1,440	1,512	1,580	1,640	1,706	1,774	1,845	1,919	1,996
Penetration rate												
LCD TV												
CCFL	%	80	60	40	15	10	6	2	0	0	0	0
LED	%	20	40	60	85	90	93	95	90	85	78	70
OLED	%	0	0	0	0	0	1	3	10	15	22	30
Monitor												
CCFL	%	76	49	25	15	10	5	3	1	0	0	0
LED	%	24	51	75	85	90	95	95	90	85	80	70
OLED	%	0	0	0	0	0	0	2	9	15	20	30
Portable PC												
CCFL	%	18	10	5	0	0	0	0	0	0	0	0
LED	%	82	90	95	100	100	98	95	90	80	70	60
OLED	%	0	0	0	0	0	2	5	10	20	30	40
Handhelds												
CCFL	%	0	0	0	0	0	0	0	0	0	0	0
LED	%	98	98	90	85	80	75	65	60	55	50	40
OLED	%	3	3	10	15	20	25	35	40	45	50	60
Backlighting content per device												
LCD TV												
CCFL	EUR	8.50	8.33	8.16	8.00	7.84	7.68	7.53	n/a	n/a	n/a	n/a
LED	EUR	21.06	17.75	17.33	15.33	13.68	12.44	11.40	10.26	8.94	7.60	6.46
Monitor												
CCFL	EUR	5.23	5.13	5.02	4.92	4.82	4.73	4.63	4.54	n/a	n/a	n/a
LED	EUR	7.34	5.69	4.35	3.35	2.63	2.05	1.69	1.48	1.30	1.14	0.99
Portable PC												
CCFL	EUR	1.51	1.48	1.45	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LED	EUR	2.30	1.74	1.34	1.14	1.00	0.86	0.75	0.68	0.61	0.55	0.49
Handhelds												
CCFL	EUR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LED	EUR	0.31	0.27	0.24	0.21	0.19	0.18	0.15	0.14	0.12	0.11	0.10
Market size												
LCD TV												
CCFL	EUR mn	1,237	1,037	738	290	201	123	42	0	0	0	0
LED	EUR mn	767	1,473	2,351	3,153	3,159	3,086	3,004	2,665	2,281	1,851	1,468
Monitor												
CCFL	EUR mn	795	527	274	166	112	56	34	11	0	0	0
LED	EUR mn	352	609	711	640	549	465	395	337	287	244	193
Portable PC												
CCFL	EUR mn	54	34	19	0	0	0	0	0	0	0	0
LED	EUR mn	371	359	330	332	315	289	258	231	195	161	131
Handhelds												
CCFL	EUR mn	0	0	0	0	0	0	0	0	0	0	0
LED	EUR mn	398	366	314	276	241	218	170	147	126	107	80

Estimates of LED market share

One of the major assumptions of the market model is LED market share. As mentioned, McKinsey conducted a global lighting survey of both lighting professionals and consumers in June 2011. Full use was made of the survey results to estimate future LED market share. Various approaches were taken to estimate LED market share in new fixture installation. The first set of questions targeted levels of price acceptance in order to estimate LED market share, which was calculated using both the responses as well as the future lighting product price trend by technology. The second approach addressed levels of payback time acceptance. Payback time forecasts were calculated based on different lighting product price levels by country/light source technology, applying varying electricity prices. Major technology barriers by application were surveyed in the third category, including the timeline by which the barrier was expected to disappear. The last area surveyed concerned future LED market share based on respondents' expertise. These replies were then combined with the survey results on key purchasing decision criteria to develop estimates on LED market share by country and application (Exhibit 24).

