

---

**LED**

---

June 2012

---

BROUGHT TOGETHER BY

**THE CLIMATE GROUP**

REPORT SPONSOR

**PHILIPS**

SUPPORTER

**HSBC**   
The world's local bank

---



# LIGHTING THE CLEAN REVOLUTION

This is part of  
**THE CLEAN REVOLUTION**

The rise of LEDs and what it means for cities

---

## ABOUT THIS REPORT

---

**REPORT SPONSOR** PHILIPS LIGHTING

---

**SUPPORTER** HSBC CLIMATE PARTNERSHIP

---

**LIGHTSAVERS PARTNERS** ADELAIDE, AUSTRALIA  
HALDIA, INDIA | HONG KONG, CHINA | KOLKATA, INDIA  
LONDON, UNITED KINGDOM | NEW YORK, UNITED  
STATES | QUEZON CITY, PHILIPPINES | SYDNEY,  
AUSTRALIA | THANE, INDIA | TORONTO, CANADA  
AND OBSERVERS GUIYANG AND TIANJIN, CHINA.

---

**MEDIA PARTNER** LEDS MAGAZINE (PENNWELL  
CORPORATION)

---

**COVER** WOMAN SITTING UNDER LED LIGHTS ALONG THE  
NANMING RIVER IN CENTRAL GUIYANG, GUIZHOU, CHINA.

---

**DISCLAIMER:** THIS PUBLICATION HAS BEEN PREPARED FOR GENERAL GUIDANCE ON MATTERS OF INTEREST ONLY, AND DOES NOT CONSTITUTE PROFESSIONAL ADVICE. YOU SHOULD NOT ACT UPON THE INFORMATION CONTAINED IN THIS PUBLICATION WITHOUT OBTAINING SPECIFIC PROFESSIONAL ADVICE. NO REPRESENTATION OR WARRANTY (EXPRESS OR IMPLIED) IS GIVEN AS TO THE ACCURACY OR COMPLETENESS OF THE INFORMATION CONTAINED IN THIS PUBLICATION, AND, TO THE EXTENT PERMITTED BY LAW, THE AUTHORS AND DISTRIBUTORS DO NOT ACCEPT OR ASSUME ANY LIABILITY, RESPONSIBILITY OR DUTY OF CARE FOR ANY CONSEQUENCES OF YOU OR ANYONE ELSE ACTING, OR REFRAINING TO ACT, IN RELIANCE ON THE INFORMATION CONTAINED IN THIS PUBLICATION OR FOR ANY DECISION BASED ON IT.

© 2012 THE CLIMATE GROUP.

ALL RIGHTS RESERVED. (UK CHARITY NUMBER: 1102909).

---

---

## TABLE OF CONTENTS

---

<b>FOREWORDS</b>	<b>01</b>
<b>EXECUTIVE SUMMARY</b>	<b>06</b>
<b>SECTION 1 LEDS: A GAME-CHANGING TECHNOLOGY</b>	<b>08</b>
THE PROMISE OF LEDS .....	08
CLIMATE IMPACT .....	10
ECONOMIC OPPORTUNITIES .....	11
CONCLUSION .....	13
<b>SECTION 2 A GLOBAL MARKET READY FOR TRANSFORMATION</b>	<b>15</b>
THE LED MARKET TODAY .....	15
LED PRICE PROJECTIONS .....	18
NON-MONETARY MARKET DRIVERS .....	19
CONCLUSION .....	20
<b>SECTION 3 THE LIGHTSAVERS TRIAL: PROVING LED PERFORMANCE</b>	<b>21</b>
RESULTS AND FINDINGS .....	23
CONCLUSION .....	25
<b>SECTION 4 SCALING UP: LED ECONOMICS, FINANCE AND PROCUREMENT</b>	<b>27</b>
BUILDING A BUSINESS CASE FOR SCALE-UP .....	27
SMART CONTROLS AND THE LED BUSINESS CASE .....	30
SOCIAL CO-BENEFITS AND THE LED BUSINESS CASE .....	32
FINANCING STRATEGIES FOR LED SCALE-UP .....	34
PROCUREMENT .....	41
CONCLUSION .....	44
<b>SECTION 5 SCALING UP: POLICY LEVERS</b>	<b>53</b>
LEADERSHIP: GOVERNMENT AS AN EARLY LED ADOPTER .....	45
ECONOMIC POLICY LEVERS .....	47
STANDARDS .....	47
CASE STUDIES: NATIONAL INDUSTRY DEVELOPMENT .....	49
CONCLUSION .....	52
<b>SECTION 6 CONCLUSIONS</b>	<b>53</b>
<b>ANNEX A HOW LEDS WORK</b>	<b>55</b>
<b>GLOSSARY</b>	<b>56</b>
<b>REFERENCES</b>	<b>57</b>

## FOREWORDS

---

### MARK KENBER, THE CLIMATE GROUP



Lighting matters. Almost a fifth of global electricity is used for lighting, which accounts for 1.9 billion tons of CO<sub>2</sub> every year. That's equivalent to the emissions from 70% of the world's passenger vehicles.

LEDs are revolutionizing the energy efficiency of lighting. They are also infinitely scalable, extremely reliable, and have a much longer lifetime than almost all other types of lighting. But like any new technology, they face barriers to adoption from a market unfamiliar with their benefits.

In 2009, The Climate Group, with the support of the HSBC Climate Partnership, established 'LightSavers', a global program to accelerate the market adoption of outdoor LED lighting and smart lighting controls. Based on a model piloted by the City of Toronto, LightSavers recruited 12 cities globally, including Kolkata, London, New York and Sydney, which under our guidance have sought to independently verify the performance of over 500 LED lamps in 15 separate trials. We worked to speed up the technology adoption process by standardizing the testing protocol and facilitating professional exchanges among city lighting managers.

The results are very encouraging. Many of the cities participating in the project are now scaling up their trials. Examples include Central Park in New York, social housing garages in Toronto, and streets and roads in Haldia, Kolkata, Quezon City, and Sydney.

This report summarizes the results, explores the global market status and potential for LED and smart control technology, and provides practical guidance for policy makers and lighting managers who want to scale up and finance large-scale LED retrofits.

We conclude that LEDs are ready to be brought to scale in outdoor applications. The independent and verifiable results from the LightSavers trials and accompanying public surveys give compelling evidence that many commercially-available, outdoor LED products offer high quality light, durability, and significant electricity savings in the range of 50 to 70%.

High capital cost and a dearth of effective financing approaches continue to be barriers to market maturity. But these will diminish as investment flows into companies making quality products; as LED and smart control device prices continue to fall; and as innovations spread in project financing and procurement in cities like Birmingham, Guangzhou and Los Angeles.

Meanwhile, countries like China that have a strategic mix of well-coordinated policies, standards, subsidies, and market aggregation initiatives, and are able to capitalize on a large internal market, are likely to rise to global dominance in LED technology, reaping economic benefits and continuing to push costs down.

This is the Clean Revolution. At light speed.

A handwritten signature in black ink, appearing to read 'Mark Kenber', written in a cursive style.

Mark Kenber  
CEO, The Climate Group

## ERIC RONDOLAT, PHILIPS



### LED LIGHTING SOLUTIONS HELP CREATE LIVABLE CITIES

We are going through a period of unprecedented urbanization. Today, more than half of us call cities our home. Twenty years from now, this figure will have risen to some 60%, and by the middle of the century over two thirds of us will live in urban areas. That's some 3 billion extra city dwellers – most living in rapidly expanding conurbations in emerging economies like China, India and Brazil.

All these people will want to live, work and enjoy their free time in safe, attractive, vibrant and environmentally sound cities. The rise in the urban population offers great opportunities for economic and social development, but at the same time it presents enormous challenges, especially in these times of financial and resource constraints.

As a leading global lighting company, Philips is committed to providing intelligent people-focused solutions that help municipal authorities build truly livable cities in an economically sustainable way. To this end, we are incorporating our innovations in LED lighting technology in fully integrated solutions for cities, thereby offering unprecedented scope to enhance city life with light.

### Energy efficiency...

Today, cities consume 70% of the world's energy supply, a figure that will only increase over time. Going forward, how will these cities manage to meet the growing energy demand while keeping costs under control?

Lighting accounts for 19% of the world's electricity consumption. Significant savings are possible – on average 40% – simply by switching to energy-efficient lighting technologies such as LED. On a global level these savings amount to €128 billion in reduced electricity cost, 670 million tons of CO<sub>2</sub>, or the equivalent of 642 power plants (in itself representing a €1,300 billion saving in reduced need for power infrastructure – virtually making this an economic necessity in these times of national budget deficits). Philips is driving the lighting industry's transition toward energy-efficient lighting, particularly LED lighting, and we aim to improve the energy efficiency of all the products we bring to market by 50% in the period from 2010 to 2015.

### ...and so much more besides

In addition to their capacity to slash energy bills and avoid greenhouse gas emissions, flexible LED lighting solutions offer exceptional freedom in terms of controlled lighting effect – color, dynamics – and design. This capability is driving a shift from 'quantitative' functional lighting towards 'qualitative' intelligent and emotive lighting that transforms urban environments, offering city residents and visitors safety and spectacle, uplifting and inspiring experiences.

### Partnering to enhance urban living

The future is full of promise. While there are major challenges to be overcome, more importantly there are discoveries to be made and lives to be improved.

We can do all of this, and more, by working together. That's why we at Philips are pleased to be part of this Clean Revolution partnership. So that, together with a broad range of partners from both the public and private sector, we can continue to deliver the cutting-edge LED lighting solutions that will help create the sustainable livable cities of the future.

Eric Rondolat  
CEO, Philips Lighting

## MAYOR SHRI CHATTERJEE, KOLKATA



The City of Kolkata, also known as the Cultural Capital of the country, is noted for its premier institutions for education, science and culture. Once the hub of economic development, the city underwent economic stagnation in the years following India's independence. The scenario, however, is now rapidly changing with economic rejuvenation leading to a rapid acceleration in the city's growth.

The Kolkata Municipal Corporation (KMC) is responsible for providing the citizens under its jurisdiction area of 185 square kilometers with services like supply of clean drinking water, sewage and drainage, public lighting, planting of trees, laying and maintaining streets among numerous other functions. The city comprises of 141 wards and each is represented by a Councillor.

Street lighting is one of the major services of KMC and the city has more than 250,000 street lights, most of which are high pressure sodium vapour (HPSV) lights. There is tremendous scope for improving the quality of light as well as saving electricity by adopting energy efficient street lighting technologies like light-emitting diodes (LEDs). The pilot project on LED street lighting initiated by The Climate Group, in collaboration with KMC, Bureau of Energy Efficiency (BEE), West Bengal State Electricity Distribution Company Limited (WBSEDCL) and West Bengal Pollution Control Board (WBPCB) through which 273 HPSV luminaires of 400W and 250W capacity have been replaced by 180W and 130W LEDs, respectively has provided KMC with valuable insights into the amount of electricity bills that can be saved by KMC by the adoption of this technology. The feedback from the citizens on the quality of light has also been very encouraging with all categories of users reporting better visibility.

KMC is now assessing the feasibility of up-scaling this path breaking project across the city. Cities across the state and country are drawing learnings from this pilot project and are designing their own LED street lighting projects. We hope many other cities learn from our experience and adopt LEDs for street lighting in their respective cities.

I would like to congratulate The Climate Group for this project and hope they keep assisting other cities in executing more of such LED projects and slowly redefine the way cities light themselves.

A handwritten signature in black ink, appearing to read 'Sovan Chatterjee'.

Sovan Chatterjee  
Mayor, Kolkata Municipal Corporation



## MAYOR HERBERT CONSTANTINE M. BAUTISTA, QUEZON CITY, PHILIPPINES



Quezon City, with 3.04 million residents, is the Philippines' most populous city, situated in the country's National Capital Region and the Manila Metropolitan Area. The City is the seat of national government institutions, such as the Philippine Congress House of Representatives, as well as the site of major university campuses, including the country's national university, the University of the Philippines Diliman. Quezon City is home to the country's major media companies, including the GMA Network, ABS-CBN and other national television broadcasting networks whose headquarters are located in the City.

Our Quezon City Government envisions itself as a model of effective governance and responsible leadership, working in partnership with the citizenry in building an ideal community where people live, work, and do business in a hospitable, progressive and peaceful environment. Hence, we are committed to establishing a "green city" dedicated to a cleaner environment and government services that implement that vision.

Key initiatives include:

- A green purchasing program for Government procurement;
- garbage segregation program being implemented in all Barangay's or local communities;
- biogas emission reduction which is the first Clean Development Mechanism of its kind in Southeast Asia and has become an electricity generator;
- green infrastructure rules and regulations providing standards and incentives to promote more energy efficient and green buildings;
- LED street lighting retrofit program.

Given the City's large land area, providing for electricity for street lights is a major part of our Government's annual energy budget. Quezon City and its local utility, MERALCO, together own and operate about 48,000 street lamps, which account for 65% of the City's annual expenditures for electricity, or about 5% of the City's overall annual budget. Hence, the task of greening our infrastructure has rated energy efficiency retrofits of street lighting as a high priority.

With technical assistance from the World Bank Institute's Climate Change Practice (Carbon Finance-Assist Program), we have identified significant cost and carbon savings associated with replacement of existing high pressure sodium lamps with LED technology. In 2011, the City joined The Climate Group's LED LightSavers program with 11 other global cities. Through participation in this global consortium, our staff gained valuable knowledge of the practical steps needed to advance a major LED street lighting retrofit program.

I am pleased that our Government is now committed to retrofitting 22,000 street lamps over the next five years. We plan to tender soon the first group of about 5,000 LED replacements and are working with the Philippine National Government to craft a national program modeled on our approach.

International collaboration through The Climate Group and World Bank assistance has brought us to this exciting juncture. Thank you and congratulations to all involved!

A handwritten signature in black ink, appearing to read 'Herbert M. Bautista'. The signature is fluid and stylized, with a long horizontal stroke at the end.

Herbert Constantine M. Bautista  
Mayor, Quezon City







## EXECUTIVE SUMMARY

Efficient lighting in our homes, offices and city streets is a key part of the Clean Revolution – a swift and massive scaling up of clean technologies to create a safe climate, boost economic growth, and secure a prosperous future for all.

Lighting is responsible for 19% of global electricity use and around 6% of global greenhouse gas emissions.<sup>1</sup> Saving 40% of lighting energy globally would have a climate impact equivalent to eliminating half the emissions of all electricity and heat production in the EU.<sup>2</sup> And like many other energy-efficient technologies, efficient lighting will boost global prosperity. In the United States alone, cutting the energy used by lighting by 40% would save US\$53 billion in annual energy costs, and reduce energy demand equivalent to 198 mid-size power stations.<sup>3</sup>

This lighting revolution is already underway. It is being driven by advances in one technology: light-emitting diodes, or LEDs. LEDs are emblematic of the emerging Clean Revolution technologies, which promise minimal environmental impact, generate immense economic value, and have the power to change our lives for the better.

And through outdoor lighting, one of the most important drivers of LED market growth today, this technology is coming to city streets and parks near you.

## THE LED REVOLUTION

LEDs are bringing a lighting revolution to our cities not seen since the days of Thomas Edison. The quantum dynamics that create light in the LED semiconductor represent as much of a technology step change as the move from candles to incandescent lamps in the 19th century.

### LEDS OFFER ADVANCES IN

- **Efficiency.** Energy savings from 50% to 70% compared with conventional technologies result in similar cuts to carbon emissions.
- **Controllability.** Superior control over light color, intensity and direction allows novel lighting system designs that can deliver a wide range of social co-benefits. Outdoor LEDs offer improved visibility for pedestrians and traffic, as well as reduced light pollution. Indoor LED smart control systems have been shown to improve student behavior and study performance. And when smart controls allow LEDs to dynamically change lighting levels in response to conditions, total system energy savings can reach up to 80%.
- **Lifespan.** Well-designed LEDs are expected to last for 50,000 to 100,000 hours or more. Lifespans can be extended even further by coupling LEDs with smart controls.

LEDs are also evolving much faster than any other lighting technology: while fluorescent tubes have doubled in efficiency since 1950, white LED efficiency has increased by a factor of ten since 2000.<sup>4</sup> Today LEDs are among the most efficient lighting sources available, but in the near future they will reach far beyond any competing technology and become the technology of choice for most applications – with energy savings reaching up to 90% compared to today's conventional technologies.<sup>5</sup>

Worldwide, the lighting market is expected to expand to US\$160 billion by 2020, largely driven by growth in demand for LEDs as their prices decline. LEDs are expected to fall in price by more than 80%<sup>6</sup> and reach a global penetration of around 60% across all lighting applications over the next eight years.

The economic benefits will come primarily to nations that invest in LED research and manufacturing today. Already, nations across the world including Canada, China, India, Italy, Japan, Korea, Malaysia, the Netherlands, Spain and the United States are racing to develop leading-edge LED industries. With an as much as US\$90 billion in LED product sales by 2020,<sup>7</sup> the industry will support hundreds of thousands of high-value jobs in supply chains that span the globe.



**LIGHTING IS RESPONSIBLE FOR 19% OF GLOBAL ELECTRICITY USE**

## BARRIERS

If LEDs are so promising, why are they not yet installed in every house, skyscraper and city street? Like any new technology, LEDs need to overcome a number of barriers before they become mainstream.

### FOR LEDs, THE KEY BARRIERS ARE

- **Up-front cost.** LEDs are already economically attractive in many settings, such as outdoor environments where energy or maintenance costs are high. But they face a particular economic disadvantage in their high up-front costs. At a time of serious financial constraints, this can limit LED sales even in settings where the long-term economic and social benefits clearly outweigh the costs. Continuing falls in LED pricing of 15% to 20% per year are expected to drive widespread adoption in general lighting over the next few years.
- **Shades of awareness.** Major governments and corporations are important drivers for the early LED market, but there is great variation between lighting managers' levels of awareness: from recognizing energy saving as an issue; being alert to the current state of LED technology; and to understanding how to proceed in procuring well-designed LED solutions. With LED technology changing so rapidly, keeping up to date can be challenging.

This report closely examines how governments can help the LED industry overcome these three barriers by trialling LEDs, using new finance models and developing supportive policy frameworks.

## THE LIGHTSAVERS CONSORTIUM: PROVING OUTDOOR LED PERFORMANCE

These three barriers have been the focus of the LightSavers consortium of 12 cities—from New York to London, Sydney to Kolkata, Toronto to Hong Kong— assembled by The Climate Group and supported by HSBC. Working across four continents, the consortium is accelerating the uptake of outdoor LED lighting by sharing knowledge around LED business cases and finance, while testing LED performance in a global trial.

The LightSavers global LED trial, running from October 2009 to January 2012, aimed to provide certainty about the state of LED technology. During the trial, lighting managers from nine of the cities independently tested the performance of more than 500 luminaires representing 27 different commercially available LED products, using the same measurement protocol.

This report shares the results of the trial publicly for the first time. The results independently validate the claims made for LED technology, finding that it provides superior performance and energy savings compared to conventional options.

### KEY FINDINGS INCLUDE

- **LEDs achieve the expected 50 to 70% energy savings, and reach up to 80% savings when coupled with smart controls.**
- **Even with these energy savings, the vast majority of tested products exceeded local lighting standards.**
- **Many commercial LED products tested show behavior consistent with claimed lifespans of 50,000 to 100,000 hours, and LED products generally show very little change in color.**
- **The 'catastrophic' failure rate of LED products over 6,000 hours is around 1%, compared, for example, up to 10% for ceramic metal halide fixtures over a similar time period.<sup>8</sup>**
- **The public prefers LED products, and around 90% of survey respondents support a full rollout of LEDs across city street lights.**

The Climate Group's LightSavers trial concludes that LEDs are now mature enough for scale-up in most outdoor applications, and that LEDs combined with smart controls promise greater savings.

## SCALING UP LEDS: ECONOMICS, FINANCE AND POLICY

This lighting revolution will accelerate rapidly if governments leap at the opportunity.

Today, the challenge for cities is to scale up LEDs in the applications to which they are suited, and to overcome economic and financial barriers to do so. To succeed, they must adopt economic models that accurately account for the long-term savings of LEDs and their associated smart control technologies, and the value of co-benefits such as better visibility and public safety. Innovative financial models, from asset leasing to public-private partnership, can help cities overcome capital limitations and potentially deliver LED solutions at zero cost.

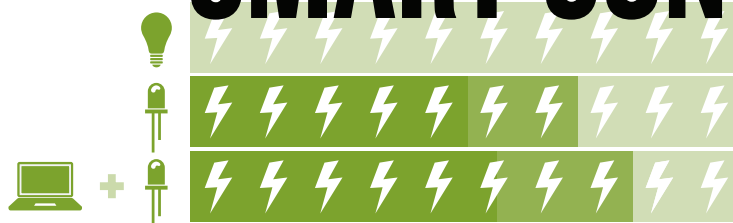
Finally, federal, state and city governments must make commitment to LEDs and smart controls a core part of their energy efficiency policies. Like all new technologies, LEDs face barriers to market entry that place them at a disadvantage to conventional technologies. Accelerating market development will help LEDs and smart controls to become mainstream in both outdoor and indoor settings, providing enormous economic and environmental returns.

- **Procurement.** City governments are among the largest consumers of lighting. They can become early adopters of LED technology through procurement leadership, as part of energy efficiency, industry development, or urban refurbishment programs. Procurement should ensure that LED luminaires are smart-control ready.
- **Economic policy levers.** Nations, states and regions can use economic policy levers to help lighting asset owners (most often cities or electricity distributors) overcome economic and financial barriers to scale-up.
- **Lighting standards.** Relevant agencies and institutions can speed up the development of lighting standards that recognize the advantages of LED technology, such as the improved visibility provided by white and uniform light.

Governments at all levels need to make LED and smart control market acceleration a policy priority, to remove the final obstacles and catalyze transformative scale-up.

The LED revolution is here. It's time to flick the switch.

**LEDS ACHIEVE THE  
EXPECTED 50 – 70%  
ENERGY SAVINGS,  
AND REACH UP TO  
80% SAVINGS WHEN  
COUPLED WITH  
SMART CONTROLS.**





## SECTION 1 LEDs: A GAME-CHANGING TECHNOLOGY

The numbers are big. Lighting worldwide accounted for 19% of grid-connected electricity generation and 9% of global energy use in 2006. The 6% of global greenhouse gas (GHG) emissions attributed to lighting is equivalent to 70% of the emissions from the world's passenger vehicles.<sup>9</sup>

Switching to efficient lighting can make a significant dent in these figures. Light-emitting diode (LED) technology offers us an extraordinary opportunity to do this. And recent advances in the technology, together with the rapid growth of the LED market, means that it is time to act now.

This is particularly critical in the streets and outdoor spaces of our cities. Outdoor lighting is proving an important early market for LEDs, and growth in this niche is driving the technology improvements and lower prices that will soon make LEDs the world's technology of choice in most applications, outdoor and indoor.

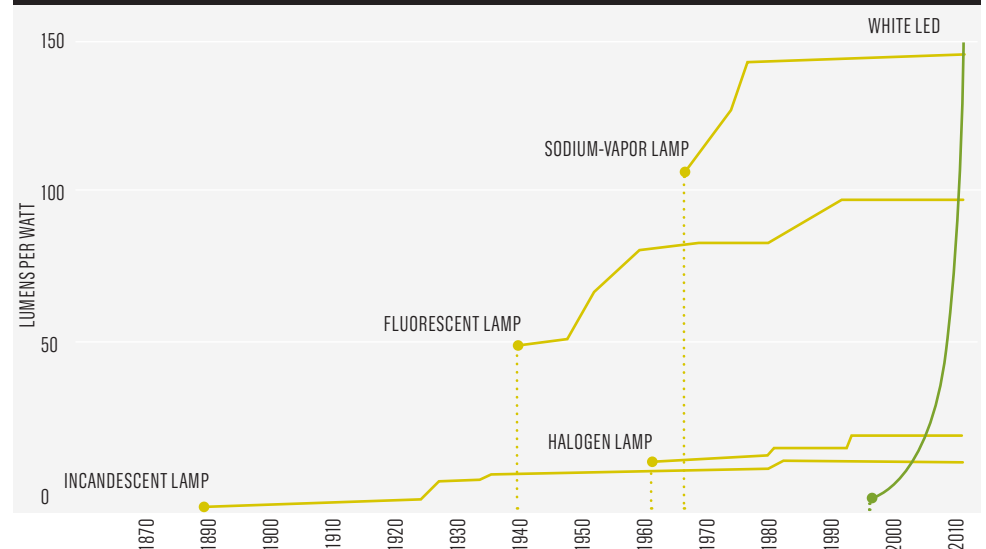
This section examines how the widespread adoption of LEDs may change our world: the technical and social benefits they will bring to our homes, offices and city streets; the potential to reduce global greenhouse gas emissions; and the economic opportunities available to the countries that embrace LED technology.

### THE PROMISE OF LEDs

LED technology offers important benefits over conventional lighting technologies because of the way that it produces light (see Annex A for details).

- **High energy efficiency potential.** LEDs have exceptionally high theoretical energy efficiency, and intensive research is rapidly unlocking this potential. Already, LED efficiency is fast surpassing that of conventional lighting technologies (see Figure 1). LED devices with an efficiency of 148 lumens per watt<sup>10</sup> are now available commercially,<sup>11</sup> and LEDs emitting 254 lumens per watt have been demonstrated in the laboratory – approaching LEDs' theoretical maximum efficiency.<sup>12</sup>

FIGURE 1 LED EFFICIENCY IS RAPIDLY SURPASSING THAT OF INCUMBENT LIGHTING TECHNOLOGIES<sup>13</sup>



- **Light intensity control.** Conventional lighting technologies tend to suffer decay in quality over time (known as lumen depreciation) and have shorter useful lives when they are dimmed. Yet the lifespan of an LED product actually increases when the average current flowing through it is reduced. This makes LEDs better suited to smart controls than any previous lighting technology, further increasing the potential for energy efficiency and making it possible to match light output closely to need.
- **Infinite color choice.** Color can be precisely controlled by embedding selected impurities in LEDs' semiconductors. Colored LEDs have brought altogether new possibilities to architectural lighting, entertainment, and other aesthetic applications. Newer white LEDs bring the potential to illuminate public spaces, homes and offices with light that mimics daylight.
- **Directionality.** LEDs provide highly directional light, meaning that they shine light only where it is needed. This accounts for a large proportion of the technology's energy-saving potential. In the case of street lighting this can reduce light pollution by preventing light from intruding into residential windows or the night sky.

- **Durability.** LEDs are extremely durable, and are resistant to vibration and other mechanical stress. This makes them a perfect match for lighting applications on bridges and elevated highways, or where vandalism is a problem.
- **Long lifespan.** The materials used in making LEDs are inherently stable. Laboratory testing, and experience with the stability of the silicon carbide from which many semiconductors are made, indicates well-produced LEDs may last from 50,000 to 100,000 hours and beyond. This is from two to five times longer than the most advanced fluorescent lamps.
- **Social co-benefits.** The controllability of LED light color, intensity and direction allows novel lighting system designs that can deliver a wide range of social benefits. In schools, for example, an LED lighting system with three color/intensity settings ('energy', 'focus' and 'calm') has been shown to dramatically improve student performance.<sup>14</sup> In public lighting, surveys detailed in Section 3 show that the public prefers the white light provided by LEDs to the color of conventional street lighting, and that LEDs bring advantages in both subjective visibility and public safety. Section 4 explores co-benefits such as public safety improvements that can arise when LEDs are combined with smart controls.

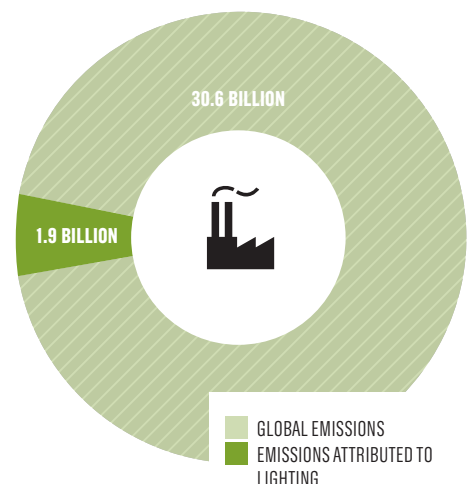
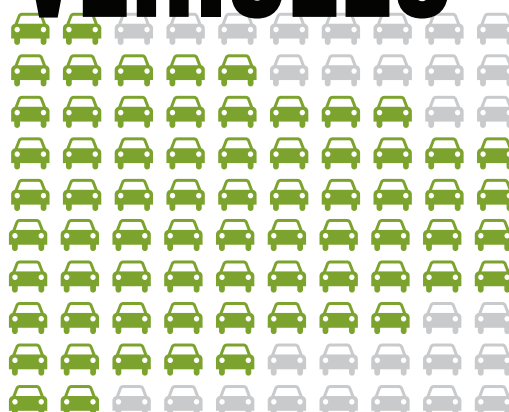
**CLIMATE IMPACT**

Given that today's LEDs promise energy savings of around 50% to 70%, and are expected to penetrate almost every niche of lighting, both indoor and outdoor,<sup>15</sup> in the long run we can conservatively expect LEDs to cut global lighting energy intensity by 40%. If they were to be implemented overnight in 2012, achieving 40% energy savings in all applications, LEDs could save 670 million tons of GHG emissions per year – around half the emissions of all electricity and heat generation in the EU.<sup>16</sup>

LED efficiency will continue to increase over the next decade, with US Department of Energy estimates placing commercial LED efficiency as high as 258 lumens per watt by 2020. This would be around two to two and a half times as efficient as today's best fluorescent lamps, and could increase energy savings in many applications by as much as 90%.<sup>17</sup>

According to the US Department of Energy, in the outdoor niche alone LEDs could prevent the emission of as much as 90 million metric tons of CO<sub>2</sub> within the US.<sup>18</sup> But beyond these savings, outdoor lighting applications have an important role to play as a 'gateway' application, critical to unlocking the wider energy-saving potential of LEDs. The outdoor lighting niche is well-suited to today's LEDs, and so has the potential to provide the economies of scale that will drive continual improvements in LED pricing and energy efficiency.

# GREENHOUSE GAS EMISSIONS ATTRIBUTED TO LIGHTING ARE EQUIVALENT TO 70% OF THE EMISSIONS FROM THE WORLD'S PASSENGER VEHICLES



GLOBAL EMISSIONS  
EMISSIONS ATTRIBUTED TO LIGHTING

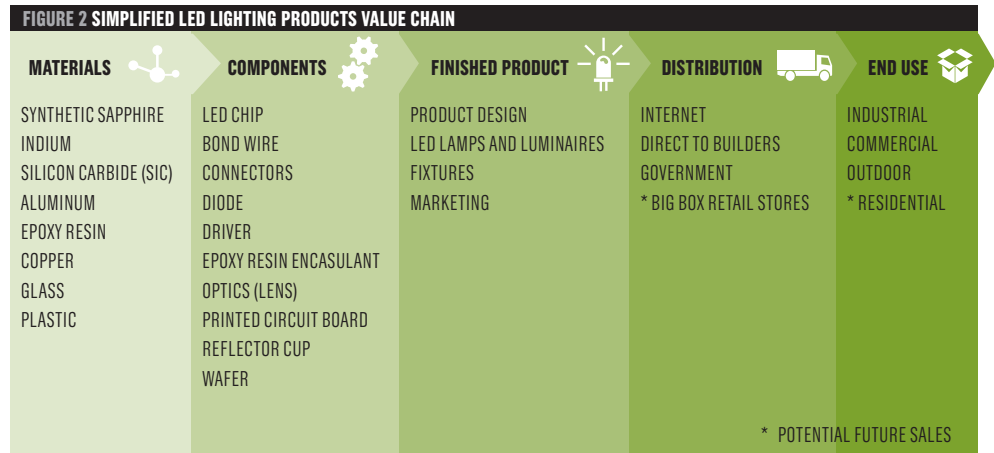
## SECTION 1 LEDs: A GAME CHANGING TECHNOLOGY

## ECONOMIC OPPORTUNITIES

The global lighting market is forecast to grow 60% by 2020, reaching US\$160 billion in value every year. Much of this growth will occur as markets for conventional lighting technologies contract and markets for LEDs expand in their place.<sup>19</sup> Economies that can win advantages in LED technology now will capture the bulk of the lighting industry in the future, securing high-value jobs and building expertise in the semiconductor industries linked to LEDs.<sup>20</sup> Already this reality has seen cities, regions and nations enter a race to strategically invest in LED manufacturing and deployment.<sup>21,22,23,24,25</sup>

The complex value chain for LEDs (Figure 2) provides economic opportunities for countries with a range of different industry specializations. For example, LEDs are produced through semiconductor manufacturing, much of which supports employment and economic development in Asia. And due to the wide variety of advanced components, the complex design processes and the marketing of final products, LEDs offer significant opportunities for job creation in more developed economies.<sup>26</sup> Finally, like any other product that needs to be distributed, sold and installed, LEDs also support local employment wherever they are deployed.

FIGURE 2 SIMPLIFIED LED LIGHTING PRODUCTS VALUE CHAIN

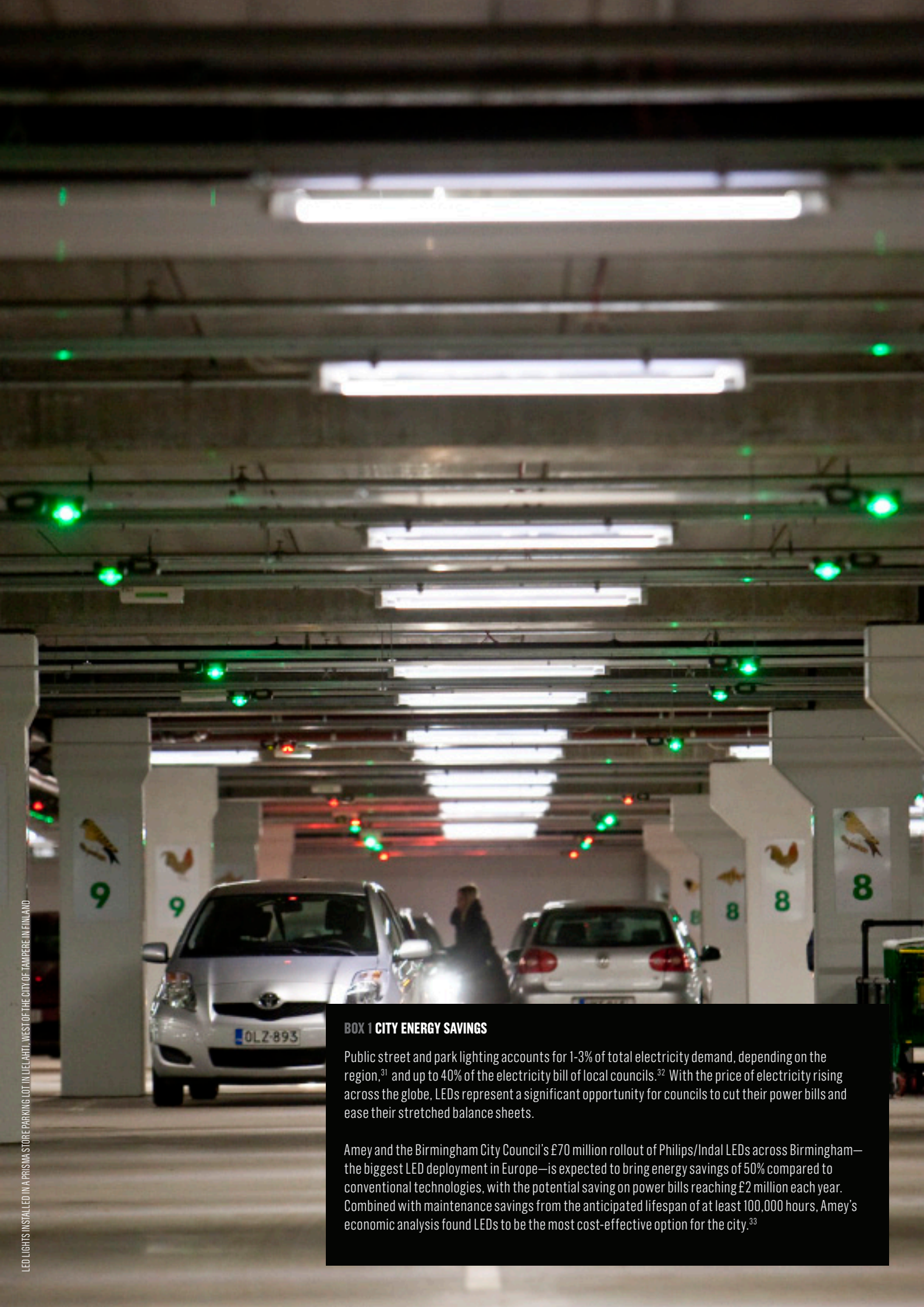


CENTER ON GLOBALIZATION GOVERNANCE & COMPETITIVENESS, DUKE UNIVERSITY

A 2008 survey of the LED industry in the United States identified more than 300 LED value chain suppliers, with 27% located in California, 8% in New York, and 7% in Florida. Among these suppliers, the survey scoped out 25 mostly small illustrative companies that provided employment for 27,000 people and generated annual sales of US\$6.7 billion.<sup>27</sup>

Municipal street lighting is one sector in particular that can support local jobs, especially where specifications for new products can vary substantially from one neighborhood to another.<sup>28</sup> One LightSavers program partner, New York City, operates an inventory of at least 17 different types of luminaire, ranging from antique designs in parks to high pole lighting along urban highways.<sup>29</sup> Whereas international firms mass produce millions of the products to the same specification, local firms can customize products for short runs to fill local niches. The potential for an infrastructure renewal investment in LED lighting of up to US\$20 - 30 billion in the United States, for example, could generate thousands of new jobs.<sup>30</sup>





LED LIGHTS INSTALLED IN A PRISMA STORE PARKING LOT IN LILJÄHTI, WEST OF THE CITY OF TAMPERE, IN FINLAND

#### BOX 1 CITY ENERGY SAVINGS

Public street and park lighting accounts for 1-3% of total electricity demand, depending on the region,<sup>31</sup> and up to 40% of the electricity bill of local councils.<sup>32</sup> With the price of electricity rising across the globe, LEDs represent a significant opportunity for councils to cut their power bills and ease their stretched balance sheets.

Amey and the Birmingham City Council's £70 million rollout of Philips/Indal LEDs across Birmingham—the biggest LED deployment in Europe—is expected to bring energy savings of 50% compared to conventional technologies, with the potential saving on power bills reaching £2 million each year. Combined with maintenance savings from the anticipated lifespan of at least 100,000 hours, Amey's economic analysis found LEDs to be the most cost-effective option for the city.<sup>33</sup>

## CONCLUSIONS

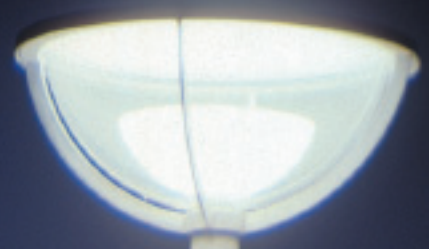
The global lighting market is in the throes of a major upheaval. The development and commercialization of LED lighting signal a revolution comparable to the transition from gas to electric lighting in the late 19th and early 20th century.

Electronics companies, including small entrepreneurial firms, are creating advanced materials and sophisticated components across a large LED supply chain that offers huge opportunities for economic development and job creation. Nations that can mobilize the necessary policies and standards, aggregate their markets, and marshal private investment to build manufacturing capacity will dominate the industry and claim the hundreds of thousands of jobs available to the leaders of the LED revolution.

Finally, given their capacity to achieve substantial emissions cuts and their continual improvement in economics, LEDs are one of the most important technologies for cutting carbon in the early 21st century. Reaching this potential depends partly upon the largest consumers of lighting—including governments and large multi-national corporations—rapidly accepting the technology and becoming prime movers in propelling market demand.

**ECONOMIES THAT CAN  
WIN ADVANTAGES  
IN LED TECHNOLOGY  
NOW WILL CAPTURE  
THE BULK OF THE  
LIGHTING INDUSTRY  
IN THE FUTURE.**

**OUTDOOR LIGHTING  
IS A 'GATEWAY'  
APPLICATION,  
CRITICAL TO  
UNLOCKING THE  
WIDER ENERGY-  
SAVING POTENTIAL  
OF LEDS.**





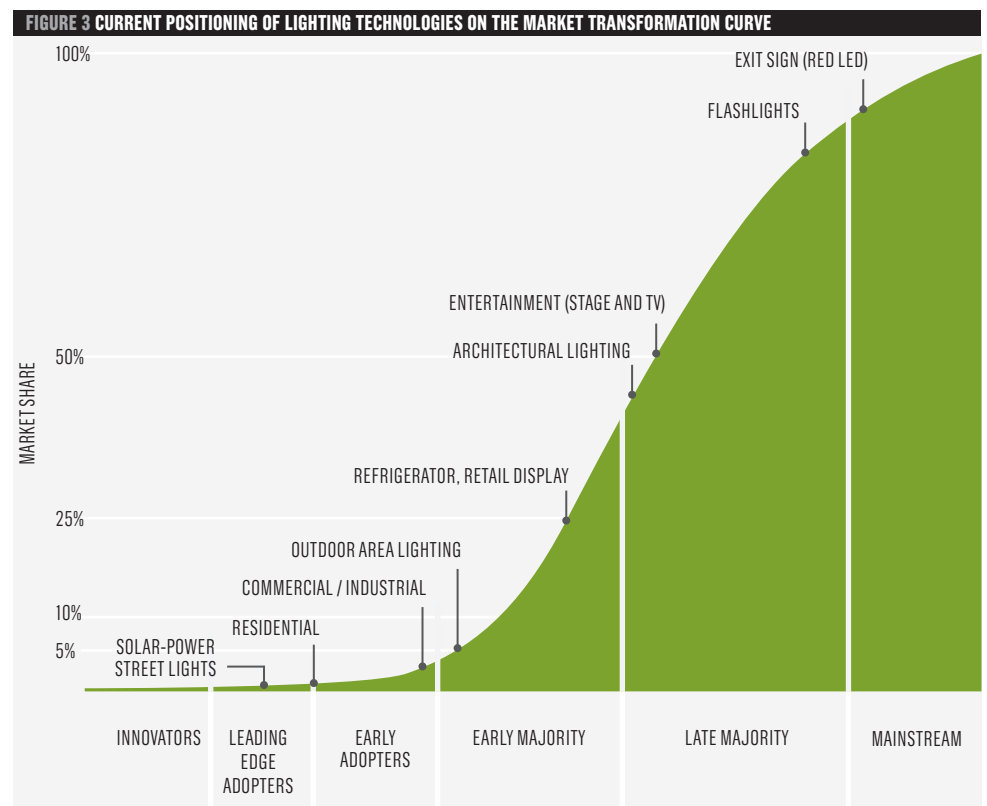
## SECTION 2 A GLOBAL MARKET READY FOR TRANSFORMATION

In 2011, the global lighting market (across all technologies) was estimated at US\$94 to \$110 billion, with general lighting products accounting for three quarters of this.<sup>34,35</sup> The high-brightness<sup>36</sup> LED market was already worth US\$12.5 billion in 2011 and is expected to reach US\$16.2 billion by 2014.<sup>37,38</sup> The market for LED lighting for indoor and outdoor applications is projected to grow at 20% annually through to at least 2016.<sup>39</sup>

How the LED market actually evolves over the next decade will depend on a wide range of drivers and barriers, many of which can be strongly influenced by interventions from city, state and national governments. This section explores the current state of the LED market, the drivers behind LED adoption so far, and future drivers of market growth especially in white light LEDs for outdoor and indoor lighting.