Exhibit 24

4 approaches are used to determine LED market share in the new fixture installation business

Price premium acceptance level
- Asked about lighting professionals' LED price premium acceptance level by application
- Calculated LED's price gap trend against each traditional technology by application
- Calculated transition percentage of each traditional technology vs. LED in each year by application
- Compiled those transition percentages to calculate LED market share in each year by application

Payback time acceptance level
- Asked about professionals' LED payback time acceptance level by application
- Calculated LED's payback time trend against each traditional technology by application based on different countries' current electricity price
- Calculated transition percentage from each traditional technology to LED in each year by application
- Compiled those transition percentages into LED market share in each year by application

Technology barriers
- Asked lighting professionals' about their expectations on when LED's technology barriers vs. traditional lighting will disappear by application

Direct estimate by professionals
- Asked the lighting professionals in the survey for their estimate of LED market share by application
- Adjusted for country-specific positive/negative bias of respondents by also asking for an estimate of smart phone penetration and comparing this to industry report estimates for this country

SOURCE: McKinsey

The following exhibits are some examples of the survey results using globally consolidated numbers. The underlying analysis contains results by country.

Exhibit 25

Decision criteria for fixture installation in new buildings/structures

What are the most important criteria when deciding on the type of light source technology in a new fixture installation?
Percent; No. of respondents[1] who selected this response as their 1st decision criterion

	Residential N = 338	Office N = 399	Industrial N = 261	Shop N = 259	Hospitality N = 127	Outdoor N = 232	Architectural N = 235
Lifetime of light source	9	12	16	8	14	12	9
Purchasing price of light source	22	11	17	10	9	14	9
Fixture design affected by light source[2]	10	10	8	19	14	5	20
Shape of light source	10	7	5	6	6	11	7
Light quality[3]	20	30	23	30	25	21	26
Light controllability[4]	8	9	8	7	16	6	12
Life cycle cost/ energy efficiency	14	14	17	15	13	21	12
Easy installation	8	8	5	5	2	10	5
Other	0	0	1	0	0	0	0
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

1 1 respondent could answer up to 3 applications in the survey
2 Incl. design flexibility
3 CRI, color temperature, color consistency, and light distribution
4 Dimmability, color controllability, etc.

SOURCE: McKinsey Global Lighting Professionals & Consumer Survey

Exhibit 26

Price premium acceptance level for LED

What price premium do you regard as acceptable for LED lighting in total price of a new fixture and light source(s) for the first installation)?
Percent; No. of respondents[1]

	Residential N = 338	Office N = 399	Industrial N = 261	Shop N = 259	Hospitality N = 127	Outdoor N = 232	Architectural N = 235	Total N = 1,851
No price premium	17	7	9	12	9	14	8	**11**
5	15	8	11	12	9	8	6	**10**
10	16	17	13	16	17	21	19	**17**
20	14	17	21	16	13	15	18	**16**
30	8	13	12	10	13	12	14	**11**
40	6	8	6	10	8	8	6	**7**
50	7	10	8	13	14	9	13	**10**
60	4	5	5	3	6	3	6	**4**
70	5	5	7	2	5	3	4	**4**
80	1	4	2	2	1	2	3	**2**
90	3	3	2	2	2	2	1	**2**
150	2	1	2	1	2	0	0	**1**
200	2	2	1	2	2	0	0	**1**
> 200%	0	2	2	1	1	2	1	**1**
Average[2] =	30%	39%	37%	33%	36%	31%	34%	**34%**
Median[2] =	20%	30%	20%	20%	30%	20%	20%	**20%**

1 1 respondent could answer up to 3 applications in the survey
2 Assumed that no price premium means "0%" and "> 200%" is 300% in the calculation

SOURCE: McKinsey Global Lighting Professionals & Consumer Survey

Exhibit 27

Payback period acceptance level for LED

At which payback period for LED vs. traditional lighting would you choose LED?
Percent; No. of respondents[1]

	Residential N = 338	Office N = 399	Industrial N = 261	Shop N = 259	Hospitality N = 127	Outdoor N = 232	Architectural N = 235	Total N = 1,851
< 1 year	22	15	16	17	12	14	9	**16**
1 year	18	18	15	22	20	23	18	**19**
2 years	18	19	23	21	18	25	18	**20**
3 years	13	17	14	19	20	17	23	**17**
4 years	8	7	8	5	8	6	9	**7**
5 years	8	11	11	5	12	6	14	**10**
6 - 7 years	4	5	3	3	3	3	3	**4**
8 - 10 years	3	3	3	2	4	1	3	**3**
> 10 years	3	2	2	3	2	2	1	**2**
Not relevant	4	4	2	3	2	2	2	**3**
Average[2] =	3	3	3	2	3	2	3	**3**
Median[2] =	2	2	2	2	2	2	3	**2**