### THE LED MARKET TODAY

How far have LEDs penetrated the general lighting market today? The adoption of innovations and new technologies typically follows an 'S-curve' over time (see Figure 3). A 'tipping point' is expected when adoption reaches 15% to 25% of the market, at which point market penetration accelerates and becomes self-sufficient—and the slope of the curve steepens.<sup>40</sup>



VRINDA BHANDARKER, LED LIGHTING MARKET TRENDS, PRESENTATION TO STRATEGIES IN LIGHT CONFERENCE, SANTA MONICA, FEBRUARY 2011

The general lighting market is highly fragmented into niche product categories. As shown in Figure 3, LEDs have already made significant headway in niche applications such as exit signs and stage and TV entertainment, with architectural illumination close behind.<sup>41</sup> These product categories have reached or will soon reach the Early or Late Majority stages of the 'S-curve', because they involve applications that benefit from LEDs' precise control of color and illumination levels, as well as their small size. As demand in these niches has grown and provided economies of scale in LED manufacturing, prices have rapidly declined.

White light LEDs, the most important type of LED for outdoor lighting, are just beginning to enter the Early stage of the S-curve. While high-brightness LEDs have evolved rapidly, improving efficiency ten-fold since 2000, they too have been adopted in specialized applications. In these niches, their high up-front cost and uncertainty about lumen maintenance and lifespan are less important than their outstanding performance benefits. In other major general lighting market segments, such as commercial, industrial, and outdoor lighting, LEDs were below 10% market penetration in 2010<sup>42</sup> and still less than 1% in the largest sector, residential.<sup>43</sup>

Overall, white light LEDs have begun to be adopted in market segments where the technology's advantages—optical performance, energy efficiency, low maintenance costs, and aesthetic quality—have outweighed its additional up-front costs. Applications where directional lighting has an advantage, where maintenance costs are significant, or where lights are turned on 24/7 offer important opportunities for early LED deployment. These include bridges, tunnels, highways, parking garages, canopy lighting in petrol station high bays, indoor ceiling down-lighting in lobbies and warehouses, retail displays and exit signs. The directional, low-maintenance and aesthetic benefits of LEDs give them a particular advantage over the high pressure sodium (HPS) lighting that currently dominates the street lighting niche. These applications—some of which provide rapid economic paybacks under three years, others of which provide equally significant social benefits—are important drivers of the white LED lighting market globally.

# GENERAL LIGHTING WILL BECOME THE MAIN MARKET DRIVER. REVENUES GREW BY 50% FROM 2010 TO 2011

## BOX 2 STRUCTURE OF THE GLOBAL LED MARKET: BY APPLICATION

Niche markets that need colored light and small product size have driven the early market for high brightness LEDs, where the new technology has outperformed its less effective competitors. These applications – including vehicle lights, signage and video displays, and LCD backlighting – still account for the majority of high brightness LED revenues globally.<sup>44,45</sup>

As white LED light output and efficiency have improved, they have rapidly entered the general illumination market. Replacement lamp and luminaire applications accounted for around 14% of high-brightness LED revenues in 2011, with key applications including the street and outdoor area lighting that forms the focus of this report.

The total value of the market for high-brightness LEDs was US\$12.5 billion in 2011, and is predicted to reach US\$16.2 billion by 2014. While growth in segments such as TV backlighting slows over the next few years, high brightness LEDs for lighting applications will become the major long-term market driver. For this segment, revenues hit US\$1.8 billion in 2011, increasing by almost 50% on the previous year.

Outdoor lighting, considered a gateway technology for many LED general lighting applications, is expected to triple in revenue from 2011 to 2015, reaching almost US\$600 million in total revenues.<sup>46</sup>



### BOX 3 STRUCTURE OF THE GLOBAL LED MARKET: BY NATION

The world's major LED producers are China, Europe, Japan, South Korea, Taiwan, and the United States, with nations including India and Russia now emerging. Each of these nations shows a different level of LED industry vertical integration,<sup>47</sup> with Europe and the United States highly integrated, China and Taiwan more fragmented, and Japan and South Korea in between.<sup>48</sup> The Chinese market in particular—with some 2,200 manufacturers in 2010—is undergoing consolidation as product quality issues and falling LED prices are squeezing out smaller companies.

China is the world leader in LED manufacturing, accounting for 46% of global consumption of high brightness LED products in 2009, followed by North America, at 30%, and Europe at 17%.<sup>49</sup> North America and Europe dominate R&D and product design, and produce some of the world's highest quality LED products. Chinese innovation capacity is developing rapidly, following central Government investments in R&D and product quality control, but in the meantime the country specializes in low-cost manufacturing and joint ventures with foreign corporations.

In 2011, McKinsey & Company found that LEDs' penetration into general lighting markets reached around 7% across Asia, Europe and North America, and closer to 3% in Africa, Latin America and the Middle East.<sup>50</sup> General lighting market penetration across the globe is expected to swell from 7% today up to 64% by 2020, with the fastest growth in China at an annual compound rate of 49%.

China, Europe and the United States are the three major markets for outdoor LED lighting.<sup>51</sup> China's support for outdoor LEDs is the strongest, with a target of 30% penetration by 2015. China's Guangdong Province has adopted the most ambitious goal of any government in the world: installing 30 million indoor LED lights by 2015. India has begun working to catch-up, with economic growth and high electricity prices driving a new interest in outdoor LED manufacturing. For a closer look at Chinese and Indian market development, and the policies spurring their rapid growth, see the analysis of their LED policy frameworks in Section 5.



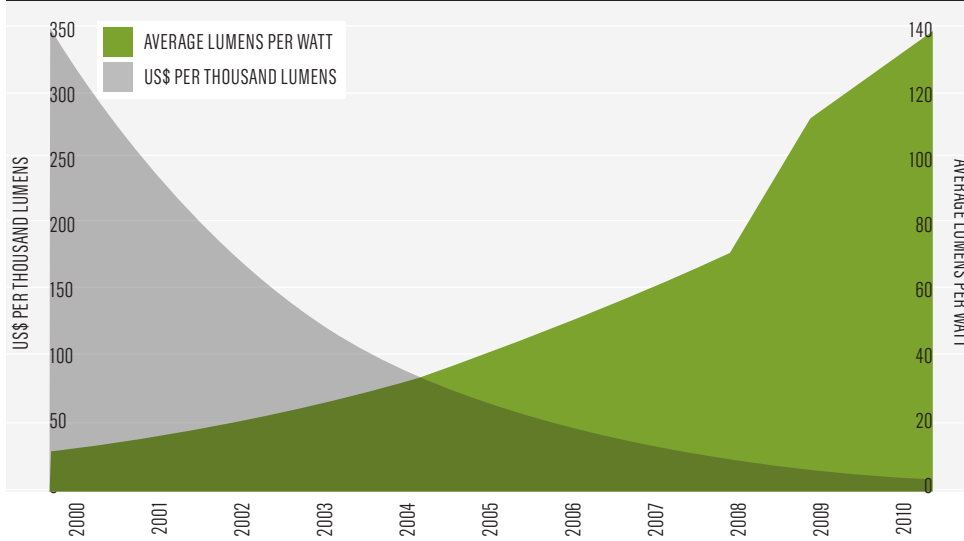
## LED PRICE PROJECTIONS

Future market development will depend chiefly upon the evolution of LED pricing.

The cost of LEDs has decreased substantially over the past decade, while light output and efficiency have steadily increased (see Figure 4). Pricing of LEDs is often measured in terms of cost per unit of light output, so in dollars per thousand lumens. Recent market data from March 2012 shows that 'cool white light' LEDs fell in price from US\$13 to US\$6 per thousand lumens from 2010 to 2011 – a fall of more than 50%.<sup>52</sup>

Prices are expected to continue their decline over the next five years as demand and production ramp up, and new innovations migrate from laboratories to factory production lines. The US Department of Energy has predicted a price of US\$2 per thousand lumens by 2015 – an 85% drop from prices in 2010.<sup>53</sup> An even steeper reduction in price is expected for 'warm white light' LEDs over the same period (see Table 1). But the LED device makes up only a portion of the cost of a luminaire. There are also the electronic driver and other optical, mechanical and electrical components to consider. Even so, the predicted decline in LED prices will still bring LED luminaire products into parity with incumbent technologies between 2015 and 2020.<sup>54</sup>

**FIGURE 4 WHITE LED TECHNOLOGY AND COST HAVE IMPROVED RAPIDLY OVER THE PAST DECADE**



BHANDARKAR, V., 2011, LED LIGHTING MARKET TRENDS, STRATEGIES UNLIMITED, PRESENTATION TO STRATEGIES IN LIGHT CONFERENCE, SANTA MONICA.

**TABLE 1 LED DEVICE EFFICACY AND PRICE ARE EXPECTED TO CONTINUE TO IMPROVE RAPIDLY**

LAMP TYPE	2010	2012	2015	2020
LED COOL WHITE EFFICACY (LM/WATT)	134	176	224	258
LED COOL WHITE PRICE (US\$/KLM)	\$13	\$6	\$2	\$1
LED WARM WHITE EFFICACY (LM/WATT)	96	141	202	253
LED WARM WHITE PRICE (US\$/KLM)	\$18	\$7.5	\$2.2	\$1

US DOE, 2011, SSL RESEARCH AND DEVELOPMENT: MULTI-YEAR PROGRAM PLAN.



## SECTION 2 A GLOBAL MARKET READY FOR TRANSFORMATION

Though rapidly improving, the upfront cost of LED luminaires and related products is high compared with conventional lighting technologies. The US Department of Energy reports that LED replacement lamps for 60W incandescent globes are 12 times more expensive than an equivalent output incandescent lamp and three times more expensive than comparable dimmable CFL lamp on a lumens per watt basis. This high upfront cost is a particular stumbling block to broad market adoption in a time of financial constraints.

But it is the total cost of ownership of LED luminaires that determines the economic benefit to users – and that is the best basis for economic evaluations of LEDs. When energy and maintenance cost savings over the product's lifetime are factored into economic calculations, there are already many applications in which LEDs are competitive today. Economic payback of five years or less is reported both anecdotally and from rigorous LED trials over the last few years. In fact, recent US Department of Energy analysis shows LED replacements for halogen downlights are already achieving payback as rapid as 1.1 years. Section 4 of this report examines business case construction in more detail.

Supportive government policy, at city, state and national levels, is vital for helping LEDs achieve the economies of scale that will fuel further price reductions. New technology applications have higher costs partly because they lack the large production runs and established support services of their conventional counterparts.<sup>55</sup> Market aggregation mechanisms and subsidy policies have been used successfully across Canada, China, Europe and the United States, to help level the playing field for LED technology – and these are explored further in Section 5.

### NON-MONETARY MARKET DRIVERS

While significant performance advantages in specific market niches such as colored traffic signals and television monitors have driven the early market for high brightness LEDs, outdoor lighting applications such as street and parking area lighting are likely to give a further boost to LED products in the wider general illumination market. The expected fall in LED package prices will be a boon to the market, helped by government policies to phase out incandescent lamps in most regions over the next few years.

### OTHER FACTORS THAT WILL ACCELERATE LED MARKET GROWTH INCLUDE

- **Testing, standards and specifications.** Independent verification of the claimed lifetime of LED luminaires will help assure adopters of the business case. Quality issues can be prevented by rigorous testing, standards and procurement specifications. Emerging field evidence supports the claimed life spans for well-designed products. As the evidence mounts, trust in the reliability of LED technology will unlock market growth. The assessment method recently recommended by the Illuminating Engineering Society's TM-21 committee will enhance confidence in LED lifespans.<sup>56</sup>
- **Growth in developing markets.** Recession and low economic growth currently dampen demand for new construction, which is a major driver of lighting demand. But growth is occurring in markets that have been less affected by the recession. In recession-prone nations, the fall in LED prices is likely to drive billions of dollars of retrofits in the short to medium term. The financial case for LED lighting is more compelling in new construction where lighting systems are designed and built from scratch, and lighting components are a small part of a much larger infrastructure investment.
- **Smart controls.** Smart, adaptive control technologies, which are not currently well understood by lighting asset managers, will be essential to mitigating the long-term risks of lumen depreciation. Controls will allow perceived light quality (illuminance) to match lighting codes precisely and allow LEDs to be powered at lower current levels, extending their lifespan.
- **Development of financing.** To overcome budget constraints, governments and companies will develop innovative finance strategies for major LED lighting investments. LED energy management contracts, supplier financing, and public-private investment contracts are possible models.
- **Policies and standards.** Governments are shaping and stimulating the LED market with technical standardization and labeling, market aggregation and subsidies, and government testing labs. This is especially important in China and India, with the United States already leading on labeling, national laboratory and field testing, and technical standards. As countries update their street and roadway lighting standards, the unique spectral output of LED lighting and its advantages of better visibility and acuity will become more widely recognized among lighting managers.

— **Outgrowth of incumbent technologies.** New technologies such as induction lighting offer relatively high efficiencies, high quality white light, and equally long lifespans to today's LEDs in some outdoor settings. But LEDs provide superior control of light color, lumen output and directionality, and are improving so rapidly in efficiency that they are likely to overtake these technologies in most applications by 2015.

## CONCLUSION

The future looks bright for LEDs. Rapid improvement in economics, along with their fundamental technical advantages, will see them become the preferred option in almost all lighting niches – both indoor and outdoor.

The LED lighting market is expected to grow by a compound rate of 20% each year until at least 2016,<sup>57</sup> to reach market penetration in general lighting of well over 60% in most of the world's nations by 2020.<sup>58</sup> But whether or not such a rapid transformation occurs will partly depend upon government interventions and procurement policies. Wide uptake in those niches where LEDs are already competitive, such as outdoor lighting, is what will drive confidence in the technology and increasing economies of scale.

The next three sections of this report focus on government strategies and interventions designed to accelerate transformation of the LED lighting market:

- The global LED trial run by The Climate Group and its LightSavers consortium of city governments;
- Accumulated city government experience in business case design, finance and quality product procurement; and
- Policy options available to city, state and national governments seeking to unlock the multiple benefits of accelerated LED deployment.

**LEDS ARE EXPECTED  
TO FALL IN PRICE BY  
MORE THAN 80%  
AND REACH A GLOBAL  
PENETRATION  
OF 64% ACROSS  
GENERAL LIGHTING  
APPLICATIONS OVER  
THE NEXT EIGHT  
YEARS.**



## SECTION 3 THE LIGHTSAVERS TRIAL: PROVING LED PERFORMANCE

Technology adoption takes time. Useful innovations rarely achieve market success without significant long-term investments in product and market development.

Compact fluorescents (CFLs) introduced commercially in 1980 were slow to penetrate the United States lighting market despite aggressive electric utility promotions throughout the 1990s. They reached only 2% of unit sales by 2005, some 25 years after their first appearance. The key factor in this slow uptake was concern about quality and durability, compounded by the relatively low cost of electricity and high CFL retail price.<sup>59</sup>

How will LED lighting products stack up against CFLs in their capacity to transform the lighting market? When will LEDs become affordable? Does the public like the light that LEDs produce? In short, have LED products reached maturity?

These are the questions The Climate Group addresses for the outdoor lighting market, through the LightSavers program (see Box 4 on the next page).

**TABLE 2 SUMMARY OF LIGHTSAVERS CITY TRIALS**

CITY	PARTNER	LIGHTING TRIALS	TRIAL START	TRIAL END
LONDON, UNITED KINGDOM	TRANSPORT FOR LONDON	BLACKFRIARS ROAD, TWO LANE SINGLE CARRIAGEWAY	NOV 2010	NOV 2011
		A40 WESTERN AVENUE, SIX LANE DUAL CARRIAGEWAY	NOV 2010	NOV 2011
NEW YORK, UNITED STATES	NYC DEPARTMENT OF TRANSPORTATION	CENTRAL PARK PEDESTRIAN PATHWAYS	OCT 2009	NOV 2010
		FDR DRIVE, SIX LANE DUAL CARRIAGEWAY	NOV 2010	NOV 2011
TORONTO, CANADA	TORONTO ATMOSPHERIC FUND	CALEDON TOWN HALL, OUTDOOR PARKING LOT	NOV 2009	DEC 2010
		ELLSMERE HOUSING, PARKING GARAGE	FEB 2010	NOV 2010
		VICTORIA PARK HOUSING, PARKING GARAGE	FEB 2010	NOV 2010
KOLKATA, INDIA	KOLKATA MUNICIPAL CORPORATION, INDIAN BUREAU OF ENERGY EFFICIENCY	BANERJEE ROAD, TWO LANE SINGLE CARRIAGEWAY	JAN 2011	DEC 2011
HONG KONG, CHINA	HK UNIVERSITY OF SCIENCE & TECHNOLOGY (HKUST) HK UNIVERSITY (HKU)	HKUST TWO LANE CAMPUS ROAD	APR 2010	AUG 2011
		HKU PEDESTRIAN PATHWAYS	AUG 2010	JUNE 2011
GUIYANG, CHINA	OBSERVER	N/A	N/A	N/A
TIANJIN, CHINA	OBSERVER	N/A	N/A	N/A
ADELAIDE, AUSTRALIA	CITY OF ADELAIDE	PARK 2, PEDESTRIAN PATHWAY	MAY 2010	MAR 2012
		BONYTHON PARK, PEDESTRIAN PATHWAY	SEP 2010	JAN 2012
SYDNEY, AUSTRALIA	CITY OF SYDNEY	GEORGE STREET, TWO LANE SINGLE CARRIAGEWAY	DEC 2010	FEB 2012
QUEZON CITY, PHILIPPINES	WORLD BANK	PROJECT IS SCALING UP AFTER EXTENSIVE STUDY	N/A	N/A
THANE, INDIA	INDIAN BUREAU OF ENERGY EFFICIENCY	MULTIPLE ROADS, STREETS, BUS STOPS AND OTHER AREAS	MAY 2012	TBD
HALDIA, INDIA	INDIAN BUREAU OF ENERGY EFFICIENCY	HP LINK ROAD, TWO LANE DUAL CARRIAGEWAY	NOV 2010	TBD





MARGARET NEWMAN, CHIEF OF STAFF AT THE NEW YORK CITY DEPARTMENT OF TRANSPORTATION, SURVEYS AN LED HERITAGE FIXTURE IN CENTRAL PARK, NEW YORK CITY.

#### **BOX 4 ABOUT THE LIGHTSAVERS PROGRAM**

The LightSavers program is a consortium of 12 major cities across four continents, assembled by The Climate Group to accelerate the uptake of LED lighting. Supported by HSBC, the program has helped member cities to share their experiences with LED business cases, finance innovation, policy, and the testing of LEDs through the LightSavers global LED trial. The program is based on a local model developed by the City of Toronto's Atmospheric Fund.

The LightSavers trial set out to independently verify industry claims about LED product durability, energy savings, compliance with local lighting standards, product lifespan, public reaction and LED economics. It involved rigorous field testing of 27 LED products in 15 trials across nine of the LightSavers cities, from October 2009 to January 2012. A total of 13 trials have been completed and analyzed to date, and the findings from these trials are summarized in this section.

The trials used a common monitoring protocol and standardized measurement equipment to determine how LED luminaires performed compared with baseline conventional lamps under a wide variety of settings and weather conditions. Settings for trials included neighborhood streets, university campuses, urban freeways, parking garages and pedestrian pathways

The trials monitored:

- product durability during the first 6,000 hours (up to 16 months) of operation
- energy savings compared with conventional lighting technologies
- whether the LED products matched or improved upon conventional luminaires' illumination, while complying with local roadway standards
- maintenance of lumen output and color temperature over time
- public reaction to LED luminaires in contrast to existing lighting
- economic case for wider scale-up and adoption.

Field trials are affected by many uncontrollable factors in the real world and provide an inherently imperfect view of performance. The LightSavers trial was designed to mitigate these challenges by generating a large volume of data across a range of different sites and settings, and testing products for a minimum of one full year.

Technical reports on each of the LightSavers trials will be posted at [www.TheClimateGroup.org](http://www.TheClimateGroup.org) as they are completed. The LightSavers project was supported by generous funding from the HSBC Climate Partnership. 'LightSavers' is a registered trade mark of the Toronto Atmospheric Fund, used with permission.



**SECTION 3 THE LIGHTSAVERS TRIAL: PROVING LED PERFORMANCE****WHY TRIALS?**

Why are trials so important? A new technology only moves from niche to mainstream when its end users realize that both performance and reliability are better than conventional products. The need to build this evidence is the reason that institutions engage in field trials before switching to a new approach. This is a critical stage in the process of market transformation, where collection of information helps to resolve uncertainties and clarify the relative advantages and disadvantages of a new technology.

Today, municipal lighting asset managers are broadly aware of the promise of LED technology, and many cities have been trying out different LED products available locally. In a recent survey of 70 municipal lighting asset managers in Canada, 91% said they were using LED lighting in some way, but none on a large scale. The high cost of advanced lighting, including LEDs, was cited as the biggest barrier to adoption. In personal interviews many managers said that they lacked confidence that LED street lighting technology had yet reached a stage where it could be adopted more broadly. Some who had pilot tested LEDs early on noted problems with failing lights. In the quantitative poll, nearly half of respondents showed high concern over the reliability of advanced lighting products.<sup>60</sup>

**RESULTS AND FINDINGS**

Among the trials in nine LightSavers cities, 13 out of 15 have concluded to date. Trials in Haldia and Thane, India, will not conclude until late in 2012 and 2013. The results reported in this section come from the trials whose data had been fully verified and analyzed at the time of writing of this report. Public surveys in Kolkata, London, Sydney and Toronto offer additional insights, and are also summarized in this section.

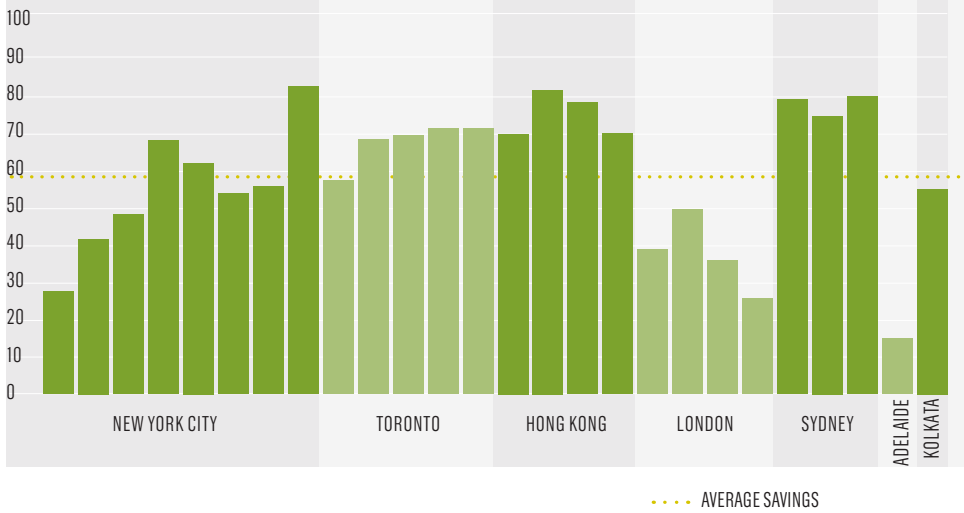
**THE PUBLIC  
PREFERS LED  
PRODUCTS. AROUND  
90% OF SURVEY  
RESPONDENTS  
SUPPORT A FULL  
ROLLOUT OF LEDS  
ACROSS CITY  
STREET LIGHTS.**

Results from the LightSavers trial and accompanying public surveys give compelling evidence that many commercially available outdoor LED products boast high durability, significant energy savings, comply with local lighting standards if sized properly, and stabilize in light output and color over the first 6,000 hours of operation after a burn-in period of 1,000 hours or so when light output is typically volatile. The surveys in four cities indicate that LEDs used to light city streets, parks and parking areas are preferred by the public to conventional lighting.

**THE KEY FINDINGS FROM THE TRIALS TO DATE ARE**

- **Product durability.** Out of 533 LED luminaires tested, only six units have failed to date, due to defects unrelated to the LED devices. This indicates a very low failure rate of just over 1% over 4,000 to 6,000 hours.
- **Energy savings.** Energy savings in the trials vary from 18% to 85%, with 20 out of 27 products achieving savings of 50% or more, and ten showing savings of 70% or more. A key reason for the LED luminaires’ superior energy performance is the inherent directionality of LED devices, resulting in more of the light emitted reaching the surface of the road. When coupled with smart controls, LED energy savings reached as high as 80%.

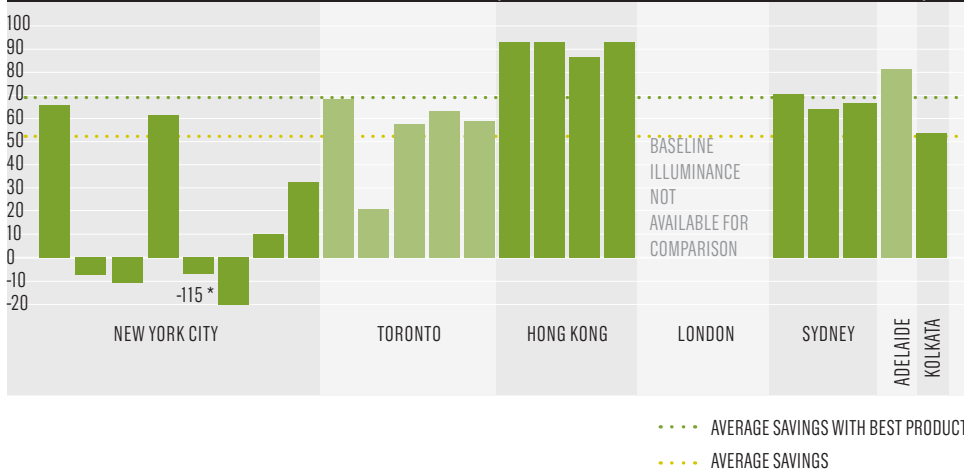
**FIGURE 5 PERCENT ENERGY SAVINGS IN LIGHTSAVERS CITIES, LED LUMINAIRE COMPARED WITH BASELINE HID LUMINAIRE**



- **Normalized energy savings.** Energy savings observed in the trials tell only part of the story of LED performance. Some LED products produced substantially more light than the baseline, cutting into their potential energy savings. Others saved energy partly because they produced less light. Figure 6 shows how much energy each LED product would save if it provided the same level of illuminance (light incident on the ground) as the product it replaced. Excluding the outlier\*, this measure indicates average potential energy savings of 53% across the trials.

- **Illuminance produced per watt.** The relative efficiency of LEDs compared to the baseline lights can also be expressed in terms of the amount of illuminance they produce per watt of power. LEDs often rate similarly to other technologies in terms of light generated at the luminaire (measured in lumens) per watt. In practice, however, they provide superior illuminance on the ground due to their intrinsic directionality; more of the light produced by LED street lights shines downwards on the area to be lit. Per watt of input energy, the average LED product in our trials produced 2.1 times as much illuminance as the baseline.

**FIGURE 6 PERCENTAGE ENERGY SAVINGS PER UNIT LUX PRODUCED (NORMALIZED, BASED ON FIRST 3000-6000 HOURS OF DATA)**

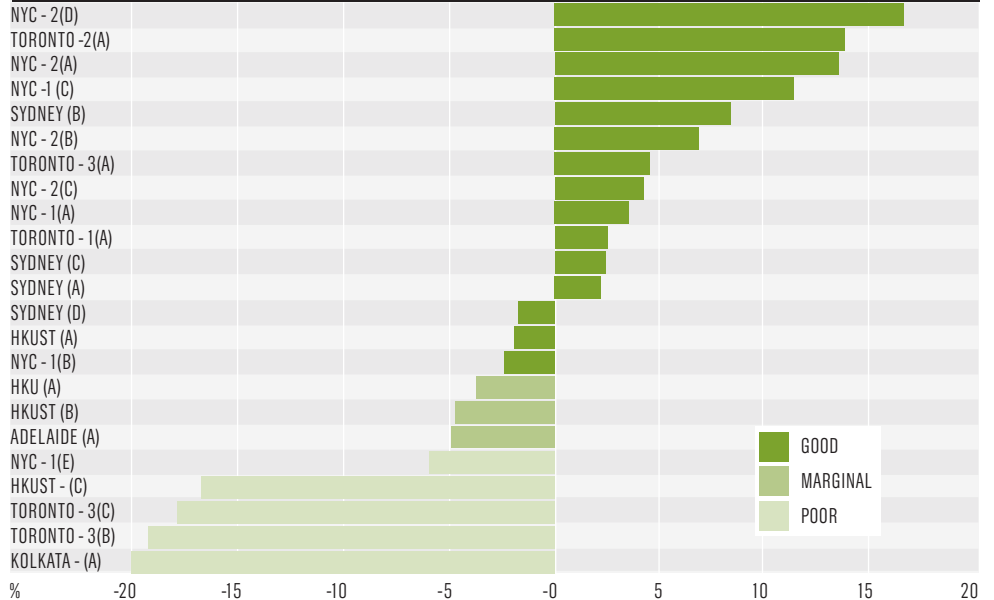


\* IN THE SPIRIT OF AN OPEN TRIAL, NEW YORK CITY ACCEPTED AND TRIALLED ALL DONATED LED LUMINAIRE, LEADING TO A WIDER RANGE IN LED PRODUCT PERFORMANCE. THE OUTLIER RESULT REPRESENTS A CLEAR CASE OF UNDERSIZED PRODUCT SUBMISSION AND WOULD BE EXCLUDED BY A FORMAL PROCUREMENT PROCESS THAT INCLUDED PRODUCT CERTIFICATION AND PHOTOMETRIC PERFORMANCE.

## SECTION 3 THE LIGHTSAVERS TRIAL: PROVING LED PERFORMANCE

- **Local lighting standards.** Most products tested complied with local lighting standards. Only five products did not meet local standards, and these products would need to be procured at a higher wattage.
- **Lumen maintenance.** There was considerable variability in the maintenance of light output among the LED products during their initial 12 to 16 months of operation. During the first 1,000 hours of operation, the light output of most products was quite volatile. Over time, however, 15 of the products maintained stable light output or showed increases, while three were marginal. Five of the products exhibited relatively rapid light depreciation. If depreciation attributable to dirt build-up were considered, most of the marginal products would have shown suitable performance.

FIGURE 7 ANNUALIZED LUMEN DEPRECIATION OF LIGHTSAVERS PRODUCTS\*



\* DATA IS BASED ON 3000-6000 HOURS OF OPERATION – TRIALS AT LESS THAN 3000 HOURS WERE EXCLUDED. DATA FROM THE TRIALS SHOULD NOT BE USED TO PREDICT LONG-TERM PRODUCT PERFORMANCE. A MINIMUM OF 10,000 HOURS OF OPERATION IS REQUIRED FOR THIS PURPOSE.

- **Color shift.** Products whose color shift was measured during the trials showed minor changes over the course of the trial, with a majority showing much smaller color variation than conventional luminaires.
- **Public opinion.** In the four cities where public surveys were conducted, residents, drivers, pedestrians and shopkeepers all expressed a strong preference for LED lighting compared with the conventional high pressure sodium HID lighting in their neighborhoods. In three cities, 70% to 80% of respondents said they felt safer with LED lighting. Majorities ranging from 68% to 90% showed support for LED rollout across their cities, with very few negative responses.

## CONCLUSION

LED outdoor luminaires have reached maturity in terms of their performance. City lighting managers from across the world have independently verified that LEDs can live up to their promise of exceptional performance, energy efficiency, and public approval, with indicators pointing towards stabilization in light output in many products after an initial period of volatility.

LEDs must be procured through a careful specification process that ensures quality. But it is now clear that anxiety about LED performance need no longer be a barrier to large-scale adoption of the technology by cities.







## SECTION 4 SCALING UP: LED ECONOMICS, FINANCE AND PROCUREMENT

Outdoor LED luminaires have reached performance maturity, and are moving into those market niches where they offer compelling, high quality performance benefits at a competitive price. But in many contexts their high up-front cost and relatively long financial payback of five years or more are still significant barriers to scale-up.

The potential benefits of LED scale-up are immense. As examined in Section 1, if LEDs achieve 40% energy savings across lighting, they could prevent the construction of 640 power stations across the globe. If municipal councils used LED street lights to achieve the level of energy savings identified in the Lightsaver trial, they could cut their electricity bills by 20% to 40%.<sup>61</sup> Expansion of important early markets for LEDs, including street lighting, will ultimately drive development of LED technology and accelerate its penetration into general lighting – potentially cutting global emissions by 670 million tons or more.<sup>62</sup>

This section explores strategies for scale-up of LED replacement projects and provides case studies of municipal scale-up projects across the globe.

### BUILDING A BUSINESS CASE FOR SCALE-UP

Simple approaches to comparing the value of lighting technologies – for example, comparing capital spend with expected cost savings over a certain period to yield simple payback – can be misleading and give an incomplete view of product value. Such an approach places excessive weight on the up-front cost of the products, without capturing some of the major economic and social benefits of a technology investment over its lifetime.

The most effective way to compare the value of LED products with their conventional counterparts is to conduct a total cost of ownership analysis to assess the total cost of ownership of each technology option. Then the potential LED adopter can compare technology alternatives on an 'even economic playing field', rather than on the basis of up-front cost and simple payback.

# CONDUCTING A TOTAL COST OF OWNERSHIP ANALYSIS PUTS LIGHTING TECHNOLOGIES ON AN EVEN ECONOMIC PLAYING FIELD

#### THE KEY DATA INPUTS FOR SUCH AN ANALYSIS WOULD INCLUDE

- Number of street light luminaires to be replaced
- Capital cost of new LED luminaires and other technologies
- Cost of installing the new luminaires, including cost of roadway closures to accommodate crews
- Maintenance cost of replacing luminaire components when they burn out or fail, including cost of roadway closures to accommodate crews
- Energy costs estimated during the lifetime of the luminaire, incorporating an estimated inflation in the utility rate over that time
- Useful lifespan of the existing and the LED luminaires
- An appropriate discount rate
- Possible benefits for public safety (and for indoor LEDs, possible benefits for productivity<sup>63</sup>).



#### **BOX 5 SERVICE STATION LED RETROFIT PROJECTS**

Both Shell and BP are retrofitting their petrol stations with LED canopy luminaires. Shell has so far retrofitted about 300 stations in Canada, and BP has retrofitted 80 stations in Austria, the Netherlands and Switzerland.<sup>64</sup> Customers expect high quality white light at service stations so they can safely operate the pumps when buying fuel. In these projects, LED lamps replaced metal halide (MH) lamps, offering equivalent or better full spectrum light compared with MH lamps while cutting energy use by 50% or more.

When the total cost of ownership for LEDs versus MH in petrol stations is considered, the business case is compelling. Payback periods of three years or less are common, thanks to substantial energy savings, the typical 24/7 operation of many gas stations, the relatively short lifetime of MH lamps (5,000 to 10,000 hours), and the high cost of using mobile elevated platforms for workers to replace lamps when they burn out. Like many lighting projects, if BP and Shell's technology choice was determined by up-front cost alone, conventional MH lamps would be installed instead – bringing short term savings, but significantly raising the costs of lighting in the long run.

## SECTION 4 LED ECONOMICS, FINANCE AND PROCUREMENT

As well as the total ownership cost of technology options, determining the internal rate of return (IRR) of a potential investment in a large LED scale-up initiative can help to measure profitability over the project's lifetime. The IRR is commonly used in business to assess the desirability of an investment. The higher the IRR the better, but in general, when the IRR exceeds the cost of capital, the investment should be economically profitable.

These two financial metrics—the total ownership cost of an LED retrofit compared with alternative technologies and the IRR analysis of the investment required to scale up an LED trial—provide robust information to make the business case for large scale-up investment.

**BOX 6 THE CITY OF LOS ANGELES BUSINESS CASE FOR SCALE-UP**

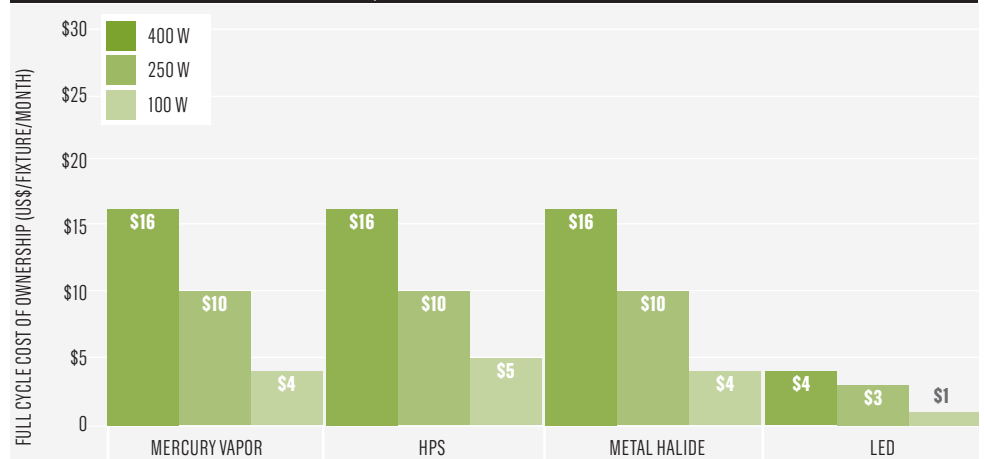
The City of Los Angeles will replace 140,000 out of 209,000 individual street lights with LED luminaires by 2014, with around 52,000 LED luminaires installed by October 1, 2011. The total cost of the five-year project is US\$56.7 million.

In 2009 Antonio Villaraigosa, the Mayor of Los Angeles, requested a full cost of ownership analysis of lighting technology options available to the City's Bureau of Street Lighting.<sup>65</sup> The study included five options: LEDs, mercury vapor, high pressure sodium (HPS), MH and incandescent. The results are shown in Figure 7. Compared with the four conventional options, LED luminaires had a lower total cost of ownership, even though the upfront cost for the other options was much lower.<sup>66</sup>

The Bureau also evaluated another promising lighting technology: induction lamps, which are fluorescent lamps energized by electromagnets. Because they lack electrodes, induction lamps are claimed to have a lifetime of 85,000 to 100,000 hours. And like LEDs, they also produce a high quality white light.

As a result of its trials, the Bureau opted for LED over induction technology due to LEDs' superior optical control and cost-effectiveness based on total cost of ownership. An analysis of the investment required, related costs, and revenue flows over a 12-year period (the expected lifetime of the LEDs) indicates an IRR of 7.4%, compared with the interest rate on Los Angeles' investment capital of 5.25%.

SEE THE CLIMATE GROUP'S LIGHTSAVERS WEBSITE FOR A DETAILED CASE STUDY OF THE LOS ANGELES LED ROLLOUT:  
[WWW.THECLIMATEGROUP.ORG/PROGRAMS/LIGHTSAVERS](http://WWW.THECLIMATEGROUP.ORG/PROGRAMS/LIGHTSAVERS)

**FIGURE 8 TOTAL LIFE CYCLE COST OF OWNERSHIP, LOS ANGELES LED STREET LIGHTS**

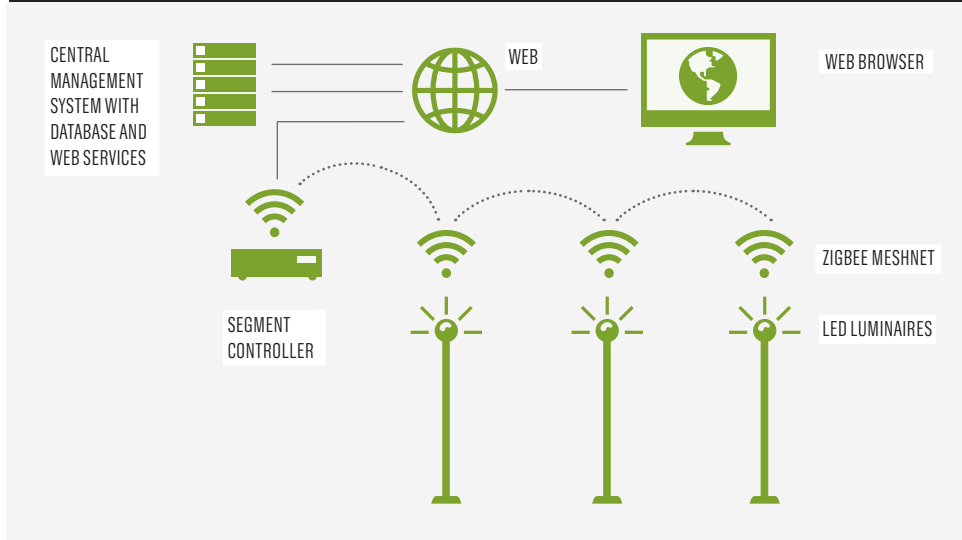
AS REPLACEMENTS FOR 400W, 250W AND 100W LOW-PRESSURE SODIUM LAMPS.

For a full discussion of incorporating non-market social benefits, see next page under the smart controls discussion.

## SMART CONTROLS AND THE LED BUSINESS CASE

Smart lighting control systems—infrastructure communications systems that allow real-time remote control of outdoor lighting—are well-suited to the rapid responsiveness and electrical characteristics<sup>67</sup> of LED technology. When applied to LED lighting applications, smart controls can increase public safety, enable monitoring of luminaire performance, and maximize both the energy efficiency and longevity of LED products. Cities can choose from two systems when installing networked controls: wireless radio communications systems, or power line carrier systems, using existing power lines for communications.

FIGURE 9 ILLUSTRATION OF A NETWORKED STREET LIGHT CONTROL SYSTEM



OWLET CONTROLS DIAGRAM. "OWLET NIGHTSHIFT," [WWW.OWLETSTREETLIGHT.DE/ENGLISH/OWLET/](http://WWW.OWLETSTREETLIGHT.DE/ENGLISH/OWLET/), ACCESSED NOVEMBER 2011. (OWLET IS A TRADEMARK OF SCHREDER SA, WHICH IS THE DEVELOPER OF OWLET LIGHTING CONTROL SYSTEMS).