1 1 respondent could answer up to 3 applications in the survey
2 Assumed that "< 1 year" is 0.5 year and "Not relevant" means "0" in the calculation

SOURCE: McKinsey Global Lighting Professionals & Consumer Survey

5. Explanation of technical terms

Chip on board. Refers to semiconductor assembly technology where the microchip or die is directly mounted on and electrically interconnected to its final circuit board, instead of undergoing traditional assembly or packaging as an individual IC. The elimination of conventional device packaging from Chip on board assemblies simplifies the overall process of designing and manufacturing the final product, as well as improving its performance as a result of the shorter interconnection paths.

Color rendering index (CRI). The effect of an illuminant on the color appearance of objects by conscious or subconscious comparison with their color appearance under a reference illuminant. In other words, CRI is a quantitative measure of the ability of a light source to reproduce the colors of various objects in comparison with a natural light source.

Conventional control gear (CCG). Ballast used to ignite and operate certain types of fluorescent lamps. Being phased out in many countries on the grounds of lacking energy efficiency compared to Electronic Control Gear (ECG).

Daytime running lamp (DRL). A type of automotive headlight designed to be automatically switched on as the engine is turned on and run during the day in order to increase the visibility of the vehicle during daylight conditions.

Downlight: A fixture installed in a hollow opening in the ceiling.

Electrical ballast/electronic control gear (ECG). Electrical/electronic device to ignite and operate certain types of lamps or LED systems.

Epitaxy. Refers to the method of depositing a monocrystalline film on a monocrystalline substrate. The deposited film is denoted as epitaxial film or epitaxial layer. The method is used to grow chips in LED production.

Heat sink. A component used to transfer heat generated by the LED out into the air to ensure cooling of the device.

Flip-chip mounting method. A method for interconnecting semiconductor devices, such as IC chips and microelectromechanical systems (MEMS) to external circuitry with solder bumps that have been deposited onto the chip pads. The solder bumps are deposited on the chip pads on the top side of the wafer during the final wafer processing step. The method allows higher light output, higher thermal conductivity, and a robust and inert sapphire surface.

Luminous efficacy (efficiency). The amount of electrical power required to produce a certain intensity of light in lumen per watt.

MOCVD. Metal organic chemical vapor deposition equipment. MOCVD is a technique for depositing thin layers of atoms onto a semiconductor wafer. The method makes it possible to build layers of a precisely controlled thickness to create material with specific optical and electrical properties. The MOCVD tool is the most expensive tool in LED fabrication.

Refractive index. A measure of the speed of light in a specific substance. It is expressed as a ratio of the speed of light in vacuum relative to that in the medium being analyzed.

Retrofit. Refers to a unit of a new technology that can be used with the old standard or interface. For instance, an LED retrofit is an LED that can be used with traditional standard lighting sockets.

RGB. The colors red, green, and blue. Any colors are replicable by combining the colors red, green, and blue.

Secondary optics. Optical elements which exist outside the LED package, such as reflector cavities, Fresnel lenses, and pillow lenses. Secondary optics are used to create the desired appearance and beam pattern of the LED signal lamp.

Total cost of ownership (TCO). Quantification of the cost of assets that includes the cost used of operating them across their entire lifecycle, in addition to the cost of acquiring them.

Wafer. A thin slice of semiconductor material, such as a silicon crystal, used in the fabrication of integrated circuits and other microdevices. The wafer serves as the substrate for microelectronic devices built in and over the wafer and undergoes many microfabrication process steps, ending in the individual microcircuits being separated (diced) and packaged.

White LED. LEDs emitting white light can be created in two ways. One way to create white light with an LED is covering a blue LED chip with yellow phosphor during the package process. The other way of creating white light with LEDs is using RGB (red, green, blue) colors.

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