Smart control systems can be used to vary the current passing through selected lights, or groups of lights, changing the brightness of the LED luminaires in real-time. This allows, for example, the amount of illumination on the road surface to be precisely matched to the levels required by road conditions and local lighting standards.

The ability to remotely monitor and adjust LED output through smart controls allows for three sources of financial savings that can enhance the business case and IRR for LED scale-up:

- Maximizing energy savings through dimming light to match the required standard, trimming output at sunset and sunrise, and dimming during periods of lower pedestrian-traffic conflict
- Maximizing LED lifespan through dimming, and through adjusting light output upward as the product depreciates over time
- Minimizing maintenance costs through remote detection of faults and failures, and through GPS mapping of luminaires.

Initial capital cost remains the largest barrier to adoption of networked controls in outdoor lighting. According to the Northeast Energy Efficiency Alliance (NEEA)'s survey of market-ready control systems, controller costs for each luminaire ranged from US\$100 to US\$250, while central management gateway costs ranged up to US\$10,000.<sup>68</sup> Additionally, NEEA reports that manufacturers may charge software license fees.

Despite the high up-front costs, the Birmingham case study shows that including sophisticated networked controls can improve the business case and economics of large LED scale-up projects, while raising the bar for best practice management of the lighting asset. Amsterdam has also shown positive results from combining LEDs and smart controls (see Box 7 on next page).





## BOX 7 CASE STUDY: SMART CONTROLS

### Birmingham's Smart Control Scale-Up

In the United Kingdom, Amey, a private public service provider, is using smart controls to trim lighting levels during sunrise and sunset, as well as to manage lumen depreciation over time as part of its Public Financing Initiative (PFI) with the Birmingham City Council. Part of this PFI will see Birmingham undertake Europe's largest LED street light scale-up project to date, targeting 90,000 street lights. According to Amey staff, the combination of energy savings and LED lifespan extension strategies—even with the extra capital cost of smart controls—enabled the Philips/Indal LED luminaires to come out on top in its financial analysis compared with other technologies.

The LED luminaires are sized initially to provide a higher level of illuminance than required, so that smart controls can reduce electrical current and illuminance levels early on in the project. As the luminaire slowly depreciates year by year, current levels are gradually increased so that illuminance levels, and therefore standards compliance, are maintained. Employing this strategy, Amey believes the luminaires will reach a lifetime of 100,000 hours, or 24 years of operation, significantly boosting the IRR over the period.

### Major Savings In Amsterdam

Amsterdam's A44, the world's first highway lit with LEDs and smart controls, provides another example of how this combination can help councils to cut their power bills and ease their stretched balance sheets. Ben Groot from the Netherlands' Public Works and Water Management authority, explains how the Philips Starsense system brought savings of 180,000 kWh to the 8 kilometer stretch of road. "Thanks to the tremendous dimming options you can reduce the light intensity from 100% during rush hour to a level of 20% during the hours following it."

The benefits from the system extend beyond electricity bills and carbon emissions, however. "The flexible dimming system vastly increases safety for road users. When it's raining or if there's been an accident, the light intensity is immediately adapted accordingly." Finally, says Groot, "Today's LED light sources hardly ever need replacing, which spares road users from a good deal of traffic nuisance and frustration."

SEE THE CLIMATE GROUP'S LIGHTSAVERS WEBSITE FOR A DETAILED CASE STUDY OF THE BIRMINGHAM LED ROLLOUT:  
[WWW.THECLIMATEGROUP.ORG/PROGRAMS/LIGHTSAVERS](http://WWW.THECLIMATEGROUP.ORG/PROGRAMS/LIGHTSAVERS)

## SOCIAL CO-BENEFITS AND THE LED BUSINESS CASE

The capacity to control the color, intensity and direction of LED light creates altogether new possibilities in lighting design – and opens up a range of new social co-benefits for lighting users.

Like many other energy efficiency projects that transform the built environment,<sup>69</sup> the greatest source of value in some LED projects will be found in their impact on people. When used indoors, LED lighting has been shown to provide benefits for productivity and student performance, especially where combined with smart controls.<sup>70</sup> For outdoor lighting, aesthetic appearance and public safety are the most commonly cited benefits, a finding reinforced by Lightsavers consortium surveys. Smart controls show particular utility in advancing public safety, as evidenced by their use in parking settings in Toronto (see Box 8 on next page).

Where possible, social co-benefits should be monetized for inclusion in business cases. Where the quantification of social benefits is difficult (for example, in the case of improved park aesthetics), multi-criterion analysis may provide a superior method for determining the relative value of each technology option. In this approach (see Figure 10):

- A list of project factors is compiled. Economic factors, such as the IRR, are placed alongside the relevant co-benefits such as aesthetics, safety, and impact on carbon emissions.
- Project factors are ‘weighted’ according to their importance, on a scale from one to ten.
- Each of the proposed technologies is rated for performance in each of the project factors, with scoring on a scale from one to ten.
- For each factor, the technology performance score is multiplied by the factor weighting to produce ‘weighted performance’.
- The weighted performance on each factor is summed, to produce an overall score for each technology.
- Finally, technologies are ranked according to their overall score.

Factor weightings reflect the priorities of the government or company in procuring luminaires, and the overall score reflects the value of each technology to the lighting owner according to these priorities. Many cities have implicitly undertaken simple multi-criterion analyses when they rule out technologies according to poor performance in one factor – for example, the rejection of LPS (and increasingly HPS) luminaires for their poor color profile, and associated low value for visibility and public safety.

FIGURE 10 MULTI-CRITERION ANALYSIS WEIGHTING SYSTEM

TECHNOLOGY OPTIONS	LIFETIME COST/BENEFIT			PUBLIC SAFETY			CARBON IMPACT			TOTAL	RANKING
	S	W	WS	S	W	WS	S	W	WS		
PRODUCT ONE	5	6	30	5	7	35	5	3	15	80	●
PRODUCT TWO	7	6	42	2	7	14	4	3	12	68	●
PRODUCT THREE	5	6	30	6	7	42	6	3	18	90	●

SYMONS, W. (2012) ‘EFFECTIVE CARBON MANAGEMENT’, PRESENTATION TO THE TONKIN TAX FORUM, AECOM.

S = SCORE  
 W = USER’S WEIGHTING  
 WS = WEIGHTED SCORE





#### **BOX 8 CASE STUDY: SMART DIMMING IN TORONTO**

Like many cities, Toronto traditionally overlights parking areas and garages to increase the public's sense of safety. But lighting public spaces 24/7 regardless of their occupancy leads to high electricity bills and unnecessary carbon emissions. In Toronto's Ellesmere and Victoria Park housing garages, a new LED smart control system has used dynamic lighting to cut energy use by as much as 80%, while delivering significant improvements in public safety.

Smart controls allow the level of light produced by the LEDs to be kept to the minimum permitted by standards, and then ramped up by simple occupancy sensors when the area is occupied by moving people or vehicles. Opinion surveys in these parking garages show this lighting strategy increases public safety, as people using the parking garage become more aware of others present in the parking area when light levels change.<sup>71</sup>

Finally, as the lumen output depreciates over time, the LEDs can also be brightened so that they maintain steady illumination. These approaches maximize the return on investment in the LEDs, by improving energy savings and extending the longevity of the luminaires, but also ensure that the parking garage users do not experience reducing lighting levels over time.



## FINANCING STRATEGIES FOR LED SCALE-UP

Many cities that have identified economically attractive outdoor LED projects still face a significant barrier to scale up: the availability of affordable financing.


The following is a review of finance mechanisms that can support LED scale-up projects, based on the experience of LightSavers partners, other cities such as Birmingham and Los Angeles who are undertaking major LED scale-up projects, and the experience of many players in the energy efficiency industry over the last few decades. They include seven models: self-financing, leasing, performance contracting, public-private partnerships (PPP), private finance initiatives (PFI) and carbon financing under the Clean Development Mechanism (CDM).

### SELF-FINANCING

The traditional way for a local government to finance an LED scale-up project is to allocate funding from its own annual capital budget, which is typically raised from bonds or debentures issued by the municipality or through financial transfers from other levels of government. But with many regions of the world struggling to recover from recession, many governments today face highly constrained budgets. As tax receipts evaporate, competition for capital proceeds from direct borrowing has become more intense. However, municipal and state governments that have strong credit ratings can still issue bonds or debentures to raise money for specific projects.<sup>72</sup>

Many of the cities that have used self-financing to support LED scale-up—such as Sydney and Los Angeles (see Box 9 on the next page)—are major economic centers with significant annual budgets and economies of scale in their LED luminaire rollouts. Smaller councils may benefit from combining their efforts to coordinate larger-scale purchases across multiple districts, or, where electricity distributors control the luminaires, to work for regulatory change so that LEDs become the distributors' technology of choice.

ADVANTAGES OF SELF-FINANCING	DISADVANTAGES OF SELF-FINANCING
<ul style="list-style-type: none"> <li>• A simple, familiar and fast method of financing projects</li> <li>• Often less expensive overall as it involves fewer parties, and therefore fewer profit margins</li> <li>• If properly structured, energy savings can be used to offset borrowing debt, allowing the possibility of a 'cost-neutral' arrangement on the city's balance sheets</li> </ul>	<ul style="list-style-type: none"> <li>• The approach is dependent on local political acceptance of additional debt</li> <li>• Access to international capital markets is required</li> <li>• The LED project must compete for capital among other potentially attractive spending options</li> <li>• The city assumes all the financial risk associated with the project</li> </ul>

A nighttime photograph of a city street with light trails from cars and illuminated buildings in the background. The sky is dark blue, and the city lights are warm and glowing.

# THE LED SEMICONDUCTOR REPRESENTS AS MUCH OF A TECHNOLOGY STEP CHANGE AS THE MOVE FROM CANDLES TO INCANDESCENT LAMPS IN THE 19TH CENTURY.

## **BOX 9 CASE STUDY: SELF-FINANCING THE LOS ANGELES SCALE-UP <sup>77</sup>**

Los Angeles is using direct borrowing to finance the largest LED street lighting project in North America – retrofitting 140,000 conventional lights. The Los Angeles Department of Water and Power (LADWP), a utility owned by the City of Los Angeles, is loaning the Bureau US\$40.2 million over seven years to invest in the project. Internal borrowing from an institution owned by the City itself has allowed an interest rate of 5.25%, lower than available commercial rates.

Another notable innovation is the use of smart controls to assist Los Angeles' debt repayment strategy. The smart controls allow precise quantification of energy savings from the retrofit, creating a credible revenue stream that can be used to service the debt. The average annual energy cost savings during the project's first seven years—expected to be on the order of US\$10 to US\$12 million annually—will be more than enough to pay back the loan during that period.

Structuring financial arrangements so that energy savings are used explicitly to fund debt repayments can help demonstrate to the City, and its constituents, the self-funding nature of long-term investments in energy efficiency.

**LEASING**

Under the leasing model of financing LED scale-up, the city chooses to rent the lighting asset rather than purchase it. An LED equipment manufacturer or finance institution provides the funds necessary for the retrofit and initially owns the equipment. A country’s tax laws, and the requirements of the LED adopter, will determine how the lease operates from there on. A variety of financing structures are available, including the operating lease, capital or finance lease, and hire purchase agreements:

- **Operating lease.** The property owner offers the lessee a fixed short-term lease, and transfers only the right to use the equipment for a fixed monthly rent, after which the asset remains the property of the owner.
- **Capital/finance lease.** Deploys capital from a third party financial institution to fund the LED retrofit over a defined period, with an option to buy the LED assets out-right at the end of the lease.
- **Hire purchase agreements.** Allows gradual payment for the LED assets over the defined operating period, and at the end of the contract the assets, now fully paid-off, automatically become the property of the lessee or customer.

ADVANTAGES OF LEASING	DISADVANTAGES OF LEASING
<ul style="list-style-type: none"> <li>• Attractive where there are constraints on available capital and direct borrowing</li> <li>• For the period of leasing, the rental expenses may be treated as an operating rather than a capital cost, which can be offset by energy savings</li> <li>• The lease value may not show up on the lessee’s balance sheet or increase indebtedness</li> <li>• The operating lease allows the lessee to transfer some of the risks of ownership to the lessor</li> </ul>	<ul style="list-style-type: none"> <li>• Likely to have a higher long-term cost than direct self-financing, due to the partial transfer of risk to the lessor</li> <li>• The lessee risks reduced control over the asset, and the lessor has an incentive to ‘cut corners’ where possible to minimize their costs</li> <li>• A capital/finance lease may increase the lessee’s indebtedness if the asset reverts back to the lessee</li> </ul>

To date, leasing solutions have primarily been applied to lighting efficiency projects in buildings, enclosed environments, and company site facilities where the environment and security of the retrofit units can be assured by the leasing company. In the United States many of the companies offering such leasing solutions have adapted financing structures they originally developed for financing solar equipment and installations.

In public street lighting applications, leasing terms need to include risk assessments in terms of environmental conditions, interfaces to existing legacy equipment, and potential vandalism. Turning these risks over to the lessor may increase the monthly payments required from the lessee.

## SECTION 4 LED ECONOMICS, FINANCE AND PROCUREMENT

## PERFORMANCE CONTRACTING

Energy performance contracts (EPCs) are common in North America, where specialized Energy Service Companies (ESCOs) have evolved over several decades to provide their clients—typically owners of building assets—with comprehensive energy services. These include technical evaluations, equipment installations, energy monitoring and verification services, billing, hazardous waste removal, and financing, often bundled together in a ‘cradle-to-grave’ package. The National Association of Energy Service Companies estimates that ESCOs have implemented US\$20 billion in projects to date in the United States.<sup>74</sup>

In a typical performance contract, the bulk or all of the capital is provided by the ESCO. Financing is structured so that energy savings are shared between the ESCO and the client over a period of time. The ESCO may actually guarantee savings, or at least guarantee that the savings will cover their clients’ costs over the period of the contract.<sup>75</sup> Note that the ESCO model is also offered by some major LED manufacturers with substantial financing capacity.

ADVANTAGES OF PERFORMANCE CONTRACTING	DISADVANTAGES OF PERFORMANCE CONTRACTING
<ul style="list-style-type: none"> <li>• The expertise of the ESCO can be harnessed to manage the project from cradle-to-grave</li> <li>• Attractive where there are constraints on available capital and direct borrowing</li> <li>• The ESCO’s capital expenditure does not show up on the client’s balance sheet or increase indebtedness</li> <li>• Low risk, as the ESCO assumes the performance risk by guaranteeing a specified level of savings</li> <li>• If energy savings outweigh the service fee of the ESCO, the project can be cost neutral or even generate net income</li> <li>• A cost-neutral project has little to no impact on the availability of finance for other city projects</li> </ul>	<ul style="list-style-type: none"> <li>• Can be more expensive overall due to risk premiums charged to compensate by the ESCO for the performance guarantee</li> <li>• EPCs can be complex and opaque, leading to difficulties in assessing the attractiveness of a proposal</li> <li>• Cities may lose some control over assets, as savings may be guaranteed only under specified operating conditions</li> <li>• In the past, unreliable ESCOs undertaking public projects have become a political liability in some countries</li> </ul>



## PUBLIC-PRIVATE PARTNERSHIPS AND PRIVATE FINANCE INITIATIVES

Public-private partnerships (PPP) emerged in the 1990s as a way for governments to fund and operate services through contracts with private companies. They come in a wide range of complex forms. Capital finance can be sourced from either the public or private sector, depending on the design of the contract. What is common to all PPPs is that the private sector brings its expertise to a project usually considered within the public domain, and assumes much of the financial risk and/or performance risk.

PPPs offer governments a way to undertake large scale LED retrofits with private sector financing and management expertise, while retaining management control and key decision powers. PPPs also shift performance risk to the private sector, with LED product failures entirely the responsibility of the private company. Large municipal governments sometimes use the PPP framework to outsource their street lighting operations. French company Citelum, for example, maintains urban street lights from Madrid to Mexico City through the PPP model.

According to the European Investment Bank, PPP transactions in the European Union stood at EUR 15.8 billion (US\$21.2 billion) in 2010. About 1,400 deals have been implemented over the past two decades.<sup>76</sup>

ADVANTAGES OF PUBLIC-PRIVATE PARTNERSHIPS	DISADVANTAGES OF PUBLIC-PRIVATE PARTNERSHIPS
<ul style="list-style-type: none"> <li>• The expertise of the private company is harnessed for all aspects of the project where required</li> <li>• Attractive where there are constraints on available capital and direct borrowing</li> <li>• The private company's capital expenditure does not show up on the client's balance sheet or increase indebtedness</li> <li>• The private company assumes the performance risk guaranteed under the contract</li> <li>• If energy savings outweigh ongoing cost of the PPP, the project can be cost neutral or even provide net income</li> </ul>	<ul style="list-style-type: none"> <li>• Can be more expensive overall due to risk premiums charged to compensate for the performance guarantee</li> <li>• PPPs can be complex and opaque, leading to difficulties in assessing the attractiveness of a proposal</li> <li>• Cities transfer some or all control over assets, and may lose public jobs associated with managing the assets</li> <li>• PPP arrangements can be controversial for privatizing public assets, and can be very costly where private owners fail to perform</li> </ul>



#### **BOX 10 CASE STUDY: LEDS IN THE BIRMINGHAM PRIVATE-PUBLIC PARTNERSHIP**

The rollout of LEDs across 90,000 of Birmingham's street lights (discussed in Box 8) is part of much larger £2.6 billion highway infrastructure modernization effort undertaken by Amey in partnership with the Birmingham City Council, as part of a 25-year Private Finance Initiative (PFI) contract. PFIs are a kind of PPP where almost all finance is sourced from the private company and the city transfers almost all project control. This allows the Birmingham City Council to utilize Amey's expertise in achieving its desired outcomes.

The Amey/Birmingham LED street light scale-up is notable because LED solutions were deemed economically superior to other conventional technology alternatives. However, £620 million (US\$996 million) in PFI credits from the UK Government will be applied to the overall contract, about 24% of the contract's value. Hence, the LED retrofit will have the benefit of subsidies comparable to those in the large Los Angeles LED street light retrofit.

SEE THE CLIMATE GROUP'S LIGHTSAVERS WEBSITE FOR A DETAILED CASE STUDY OF THE BIRMINGHAM LED ROLLOUT:  
[WWW.THECLIMATEGROUP.ORG/PROGRAMS/LIGHTSAVERS](http://WWW.THECLIMATEGROUP.ORG/PROGRAMS/LIGHTSAVERS)

## CARBON FINANCING—CLEAN DEVELOPMENT MECHANISM (CDM)

Capital constraints are a problem common to many developed nations, but are even more widespread among developing nations. To address this barrier, the Kyoto Protocol established 'flexibility mechanisms' that allow governments and companies located in industrialized countries to buy and sell GHG emissions credits generated in developing countries. These credits come from projects that reduce greenhouse gases through a variety of means, including energy efficiency and renewable energy. The Clean Development Mechanism (CDM) is one of the methods established to enable carbon financing to flow to projects in developing countries.

Approved CDM projects produce Certified Emissions Credits (CERs), which are then traded in the international carbon market. As a technology that can deliver energy savings and cut carbon emissions, LEDs are a prime candidate for engaging with the CDM. The CERs generated by LED installations in developing countries can be used as an additional source of income to improve project economics and overcome finance barriers.

A California-based company is undertaking a CDM project by establishing a rural LED lighting project in the states of Uttar Pradesh and Bihar in India. The project will sell and distribute one million solar LED lanterns to households in these states as replacements for kerosene lamps, achieving an average annual CO<sub>2</sub> emissions reduction of 30,000 tons over a ten-year period. Funds from these 30,000 CERs will be used to subsidize the sale of the lanterns, and it is this additional carbon finance that makes the project economically viable.

There is guarded optimism about the future of CDM. The Cancun Conference in December 2010 secured the continuation of Kyoto flexibility mechanisms and delivered improvements in the CDM process—including standardized baselines and monitoring methodologies. The decision by the EU to restrict its CERs registered after 2012 to CDM projects from the 78 least developed countries will remove China and India from the largest source of this type of carbon finance, and focus projects particularly in Africa and the Pacific Islands. As a result, LED technologies such as the solar lantern are likely to scale up significantly in those regions.

## PROCUREMENT

Novel technologies like LEDs and smart controls present a new set of procurement challenges, but cities can benefit from the accumulated experience of pioneers like Los Angeles, Birmingham and the cities participating in the global LightSavers consortium.

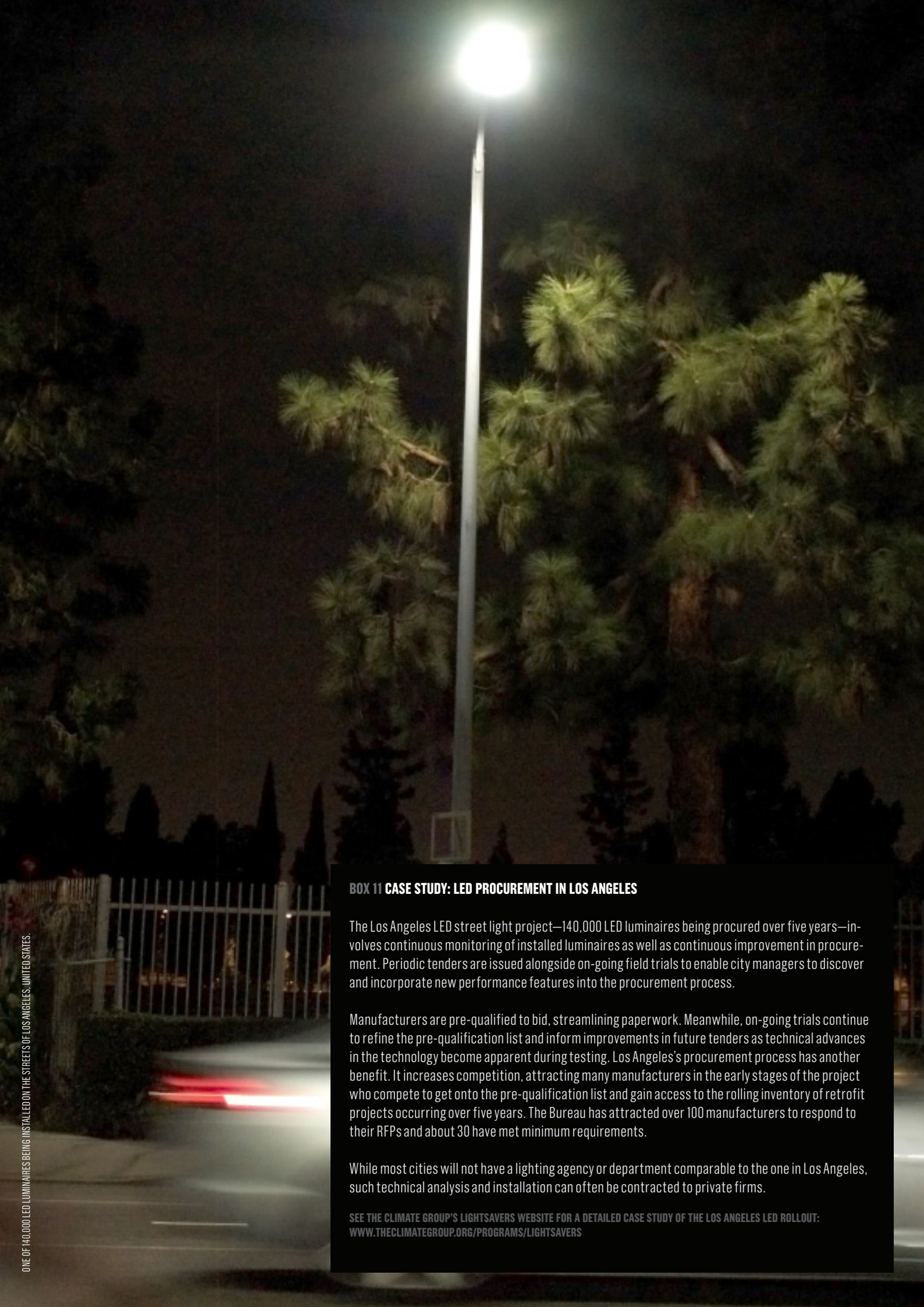
In fact, many cities' procurement documents are made publicly available for download, so can be viewed as examples. Another resource is the US DOE Municipal Solid-state Street Lighting Consortium, which has developed and published model specifications for LED roadway luminaires for the US market that can be customized to an organization's specific needs.<sup>77</sup>

Experience drawn from these sources has identified some of the basic elements that organizations may wish to include in their tenders. In response to a tender, the supplier or proponent should submit at minimum the following:

- **Quality assurance.** IES LM-79 certification to verify the technical performance of the supplier's product, undertaken by an independent laboratory
- **Photometric performance.** Software generated modeling reports which show that the proposed product(s) meet local roadway lighting standards and the city's specific illumination needs in the locations indicated in the tender
- **Lumen maintenance.** IES LM-80 certification of the lumen maintenance of the LEDs used in the supplier's product, accompanied by calculations that support the supplier's claim of product lifetime in the application described in the tender; in the near future IES TM-21 extrapolations of lumen maintenance should also be requested, once suppliers are able to adopt this new recommended practice
- **Color temperature.** Allowable deviations of correlated color temperature (CCT) from the manufacturer's nominal rated value
- **Warranty.** A minimum of five years covering the integrity and functioning of the whole luminaire system. Warranties of ten years or more are being offered by suppliers as competition among them increases and the performance of product achieves more certainty
- **Smart control readiness.** Whether or not smart controls are being purchased, lighting managers should request documentation on the compatibility of luminaires with future smart control upgrades. This approach can minimize future costs should a wider upgrade to smart controls become an attractive option for managing lighting assets.<sup>78</sup>

The procurement process can also be structured to address other issues relating to LEDs. Box 11 on the next page explores Los Angeles' approach to LED procurement, which has allowed the city to benefit from the rapidly evolving character of the technology in a scale-up project that spans several years.





ONE OF 140,000 LED LUMINAIRES BEING INSTALLED ON THE STREETS OF LOS ANGELES, UNITED STATES.

### **BOX 11 CASE STUDY: LED PROCUREMENT IN LOS ANGELES**

The Los Angeles LED street light project—140,000 LED luminaires being procured over five years—involves continuous monitoring of installed luminaires as well as continuous improvement in procurement. Periodic tenders are issued alongside on-going field trials to enable city managers to discover and incorporate new performance features into the procurement process.

Manufacturers are pre-qualified to bid, streamlining paperwork. Meanwhile, on-going trials continue to refine the pre-qualification list and inform improvements in future tenders as technical advances in the technology become apparent during testing. Los Angeles's procurement process has another benefit. It increases competition, attracting many manufacturers in the early stages of the project who compete to get onto the pre-qualification list and gain access to the rolling inventory of retrofit projects occurring over five years. The Bureau has attracted over 100 manufacturers to respond to their RFPs and about 30 have met minimum requirements.

While most cities will not have a lighting agency or department comparable to the one in Los Angeles, such technical analysis and installation can often be contracted to private firms.

SEE THE CLIMATE GROUP'S LIGHTSAVERS WEBSITE FOR A DETAILED CASE STUDY OF THE LOS ANGELES LED ROLLOUT:  
[WWW.THECLIMATEGROUP.ORG/PROGRAMS/LIGHTSAVERS](http://WWW.THECLIMATEGROUP.ORG/PROGRAMS/LIGHTSAVERS)

## CONCLUSION

The remaining barriers to market transformation—assessing the full value, economic and otherwise of LED projects, and finding capital to finance them—can be effectively addressed through applying well-understood techniques, many of them originally developed in the energy efficiency industry, to LED projects.

Full life-cycle analysis creates an ‘even playing field’ and will maximize the long-term value reaped by the owner of the outdoor lighting assets. Smart controls have been proven to save energy, reduce maintenance costs and extend product lifespan, making them a worthwhile up-front investment for many large-scale projects.

Social co-benefits beyond efficiency savings, such as improved public safety or aesthetic advantages (or improvements in productivity for LEDs in schools and offices), can be of immense value. Where possible these should be monetized for inclusion in the business case, or, where this is not possible, economic indicators like the project IRR and social co-benefits should be assessed alongside one another in a multi-criterion analysis.

To finance those projects found to be attractive, a variety of effective models have already been tested in the large scale-ups in Los Angeles and Birmingham. Key to successful financing is rigorous life-cycle cost modeling that will generate credible estimates of energy and maintenance savings, project cash flow, and rates of return on the investment. While subsidies have been instrumental in the case studies here, LED prices are declining rapidly. Structured financing without subsidies, public or private, will become even more able to catalyze large-scale LED retrofit projects in the near future.

# FOR MANY MUNICIPAL COUNCILS, LED STREET LIGHTS WOULD CUT THEIR ELECTRICITY BILLS BY 40%

Key principles to consider when developing finance models are the city’s appetite for risk, the need for external expertise, the desire for asset control, and the impact of the project on the balance sheet. Where possible, LED projects should be structured so that energy savings are explicitly used to cover project costs over time. This can help show how an LED project that appears to be high cost can in fact pay for itself.

Finally, when procuring LEDs, the tender issuer should be careful to include recently published IES standards, computerized photometric analysis, clear warranty conditions, and assess compatibility with future smart control upgrades.







## SECTION 5 SCALING UP: POLICY LEVERS

Supportive government policy, at the city, state and national level has been — and will continue to be — a critical driver of the LED lighting market. LEDs face a number of disadvantages that need to be addressed by well-crafted policy. Firstly, new technology applications are high-cost partly because they lack the economies of scale of their counterparts. Early adoption helps technologies overcome disadvantages like the scarcity of support services and small production runs.<sup>79</sup> Secondly, the cost of LED ownership is front-loaded, making them a challenging option for financially-constrained cities, even where the business and social case for LED rollout is clear. A wide mix of policies is in use by governments across China, North America, Europe, and several other nations, to help level the playing field for LED technology and catalyze market development.

This section surveys policies that have been successfully employed to accelerate government LED procurement, improve the economics of deployment, ease capital constraints, and address the perception of risk that accompanies new technologies, alongside case studies of their implementation in practice, in California, China, India, Sydney, and the wider United States.

### LEADERSHIP: GOVERNMENT AS AN EARLY LED ADOPTER

Before new technologies become mainstream, they are often deployed by governments. With their own significant asset bases, capacity to absorb risk, and their responsibility to assess the broader social value of projects beyond simple economic payback, governments are well placed to adopt technology early on the market transformation curve.

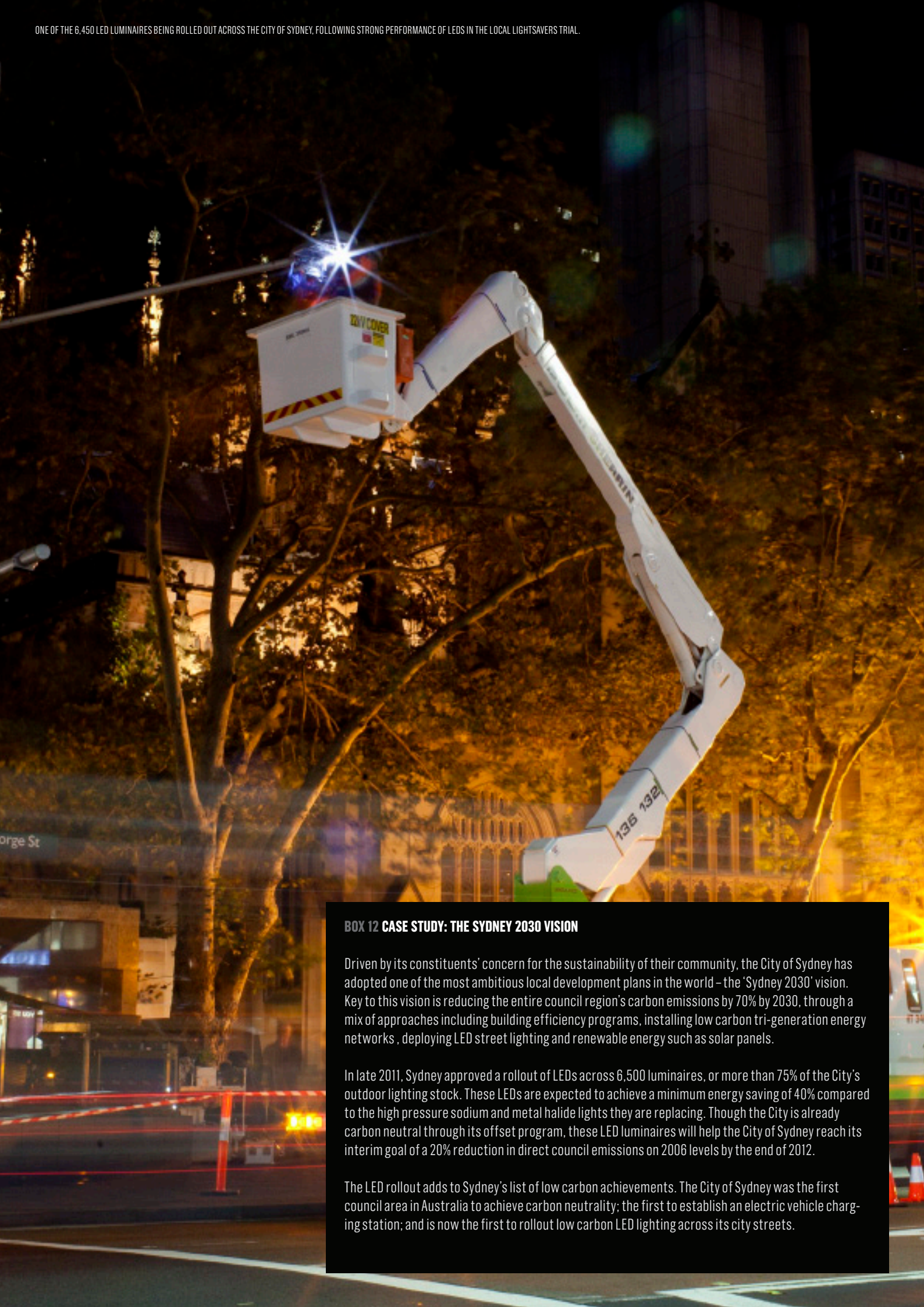
### THROUGH LED DEPLOYMENT, CITY, STATE AND FEDERAL GOVERNMENTS CAN

- Support job creation in regional or national LED industries
- Accelerate declines in LED pricing
- Deliver aesthetic revitalization of urban areas
- Improve citizen safety in public spaces and on roads
- Achieve energy efficiency or carbon reduction targets
- Improve resilience to volatility in energy prices
- Build a wider branding narrative, for example, the 'high-tech, clean city'.

Framing technology deployment decisions within these broader goals helps governments to deliver benefits that extend well beyond narrow economic modeling. As in the case of the City of Sydney (see Box 12 on next page), developing a wider narrative can help technology projects generate a sense of direction, momentum, and even branding that can help make the city an exciting place to visit, work and live.

Finally, market aggregation strategies, where councils across a region combine procurement processes to maximize their purchasing power, are a key strategy for achieving the lowest possible LED prices. State or regional-level governments, or regional electricity distribution companies (as in California), are good candidates for managing the procurement and offering low-cost LED products to the council level. China, with the world's largest population, has placed market aggregation as a foremost strategy in its efforts to gain competitive advantage in LED manufacturing (see the China section on page 49).





#### **BOX 12 CASE STUDY: THE SYDNEY 2030 VISION**

Driven by its constituents' concern for the sustainability of their community, the City of Sydney has adopted one of the most ambitious local development plans in the world – the 'Sydney 2030' vision. Key to this vision is reducing the entire council region's carbon emissions by 70% by 2030, through a mix of approaches including building efficiency programs, installing low carbon tri-generation energy networks, deploying LED street lighting and renewable energy such as solar panels.

In late 2011, Sydney approved a rollout of LEDs across 6,500 luminaires, or more than 75% of the City's outdoor lighting stock. These LEDs are expected to achieve a minimum energy saving of 40% compared to the high pressure sodium and metal halide lights they are replacing. Though the City is already carbon neutral through its offset program, these LED luminaires will help the City of Sydney reach its interim goal of a 20% reduction in direct council emissions on 2006 levels by the end of 2012.

The LED rollout adds to Sydney's list of low carbon achievements. The City of Sydney was the first council area in Australia to achieve carbon neutrality; the first to establish an electric vehicle charging station; and is now the first to rollout low carbon LED lighting across its city streets.

## SECTION 5 SCALING UP: POLICY LEVERS

**ECONOMIC POLICY LEVERS**

State or federal governments can use economic policy levers to help street lighting owners overcome economic and financial barriers to scale-up. Common tools include subsidies, rebates, energy efficiency credits, concessional loans, grants and tax breaks. Each of these provides some level of financial assistance to cities facing capital constraints and/or help to improve the overall economics of an LED project for the early adopter.

Which policy lever is best will depend upon the desired effect.

- Tax breaks, subsidies, rebates or tariff incentives are effective policy tools for projects that need a small improvement in economics to go forward. These are low-complexity options with small transaction fees, allowing smaller stakeholders to access the program. When predictable on the long-term, economic support of this type is effective at supporting industry development, but care should be taken that LED markets are not overheated with excessively generous subsidies.
- Concessional loans and grants can be particularly effective at assisting cities facing capital constraints. Examples include California's Energy Efficiency and Conservation Block Grant Program (see Box 13), part of the United States' stimulus spending program. This is only an option where state or national entities have the financial resources to provide direct funds or loans below market rates. Loans and grants for deployment provide temporary bursts in demand rather than supporting stable long-term market growth, so are less suited to supporting industry.
- Including LED projects within tradable energy efficiency or carbon credit programs is a technology-agnostic approach, making LEDs compete with other energy efficiency or low carbon projects in terms of economic value. This option can be a least-cost strategy for achieving the wider goal of energy efficiency or emissions reduction, but provides less of a guaranteed market for LEDs. Without careful design, it is more likely to support low-risk and well-understood energy efficiency projects rather than innovative LED deployments.
- Finally, policies that increase the cost of polluting, such as carbon pricing, can further improve LED economics by increasing the costs faced by cities that install inefficient conventional technologies. This provides another technology-neutral incentive, and is best accompanied by complementary policies targeting the specific barriers faced by promising low carbon technologies like LED lighting.

Research and development (R&D) support is just as crucial as deployment support. Many of the gains in LED efficiency over the past decade have been supported by R&D tax credits, government grants, collaborative roundtables,<sup>80</sup> or programs run within government agencies. Because the benefits of a company's R&D breakthroughs spill over to wider society—and to other firms—the private sector tends to under-invest in R&D. Public support for promising innovations can provide some of the most rapid paybacks of any investment type.<sup>81</sup>

**BOX 13 CASE STUDY: CALIFORNIAN LED GRANT SUBSIDIES**

Using stimulus funds provided through the federal job creation Recovery Act of 2009, California's Efficiency and Conservation Block Grant Program (EECBG) has offered economic and financial support to municipal governments undertaking energy efficiency projects.<sup>82</sup> Many energy efficiency projects are economically attractive, with rapid payback, and are an especially strategic investment during a period in which local governments are facing financial and resource constraints.

At the time of writing, the EECBG has committed US\$37.3 million of a total US\$49.6 million in grants available, with over 40 small cities and counties receiving support for LED street and parking area retrofit projects. The program is expected to save US\$9 million in annual energy costs, create around 2,400 jobs, and reduce CO<sub>2</sub> emissions in the state by 22,500 tons.

Without EECBG grants to offset the high capital cost of LED street light luminaires, it seems doubtful that California's municipalities would have been able to undertake these projects and secure the employment benefits and energy savings they provide.

## STANDARDS

LEDs represent a step change in lighting technology, and their rapid entry to the street lighting market has left standard makers scrambling to catch up. The lighting rules of today still reflect yesterday's technologies. As a result, LEDs can pose some contradictory compliance issues for street lighting managers. Priorities for standard development and integration across the globe include the following.

- **The white light effect.** It is reported that LEDs provide superior visibility per lumen compared to many conventional technologies—especially sodium lamps. White light is better suited to the receptors active in the human eye at night, and also allows the visual system to more easily discriminate objects by their color.<sup>83</sup> Lighting standards, however, do not presently account for these benefits. As a result, there is a risk that LED retrofits will over-light public spaces, creating more glare and using more energy than necessary.
- **LED lifespan and lumen depreciation.** Performance standards can also help address the perception of risk around LED luminaire lifespans, by providing an accepted method for predicting lumen depreciation behavior of 50,000 hours or more. The Illuminating Engineering Society (IES) has developed the LM-80 and TM-21 recommended practices for this purpose (see Box 14).<sup>84</sup> As TM-21 becomes widely adopted in the LED industry (LM-80 is already in wide use), standards boards and governments across the globe should consider integrating TM-21 documentation into best practice LED standards, policy and procurement.
- **Efficiency standards.** Governments may introduce efficiency standards in public lighting policy, procurement processes and contracts for third party public lighting owners. The American Council for an Energy-Efficient Economy (ACEEE) has shown that efficiency standards currently in place across all products will save US consumers and businesses more than US\$1.1 trillion dollars by 2035—and updating current standards could save another US\$170 billion by 2015.<sup>85</sup> If standards respond rapidly to the expected advances in LED technology, businesses, consumers and cities will reap economic and environmental rewards.

# THE LIGHTING RULES OF TODAY STILL REFLECT YESTERDAY'S TECHNOLOGIES.

### BOX 14 LED STANDARDS DEVELOPMENT AT THE US DEPARTMENT OF ENERGY

The US Department of Energy's Solid State Lighting Program has demonstrated the superior visibility provided by the white light of technologies such as LEDs, due to higher scotopic lumen output from such sources.<sup>86,87,88</sup> The Department of Energy concludes that in many settings, choosing a whiter light source can allow overall illuminance to be decreased, with additional energy savings from 20 to 40% regularly possible. Despite these findings, the effects of scotopic illuminance on street visibility needs further research before it can be widely integrated into street lighting standards. Combined with the 50 to 80% energy savings possible from LEDs with smart controls, another 20 to 40% may be unlocked by updating standards.

Working with a range of national research bodies and major LED manufacturers including Philips, Osram, Nichia, Illumitex, GE and Cree, the US Department of Energy's Pacific Northwest National Laboratory has also led research resulting in the new TM-21 standard – offering a mathematical method for projecting LED lifespan over periods up to 100,000 hours.<sup>89</sup> TM-21 complements the LM-80 standard, which provided a standard test protocol for assessing LED lifespan up to only 6000 hours. Industry commentators expect that a product's TM-21 data will become a standard part of performance documentation, used by manufacturers, program certifications such as Energy Star, and in procurement processes.<sup>90</sup>



## SECTION 5 SCALING UP: POLICY LEVERS

**CASE STUDIES: NATIONAL INDUSTRY DEVELOPMENT**

Two of the regional lighting markets that are expanding the fastest are those of India and China, largely due to two forces:

- Their rapid economic growth, which stimulates demand for new construction as cities expand. Due in part to this explosive construction, Asia accounts for about 35% of the global lighting market across all technologies—a figure set to rise to 45% by 2020;<sup>91</sup> and
- Highly supportive policy environments. Both countries represent exemplary use of LED procurement, economic policy levers improving LED financials, and rapid LED standards development in both their manufacturing and deployment.

China is the epicenter of the LED revolution, accounting for 46% of the consumption of high brightness LED products in 2009.<sup>92</sup> India provides an example of a nation catching up, learning from the strong policy support for LEDs in nations like China and introducing policies to jump-start its own LED industry.

A key driver for LED policy and investment in both countries is the need for a significant increase in energy efficiency across all sectors of their economies, in order to decouple energy demand from economy growth. Currently, neither country is self-sufficient in energy, and the need to import energy resources acts as a constraint on economic growth.

**CHINA**

China has the largest LED lighting industry in the world, with over 2,200 manufacturers producing LED devices, packages and luminaires. Much of the industry performs contract manufacture for western head-quartered companies, focused especially on low brightness LED applications. These include toys, flashlights, decorative lighting and display applications. All of the major western lighting companies have joint ventures to manufacture lamps in China.

**21 CITIES OF 10,000 LIGHTS PROGRAM**

The Chinese Government is now concluding a five-year, US\$44 million R&D program on LEDs, initiated as part of the 11th Five Year Plan (2006-2010) and involving more than 15 research labs and universities. As a part of the program, the Ministry of Science and Technology has been promoting China's nascent high brightness industry through the 21 Cities of 10,000 Lights project, funding the installation of at least 10,000 street lights in each of 21 cities.<sup>93</sup> The Ministry announced the program in April 2009, aiming for an eventual total of one million LED outdoor and indoor installations saving 220 million kilowatt-hours annually.

A key aim of the project is to enable local LED companies to develop markets for their LED products in the cities where they are located, using these large installations as platforms for wider market development. As a result, the Ministry often provided limited subsidies directly to the LED companies, typically amounting to 10% of the project cost. The companies could then approach their local municipal governments to partner with them on LED demonstrations.

Unfortunately, the project has been hampered by LED product quality issues. Failure rates as high as 70% and annual lumen depreciation as high as 30% in some individual demonstrations have been reported anecdotally. Hence, the project slowed in 2011 to allow time for an evaluation by the China Solid State Lighting Alliance (CSA).

Major recommendations from CSA's evaluation include creating a national guide providing LED evaluation criteria; setting up a quality control system; providing central government subsidies to local governments; establishing better coordination among relevant central government agencies; improving standards for LED manufacturing processes; and supporting further research and development.



# CHINA NOW LEADS THE WORLD IN THE DEPLOYMENT OF LED STREET LIGHTS WITH 74% OF THE GLOBAL TOTAL.

## BOX 15 GUANGDONG LEADERSHIP

Despite product quality issues in some regions participating in the 21 Cities of 10,000 Lights program, demonstration projects in Guangdong Province proved successful. This stemmed from more rigorous technical requirements and standards associated with energy management contracts (EMC), which were pioneered in China by Guangdong's cities. In this model, banks provide project financing to cities to cover third-party testing data, feasibility analysis, street reconstruction and lighting sources. The loans are repaid from energy savings over a six-year period, which requires periodic field monitoring. Meanwhile, product quality and life are protected by warranty for five years and further guaranteed by insurance companies. Typically, 10% of the project cost was subsidized by Guangdong Province, 15% by municipal government, and the remaining 75% financed through an EMC with an energy service company (ESCO).

Guangdong's leadership on LEDs is driven by the importance of the technology to the Province's economy. Companies located in the province supplied 70% of China's LED packages in 2010, with foreign investment in local LED firms approaching US\$1.5 billion, much of it centered in Shenzhen's Special Economic Zone. In order to maintain this momentum, Guangdong relies on expanding local procurement to grow the provincial market for locally-produced LED products. By the end of 2011, 200,000 street lights had been installed on 2,000 kilometers of provincial streets and roads, including 100,000 in the provincial capital, Guangzhou. Installation of another three million LED street lights has been set as a medium-term goal for the Province.

Partly due to the 21 Cities of 10,000 Lights program and Guangdong's LED installations, China now leads the world in the deployment of LED street lights. In 2010, approximately 350,000 LED street lights were installed in Chinese cities, 74% of the global total. This volume is likely to decline to 200,000 in 2011 due to the slowdown in the project.<sup>94</sup>

## SECTION 5 SCALING UP: POLICY LEVERS

## 12TH FIVE YEAR PLAN (2011-2015)

China is expected to continue its ambitious LED program in the current Five Year Plan, which aims for LEDs to achieve 30% market share of China's general lighting market by 2015. Guangdong Province has adopted probably the most ambitious provincial goal under the Plan: installation of 30 million indoor LED lights by 2015. As well as improvements and expansion of its 21 Cities of 10,000 Lights program, China will continue to invest in R&D (including the establishment of national photonics laboratories) and develop advanced LED manufacturing technologies, as well as include LEDs in the central Government's Green Lights program of subsidies and aggregate LED procurement.

While product quality issues have dogged China's LED efforts to date, it is clear that this will not impede the country's long-term ambition to become a world leader in LED manufacture.

Indeed, the current status of LED manufacturing in China today mirrors the nation's experience with rollout of CFLs previously. The low quality of early CFL products from China dampened consumer enthusiasm for the technology in the 1990s. But today, Chinese firms manufacture high quality CFLs, dominating global markets. It is expected that Chinese governments will address LED product quality problems throughout the supply chain using R&D and procurement initiatives as well as joint ventures with western LED companies. By deploying a mix of policies, subsidies, and market aggregation initiatives that capitalize on the large size of China's market, the country is well placed to gain comparative advantage.

## INDIA

Until recently, the high brightness LED revolution had bypassed India. This is perhaps surprising because the lighting market in India is valued at US\$1.4 billion and has been growing at the robust rate of 18% annually.<sup>95</sup> Western lighting companies have been manufacturing in India for 75 years, now with thousands of employees alongside well known Indian brands.

In 2009, the rapidly growing influx of inexpensive Chinese manufactured LED products caught the attention of Indian policymakers. By 2010, the LED lighting market in India had grown to US\$73 million, with a forecast growth rate of 45% to at least 2015.<sup>96</sup> India's National Manufacturing Competitive Council, an agency with Cabinet ranking, convened a Core Committee chaired by the Ministry of Power to look into the appropriate policy measures for accelerating adoption of LEDs in India. After extensive consultation with the lighting industry, LED manufacturers, states and cities, and other stakeholders, the Committee submitted its report, *The Economic Case to Stimulate LED Lighting in India*, in May 2010.

A key driver of Indian government LED policy is the need to achieve significant energy efficiency across all sectors of the economy, in order to decouple growth in energy demand from economy growth. Otherwise, a costly three to four-fold increase in primary energy production will be required by 2031 to 2032 to sustain economic growth of 8% to 9% annually,<sup>97</sup> which is the rate India wants to maintain to eradicate poverty and improve living standards. The Core Committee's report, which was drafted largely by the Ministry's Bureau of Energy Efficiency (BEE), highlighted the potential for LEDs to reduce electricity demand for lighting, which consumes 18% of the national load.

The report identified the key barriers to the market penetration of LEDs in India. These included: limited product availability locally; high initial cost; absence of national technical standards leading to the import of sub-standard devices; absence of testing protocols and laboratories; and inadequate incentives to attract major LED firms to manufacture in India.

In order to address these barriers, a new aggregate demand policy, modeled after the Government of India's innovative Bachat Lamp Yojana (BLY) program—the Lamp Savings Plan—was proposed. BLY had successfully increased CFL sales from 20 million annually in 2003–2004 to 250 million in 2009–2010 by creating an aggregate demand mechanism where utilities pool product purchases with funds from private investors, who in turn received CO<sub>2</sub> emissions reduction certificates through the Clean Development Mechanism.

The aim of the new LED aggregate demand policy will be to attract leading LED manufacturers to India and to rapidly reduce the cost of the product. The Government has established a Central Institutional Mechanism (CIM) with representation of all the key ministries and regulatory bodies to implement the new aggregate demand policy and other measures recommended by the Core Committee's report.

Meanwhile, since 2009 the Ministry's Bureau of Energy Efficiency has been providing grants to municipalities to pilot LED street lamps. Public lighting in India requires approximately 4,400 megawatts of connected load, meaning that LED street lighting with 50% to 70% energy savings could reduce energy demand by an amount

equivalent to the output of two or three large power plants. To date, 13 LED projects have been completed in cities in Arunachal Pradesh, Assam, Maharashtra and Nagaland. While anecdotal evidence suggests that the pilots' results have been mixed, with some product failures, this is largely due to poor knowledge about quality LED procurement at the municipal level.

## CONCLUSION

Governments have a key role to play in removing the remaining obstacles to LED scale-up. Well-crafted policy interventions will accelerate the LED revolution, ensure that general lighting is transformed by 2020, and bring immense dividends through economic growth and improved quality of life.

Cities are among the largest consumers of lighting, and as such are a critical source of early market demand – and impetus for the ongoing market penetration of LED and smart control technologies. Early adoption of outdoor LED lighting is not, however, merely an act of philanthropy: LEDs are mature in outdoor lighting, and are the most cost-effective option in several niches. Procuring LED luminaires allows cities to benefit from energy and maintenance savings. But perhaps even more compellingly, it allows them to unlock a range of non-monetary benefits – the positive effects of LEDs on safety, visibility, aesthetics, reputation, and on reducing the city's carbon footprint.

For many cities, LEDs may provide the highest-value technology, but are unreachable due to financial constraints or project-specific economic factors. States and nations can use the larger resources at their disposal to provide economic and financial incentives for LED deployment. The goal of such investments may vary: helping develop local LED industries and reducing pressure on regional electricity grids are key factors in China and India; stimulating jobs growth has been a core goal of California's program; and improving quality of life in the area and reducing carbon emissions are goals common to almost all LED projects.

Finally, nations and states can also influence the standards development process. Ensuring that standards keep up with the rapid pace of technological progress will be critical for introducing more certainty among lighting managers about how to treat LED lighting – and how to reap its full benefits as soon as possible.



**SECTION 6 CONCLUSIONS**

LEDs are a technology emblematic of the Clean Revolution: their environmental impact is growing ever closer to zero, their potential to unlock long term growth is growing ever-larger, and they promise to shed new light upon our city streets, our workplaces and our homes – making our cities better places to live.

Performance from the LightSavers trial, testing 27 products across nine world cities, indicates that LEDs have reached maturity in outdoor settings. A wide range of LED products that provide 50% to 70% energy savings, superior visibility, and lumen maintenance consistent with useful lives of 50,000 to 100,000 hours are commercially available today. And smart controls extend both the lifespan and energy savings possible through LEDs.

Surveys in Kolkata, London, Sydney and Toronto indicate that citizens across the world prefer LED lighting, with 68% to 90% of respondents endorsing city-wide rollout of the technology. The key social co-benefits that stood out for these respondents were improved visibility, a greater sense of safety, aesthetic impact on public spaces, and a low environmental impact.

LEDs are unique among lighting technologies in their potential to have a positive impact on the world's climate. The carbon emissions reductions possible through applying 40% energy savings across the whole lighting market are enormous, reaching at least 670 million tons of emissions savings every year. Should LEDs reach full market penetration, and the much higher efficiencies anticipated by 2020, they could almost single-handedly eliminate lighting as a major source of CO<sub>2</sub>.

Their impact on global economic development may be of a similar magnitude. Despite high up-front costs, there are already many settings in which LED projects can achieve payback times of less than three years, or can bring even more significant social co-benefits. With LED prices set to fall by more than 80% by 2020, the technology will soon save billions in energy and maintenance costs across the globe. Those countries that develop leading LED industries today will capture the bulk of the US\$160 billion lighting market of 2020 – with its high value jobs and associated benefits for other semiconductor industries.

This lighting revolution will happen more quickly if governments leap at the opportunity. Like all new technologies, LEDs and smart controls face barriers to market entry that place them at a disadvantage compared to conventional technologies. They lack economies of scale in manufacturing, they are capital-intensive in a time of financial constraints, and they lack fully supportive standards that could enable city lighting managers to capture all their benefits with greater certainty.

Governments at all levels should elevate LED market acceleration as a policy priority, to remove the final obstacles and catalyze transformative scale-up. LEDs are ready to be rolled out across the parks and streets of the world's cities. It's time to flick the switch.

**LEDs ARE READY  
TO BE ROLLED  
OUT ACROSS THE  
WORLD'S PARKS AND  
STREETS**



**SHOULD LEDS REACH  
FULL MARKET  
PENETRATION, THEY  
COULD ALMOST  
SINGLE-HANDEDLY  
ELIMINATE LIGHTING  
AS A MAJOR  
SOURCE OF CO**

**2**

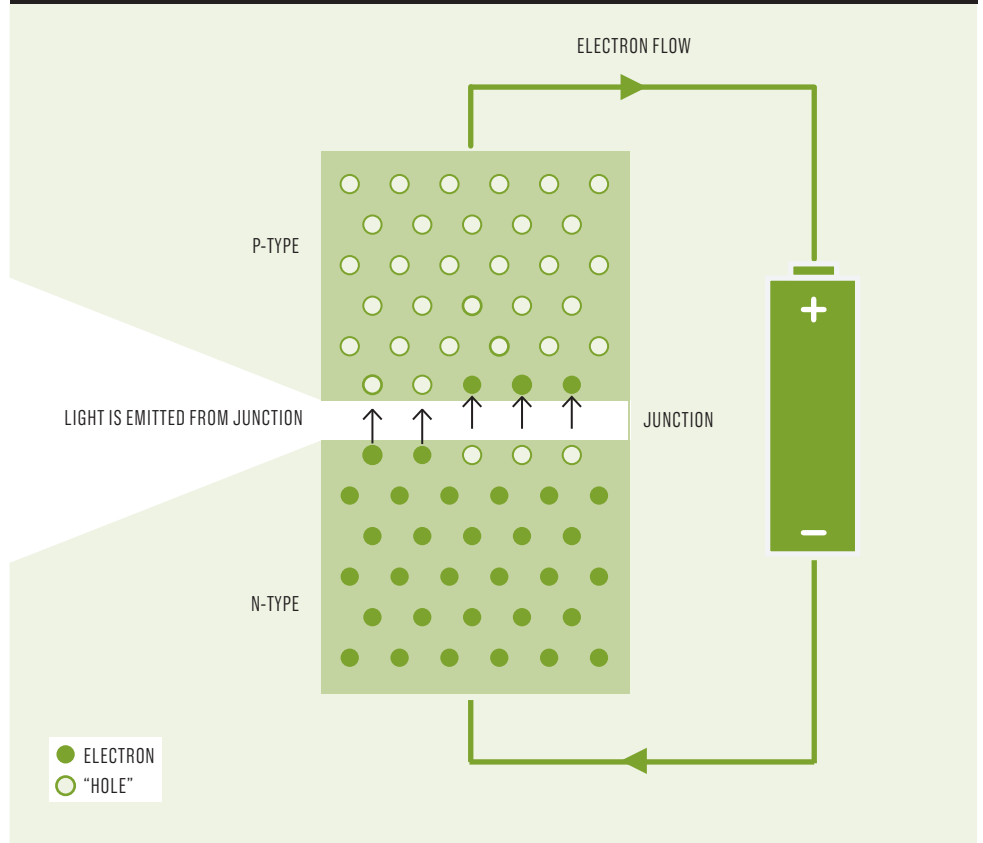
## ANNEX A: HOW LEDS WORK

Light is the visible portion of the electromagnetic radiation spectrum, encompassing wavelengths from 450 nanometers (blue light) to 674 nanometers (red light). The photon is a tiny packet of electromagnetic radiation that we see as light. The lumen is the primary unit of measurement of light traveling across a defined space, as perceived by the human eye.

In the incandescent lamp, a metal such as tungsten formed into a thin wire resists electrons flowing through it, thus causing friction and heat. The metal glows as the cramped electrons bounce around and shed some of their excess energy as photons. The incandescent lamp is essentially a heat source—light is merely a byproduct representing only 10% to 25% of the energy consumed, 10–15 lumens per watt. The lamp's filament is very breakable, and its life span is only 3,000 hours. It is surprising that a technology lacking sturdiness and that is so inefficient has dominated lighting for a century. Its secret? It is easy to manufacture and extremely cheap. A 100 watt screw-in A-lamp costs about US\$1 or less in most countries.

In the fluorescent lamp, a gas saturated with mercury vapor is charged by a high voltage arc inside a linear tube, exciting electrons that are in turn absorbed by the tube's phosphor coating, causing it to glow or fluoresce. Fluorescent lamps dominate commercial lighting today and have achieved high energy efficiency levels of 80–100 lumens per watt and lifespans up to 20,000 hours. Due to their present high efficiency, they will be the last redoubt of conventional lighting technology to be replaced by LEDs.

FIGURE 10 HOW LEDS PRODUCE LIGHT AT THE P-N JUNCTION



The light that LEDs produces comes from surplus electrons that race energetically towards quantum holes across the border in a sandwich of two different semi-conductor materials. One material is a N (negative) semiconductor, usually silicon, which has too many electrons due to the makeup of a special impurity in its lattice. The other is a P (positive) semiconductor that has too few electrons due to the special makeup of a different impurity, thus creating "holes" in its lattice.

At the P-N junction where the two semiconductors meet—a diode—the free electrons on one side of the junction are attracted to the holes on the other side. (See Figure 10 above.) When the electrons settle into their new found holes, they resume their normal energy state, giving up excess energy in the form of photons. The diode glows as a result.

## GLOSSARY

**A-Lamp** Indicates the standard indoor incandescent lamp as well as the lighting products (including LED) that seek to replace these lamps.

**Backlighting** Lighting used to illuminate a display screen, such as an LCD, from behind.

**Ballast** The current-limiting component of the electric circuit that provides power to luminaires.

**BEE** Indian Bureau of Energy Efficiency

**BLY** Bachat Lamp Yojana, or the 'Lamp Savings Plan' -- an Indian Government program to expand CFL sales.

**Burn-in period** The first 1,000 hours of LED operation, during which the lumen output is less predictable and therefore less useful for predicting long-term performance.

**CFL** Compact Fluorescent

**CO<sub>2</sub>** Carbon dioxide

**Color temperature** The technical measure, in units of Kelvin, of the color of a luminaire's output, typically ranging from 2000-3000K (warm yellow-red) to 5000-6000K (cool blue-white).

**CCT** Correlated color temperature -- an approximation of color temperature for non-incandescent light sources such as fluorescent, HID and LED luminaires.

**CDM** Clean Development Mechanism

**CER** Certified Emissions Reduction credit -- a ton of certified CO<sub>2</sub> reduction under the CDM.

**Driver** The part of the luminaire that provides power to the LED, and one of the more common causes of luminaire failure.

**Depreciation rate** The rate of decline in lumen output of lighting products over time.

**DOE** US Department of Energy

**EMC** Energy Management Contract

**ESCO** Energy Service Company

**GHG** Greenhouse gases, including CO<sub>2</sub>, methane, chloro-fluro carbons

**GW** Gigawatt

**GWh** Gigawatt hour

**HID** High Intensity Discharge lamp

**HPS** High Pressure Sodium lamp -- a common outdoor HID emitting red light.

**IEA** IES Illuminating Engineering Society of North America

**Illuminance** A measure of the amount of light reaching the ground, measured in units of lux.

**IRR** Internal rate of return -- a measure of the rate of return on an investment.

**kW** Kilowatt

**kWh** Kilowatt hour

**LADWP** Los Angeles Department of Water and Power

**L70** The point at which a luminaire's output falls to 70% of its original value, typically considered the end of useful life for a lighting product.

**LCD** Liquid Crystal Display, commonly backlit by LEDs.

**LDD** Luminaire Dirt Depreciation, the component of depreciation due to accumulation of dirt on the luminaire, which can be removed by cleaning.

**LED** Light-emitting diode

**Lumen** The standard international unit of luminous flux, measuring the amount of visible light emitted by a source (e.g. an LED luminaire that emits 4600 lumens).

**Lumen maintenance** Stability of lumen output over time -- the opposite of depreciation.

**Luminaire** The complete light system including components such as the driver, reflectors, and case.

**Luminance** A measure of the amount of light reaching the eye from the ground, measured in units of lux.

**Lux** See 'Illuminance' and 'Luminance'.

**Magnetic induction lamp** A relatively new, high-efficiency, long-

lifespan, white light technology.

**MH** METAL HALIDE -- A COMMON HID LAMP EMITTING WHITISH LIGHT.

**MW** Megawatt

**MWh** Megawatt hour

**NEEA** US Northeast Energy Efficiency Alliance

**OLED** Organic LEDs -- a relatively immature LED technology with high potential.

**PFI** Private Finance Initiative, funding public infrastructure with private capital.

**Phosphor** A chemical that re-emits incident light in a desired color, used to coat LED chips and change the color temperature of emitted light.

**PLC** Power line carrier -- a smart control communications technology utilizing power lines to transmit commands.

**R&D** Research and development

**RF** Radio frequency smart control communications technology

**Smart controls** Controls embedded in luminaires that allow remote control.

**SSL** Solid-state lighting -- another term for LEDs.

**SU** Strategies Unlimited -- a leading LED market research firm.

**TW** Terawatt

**TWh** Terawatt hour

**UV** Ultraviolet light, emitted by many conventional lighting technologies.



## REFERENCES

1. IEA (2006) Light's Labour's Lost, OECD/IEA
2. Figures from: IEA, 2011, CO<sub>2</sub> emissions from fuel combustion: Highlights.
3. Power stations at 2 TWh of generation each year. Data from Philips Market Intelligence and IEA: Philips (2011) 'The LED lighting revolution: A summary of the global energy savings potential', based on IEA analysis.
4. Narukawa, Y. et al. (2010) 'White light emitting diodes with super-high luminous efficacy', J. Phys. D: Appl. Phys. 43
5. Energy savings of 90% are already achieved when today's LEDs are used as replacements for incandescent globes, and has been observed in LightSavers trials in Hong Kong where high performing LEDs were compared to older conventional products. The US Department of Energy expects LED efficacy to more than double from the LEDs used in the LightSavers trial, and smart controls are able to extend LED savings by a further 20-40%. Together these will make savings of 90% possible.
6. Falling from US\$7.5 per thousand lumens of warm white LED light in 2012 to US\$1 by 2020. See US DOE (2011), SSL Research and Development: Multi-Year Program Plan.
7. Or 60% of the US\$140 to US\$160 billion lighting market in 2020.
8. Ceramic metal halide failures at 8000 hours reach 10%. See Philips (2010) 'A new age in outdoor city lighting'.
9. IEA (2006) Light's Labour Lost: Policies for Energy-efficient Lighting, OECD/IEA
10. The lumen is the primary measure of light travelling across a defined space, as perceived by the human eye
11. Wright, M. (2012) 'Cree announces 3.45-mm LEDs, hits hot 148 lm/W for cool white', LEDs Magazine, Feb 7. Accessed on 11/04/2012: [www.ledsmagazine.com/news/9/2/7](http://www.ledsmagazine.com/news/9/2/7)
12. Cree Inc. (2012) "Cree Sets New R&D Performance Record with 254 Lumen-Per-Watt Power LED". Accessed on 4/06/2012: [www.cree.com/news-and-events/cree-news/press-releases/2012/april/120412-254-lumen-per-watt](http://www.cree.com/news-and-events/cree-news/press-releases/2012/april/120412-254-lumen-per-watt)
13. Narukawa, Y. et al. (2010) 'White light emitting diodes with super-high luminous efficacy', J. Phys. D: Appl. Phys. 43
14. See, for example, Barkmann, C., Nino, W. & Schulte-Markwort, M. (2009) 'Wirksamkeit von dynamischem Licht in Hamburger Schulklassen' (Effectiveness of dynamic lighting in Hamburg schools), Department of Children and Youth Psychosomatics, University Medical Center Hamburg-Eppendorf. Accessed on 20/04/2012: [www.ubp-herthen.de/UK-Ergebnisbericht\\_Feldstudie.pdf](http://www.ubp-herthen.de/UK-Ergebnisbericht_Feldstudie.pdf)
15. McKinsey & Company (2011) Lighting the way: Perspectives on the global lighting market.
16. Figures from: IEA (2011) CO<sub>2</sub> emissions from fuel combustion: Highlights.
17. Energy savings of 90% are already achieved when today's LEDs are used as replacements for incandescent globes, and has been observed in LightSavers trials in Hong Kong where high performing LEDs were compared to older conventional products. The US Department of Energy expects LED efficacy to more than double from the LEDs used in the LightSavers trial, and smart controls are able to extend LED savings by a further 20-40%. Together these will make savings of 90% possible.
18. Wright, M., 2011, DOE report estimates energy savings for LED lighting, LEDs Magazine. Accessed on 11/04/2012: [www.ledsmagazine.com/news/8/2/18](http://www.ledsmagazine.com/news/8/2/18).
19. The Economist (2011) 'Charge of the LED brigade', The Economist, Business. Accessed on 11/04/2012: [www.economist.com/node/21526373](http://www.economist.com/node/21526373)
20. For example, see Kuala Lumpur's strategies around LEDs and related semi-conductor technologies at InvestKL (2011) 'Sector Opportunities: Electronics and Electrical', Economic Transformation Program, Government of Malaysia.
21. US Department of Energy (2012) 'Solid-State Lighting Building Technologies Program', US Government. Accessed on 11/04/2012: [www1.eere.energy.gov/buildings/ssl/](http://www1.eere.energy.gov/buildings/ssl/)
22. InvestKL (2011) 'Sector Opportunities: Electronics and Electrical', Economic Transformation Program, Government of Malaysia. Accessed on 11/04/2012: [www.investkl.gov.my/Sector\\_Opportunities-@-Electronics-\\_%E2%97%98-\\_\\_Electrical.aspx](http://www.investkl.gov.my/Sector_Opportunities-@-Electronics-_%E2%97%98-__Electrical.aspx)
23. Hausken, T. (2011) 'Chinese LED manufacturing – more than just LEDs', LEDs Magazine, Nov. Accessed on 11/04/2012: [www.ledsmagazine.com/features/8/11/1](http://www.ledsmagazine.com/features/8/11/1)
24. Jessup, P. (2011) 'India identifies LED lighting as key technology to control energy demand', LEDs Magazine, Oct. Accessed on 11/04/2012: [www.ledsmagazine.com/features/8/10/5](http://www.ledsmagazine.com/features/8/10/5)
25. For example, see: City of Cleveland (2011) 'LED Lighting Initiative for Jobs and Economic Sustainability'. Accessed on 11/04/2012: [www.city.cleveland.oh.us/clnd\\_images/PDF/Mayor/LED\\_Initiative.pdf](http://www.city.cleveland.oh.us/clnd_images/PDF/Mayor/LED_Initiative.pdf)
26. For example, most design jobs are concentrated in Europe and the United States. See Bhandarkar, V (2011) World status of SSL Manufacturing, presentation to the US Department of Energy Manufacturing Workshop, San Jose.
27. Gereffi, G., Dubay, K. & Lowe, M. (2008) 'Manufacturing Climate Solutions: Carbon-Reducing Technologies and U.S. Jobs', Duke University Center on Globalization Governance & Competition.
28. McKinsey & Company (2011) Lighting the way: Perspectives on the global lighting market.
29. NYC Department of Transportation (2010) Street Design Manual, Government of New York City. Accessed on 16/04/2012: [www.nyc.gov/html/dot/downloads/pdf/nycdot\\_streetdesignmanual\\_ch4.pdf](http://www.nyc.gov/html/dot/downloads/pdf/nycdot_streetdesignmanual_ch4.pdf)
30. Navigant Consulting (2011) Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications, US DOE.
31. In the US, lighting accounts for 2% of electricity use. See Smith, R. (2009) 'The old street light of the past gets updated for a green future', Wall Street Journal.
32. For example, see CSIRO & Griffith University (2007) 'Energy Transformed: Sustainable Energy Solutions for Climate Change Mitigation', The Natural Edge Project. Also see Department of Environmental Conservation (2012) 'Reduce utility bills for municipal facilities and operations', Government of New York State. Accessed on 23/04/12: [www.dec.ny.gov/energy/64089.html](http://www.dec.ny.gov/energy/64089.html)
33. See The Climate Group's LightSavers website for a detailed case study of the Birmingham LED rollout: [www.theclimategroup.org/programs/lightsavers/](http://www.theclimategroup.org/programs/lightsavers/)
34. McKinsey & Company (2011) Lighting the way: Perspectives on the global lighting market.
35. US DOE (2011) SSL Lighting Research and Development: Multi-Year Plan.
36. 'High brightness' refers to LEDs that, when compared with the low brightness LEDs that have flooded the market, consume higher amounts of power, produce more light, and exhibit greater relative energy efficiency.
37. Whitaker, T. (2012) 'LED market grew almost 10% in 2011, with 44% growth in lighting', LEDs Magazine, Feb. Accessed on 16/04/2012: [www.ledsmagazine.com/news/9/2/6](http://www.ledsmagazine.com/news/9/2/6)
38. Overton, G. (2011) 'Strategies Unlimited says HB LED revenue will peak at \$16.2B in 2014', Opto IQ. Accessed on 11/04/2012: [www.optoig.com/articles/2011/10/hb-led-market-su-2011.html](http://www.optoig.com/articles/2011/10/hb-led-market-su-2011.html)
39. Peter, L. & Wright, M (2012) 'LED lighting market to grow while LED component market goes flat', LEDs Magazine, March. Accessed on 16/04/2012: [www.ledsmagazine.com/features/9/3/2](http://www.ledsmagazine.com/features/9/3/2)

40. Rogers, E. (2003) Diffusion of Innovations, 5th Edition, Free Press.
41. Bhandarkar, V. (2011) 'LED Lighting Market Trends', Presentation to Strategies in Light conference, Santa Monica.
42. Strategies Unlimited (2010) The Market for High-Brightness LEDs in Lighting: Application Analysis and Forecast, 4th Edition.
43. McKinsey & Company (2011) Lighting the Way: Perspectives on the Global Lighting Market.
44. Strategies Unlimited (2010) op. cit.
45. Whitaker, T. (2012) 'LED market grew almost 10% in 2011, with 44% growth in lighting', LEDs Magazine, Feb. Accessed on 16/04/2012: [www.ledsmagazine.com/news/9/2/6](http://www.ledsmagazine.com/news/9/2/6)
46. Bhandarkar, V. (2011) 'Street-lighting market shows momentum is behind quality luminaires', LEDs Magazine. Accessed on 11/04/2012: [www.ledsmagazine.com/features/8/9/9](http://www.ledsmagazine.com/features/8/9/9).
47. A 'vertically integrated' company owns operations across multiple steps of the LED value chain. For example, a company may be involved in steps from LED chip manufacture, product design, luminaire assembly and marketing and sales. Vertically integrated companies can gain product quality advantages by guaranteeing access to the best components at each point of the LED manufacturing chain.
48. Bhandarkar, V. (2011) World status of SSL Manufacturing, presentation to the US Department of Energy Manufacturing Workshop, San Jose.
49. Strategies Unlimited (2010) The Market for High-Brightness LEDs in Lighting: Application Analysis and Forecast.
50. McKinsey & Company (2011) Lighting the Way: Perspectives on the Global Lighting Market.
51. Bhandarkar, V. (2011) 'Street-lighting market shows momentum is behind quality luminaires', LEDs Magazine. Accessed on 11/04/2012: [www.ledsmagazine.com/features/8/9/9](http://www.ledsmagazine.com/features/8/9/9)
52. Peter, L. & Wright, M. (2012) 'LED lighting market to grow while LED component market goes flat', LEDs Magazine, March. Accessed on 16/04/2012: [www.ledsmagazine.com/features/9/3/2](http://www.ledsmagazine.com/features/9/3/2)
53. US DoE (2011) Solid State Lighting Research and Development: Manufacturing R&D Roadmap.
54. Ibid.
55. For example, for a discussion of common barriers for new technologies and the use of policies to address them see Fischer, C. (2009) The role of technology policies in climate mitigation, Resources for the Future.
56. Illuminating Engineering Society (2011) TM21: Lumen degradation lifetime estimation method for LED light sources, Illuminating Engineering Society, New York.
57. Peter, L. & Wright, M. (2012) 'LED lighting market to grow while LED component market goes flat', LEDs Magazine, March. Accessed on 16/04/2012: [www.ledsmagazine.com/features/9/3/2](http://www.ledsmagazine.com/features/9/3/2)
58. McKinsey & Company (2011) Lighting the way: Perspectives on the global lighting market.
59. Pacific Northwest Laboratory (2006) Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market, U.S. Department of Energy, US Government.
60. Toronto Atmospheric Fund (2011), A National Survey of Municipal Street Managers, research conducted by Ekos Research Associates, Inc.
61. From 40% to 70% of council electricity bills arise from street lighting, as indicated by communications with staff from various city councils and studies such as CSIRO & Griffith University (2007) 'Energy Transformed: Sustainable Energy Solutions for Climate Change Mitigation', The Natural Edge Project.
62. Philips (2011) 'The LED lighting revolution: A summary of the global energy savings potential', based on IEA analysis.
63. See, for example, Barkmann, C., Nino, W. & Schulte-Markwort, M. (2009) 'Wirksamkeit von dynamischem Licht in Hamburger Schulklassen' (Effectiveness of dynamic lighting in Hamburg schools), Department of Children and Youth Psychosomatics, University Medical Center Hamburg-Eppendorf. Accessed on 20/04/2012: [www.ubp-herthen.de/UK-ERgebnisbericht\\_Feldstudie.pdf](http://www.ubp-herthen.de/UK-ERgebnisbericht_Feldstudie.pdf)
64. Lighting Science Group (2012) 'BP Gas Stations', Lighting Science Group website. Accessed on 11/04/2012: [www.lsgc.com/europe/commercial-europe/bp-gas-stations](http://www.lsgc.com/europe/commercial-europe/bp-gas-stations)
65. Undertaken by the Clinton Climate Initiative.
66. Clinton Climate Initiative (2011) City of Los Angeles LED Street lighting Case Study. Accessed on 11/04/2012: [www.clintonfoundation.org/what-we-do/clinton-climate-initiative/cities/lighting](http://www.clintonfoundation.org/what-we-do/clinton-climate-initiative/cities/lighting).
67. Unlike fluorescents and many other conventional lighting technologies, LEDs reach full power rapidly after switching on, and do not suffer shortened lifespan if dimmed (in fact, dimming extends LED life).
68. Northeast Energy Efficiency Alliance (2011) Technology and Market Assessment of Networked Outdoor Controls, Prepared by Energy Solutions, Report #40265.
69. For example, see The Institute for Building Efficiency (2011) 'Green building asset valuation: trends and data', Johnson Controls research snapshot. Accessed on 29/04/2012: [www.institutebe.com/InstituteBE/media/Library/Resources/Green%20Buildings/Research\\_Snapshot\\_Green\\_Building\\_Asset\\_Value.pdf](http://www.institutebe.com/InstituteBE/media/Library/Resources/Green%20Buildings/Research_Snapshot_Green_Building_Asset_Value.pdf)
70. See, for example, Barkmann, C., Nino, W. & Schulte-Markwort, M. (2009) 'Wirksamkeit von dynamischem Licht in Hamburger Schulklassen' (Effectiveness of dynamic lighting in Hamburg schools), Department of Children and Youth Psychosomatics, University Medical Center Hamburg-Eppendorf. Accessed on 20/04/2012: [www.ubp-herthen.de/UK-ERgebnisbericht\\_Feldstudie.pdf](http://www.ubp-herthen.de/UK-ERgebnisbericht_Feldstudie.pdf)
71. Toronto Atmospheric Fund (2010) User Reactions to Advanced Lighting Pilot Installations in Toronto Community Housing Parking Garages, City of Toronto.
72. In the U.S., the interest generated from municipal bonds is tax-free to the bond holder, hence the interest rate paid on municipal bonds is typically lower than for commercial issuances.
73. See The Climate Group's LightSavers website for a detailed case study of the Los Angeles LED rollout: [www.theclimategroup.org/programs/lightsavers/](http://www.theclimategroup.org/programs/lightsavers/)
74. National Association of Energy Service Companies (2011) 'What is an ESCO?', Washington DC. [www.naesco.org/resources/esco.htm](http://www.naesco.org/resources/esco.htm)
75. Goldberger, D. & Jessup, P. (1994) Profiting from Energy Efficiency: A Financing Handbook for Municipalities, ICLEI.
76. Kappeler, A. & Nemoz, M. (2010) Public-Private Partnerships in Europe—Before and During the Recent Financial Crisis, European Investment Bank
77. US DOE MSSLC (2011) Model Specification of LED Roadway Luminaires, Version 1.0., US Department of Energy, US Government.
78. See for example Siminovich (2011) 'UC Davis professor calls for statewide "time out" on further public purchases of LED street lights', California Lighting Technology Center.
79. Fischer, C. (2009) Op cit.
80. See, for example, the US Department of Energy's Solid State Lighting R&D Roundtable: US Department of Energy (2011) Roundtable

- discussion of the Solid-State Lighting R&D Task Priorities, US Government, Washington DC. Accessed on 11/04/2012: [http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl-rd-roundtable-report\\_jan12.pdf](http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl-rd-roundtable-report_jan12.pdf)
81. For example, see Jones, C. & Willians, J. (1998) 'Measuring the social return to R&D', *The Quarterly Journal of Economics*, 113 (4): 1119-1135; Hall, B., Mairesse, J. & Mohnen, P. (2010) 'Measuring the returns to R&D', CIRANO, Montreal; and Fischer, C. (2009) *Op. cit.*
  82. The California Energy Commission (2012) 'Energy efficiency and conservation block grant program', Government of California. Accessed on 11/04/2012: [www.energy.ca.gov/recovery/blockgrant.html](http://www.energy.ca.gov/recovery/blockgrant.html)
  83. US Department of Energy (2012) 'Spectrally Enhanced Lighting', US Government. Accessed on 11/04/2012: [www1.eere.energy.gov/buildings/spectrally\\_enhanced.html](http://www1.eere.energy.gov/buildings/spectrally_enhanced.html)
  84. Hodapp, M. (2011) 'IESNA LM-80 and TM-21', Philips Lumileds presentation for US Department of Energy, US Government. Accessed on 11/04/2012: [http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/msslc-se2011\\_hodapp.pdf](http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/msslc-se2011_hodapp.pdf)
  85. Lowenberger, A., Mauer, J., deLaski, A., DiMascio, M., Amann, J. & Nadel, S. (2012) 'The efficiency boom: Cashing in on the savings from appliance standards', American Council for an Energy-Efficient Economy (ACEEE). Accessed on 11/04/2012: <http://aceee.org/research-report/a123>
  86. US Department of Energy (2012) 'Spectrally Enhanced Lighting', US Government. Accessed on 11/04/2012: [www1.eere.energy.gov/buildings/spectrally\\_enhanced.html](http://www1.eere.energy.gov/buildings/spectrally_enhanced.html)
  87. US Department of Energy (2009) 'Response to IES Position Statement PS-02-09', US Government. Accessed on 11/04/2012: [http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/ies\\_position\\_response.pdf](http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/ies_position_response.pdf)
  88. US Department of Energy (2008) 'Final Report prepared in support of the U.S. DOE Solid-State Lighting Technology Demonstration Gateway Program and PG&E Emerging Technologies Program', US Government. Accessed on 11/04/2012: [http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway\\_sf-streetlighting.pdf](http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_sf-streetlighting.pdf)
  89. Hodapp, M. (2011) 'IESNA LM-80 and TM-21', Philips Lumileds presentation for US Department of Energy, US Government. Accessed on 11/04/2012: [http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/msslc-se2011\\_hodapp.pdf](http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/msslc-se2011_hodapp.pdf)
  90. *Ibid.*
  91. McKinsey & Company (2011) *Lighting the way: Perspectives on the global lighting market.*
  92. Strategies Unlimited (2010) *The Market for High-Brightness LEDs in Lighting: Application Analysis and Forecast.*
  93. The 21 cities are: Tianjin, Shijiazhuang, Baoding (Hebei Province), Dalian (Liaoning), Harbin (Heilongjiang), Shanghai (Shanghai), Yangzhou (Jiangsu), Ningbo, Hangzhou (Zhejiang), Xiamen, Fuzhou (Fujian), Nanchang (Jiangxi), Weifang (Shandong), Zhengzhou (Henan), Wuhan (Hubei), Shenzhen, Dongguan (Guangdong), Chengdu, Mianyang (Sichuan), Chongqing and Xi'an (Shaanxi).
  94. Strategies Unlimited (2011) *LED Outdoor Area and Street Lighting Market Analysis and Forecast 2011.*
  95. Illuminex (2011) 'About the market', Illuminex. Accessed on 12/04/12: [www.illuminex-india.com/For-Exhibitors/About-the-market.aspx](http://www.illuminex-india.com/For-Exhibitors/About-the-market.aspx)
  96. India Infoline News (2011) 'Indian LED market expected to grow at CAGR of 45.53% till 2015', India Infoline News report on Frost and Sullivan Research. Accessed on 24/04/12: [www.indiaonline.com/Markets/News/Indian-LED-lighting-market-expected-to-grow-at-CAGR-of-45.53-percent-till-2015-Frost-and-Sullivan/5309140144](http://www.indiaonline.com/Markets/News/Indian-LED-lighting-market-expected-to-grow-at-CAGR-of-45.53-percent-till-2015-Frost-and-Sullivan/5309140144)
  97. India Ministry of Power (2010) *The Economic Case to Stimulate LED Lighting in India*, Government of India.



## ACKNOWLEDGEMENTS

---

**Contributing Authors:** Philip Jessup, Reuben Finighan, Jim Walker, Peter Curley, Handuo Cai

**Editors:** Sophie de Albuquerque, Clare Saxon

**Design:** Guyang Chen

**Photography:** Cover, Pages 17, 22, 26, 33, 44 & 50: © Ryan Pyle for The Climate Group - [www.ryanpyle.com](http://www.ryanpyle.com)

Pages 5, 12, 14, 28 & 39: © Philips | Page 31: [www.wrtl.co.uk](http://www.wrtl.co.uk) | Page 35: Flickr

Page 42: Phil Jessup | Page 46: City of Sydney, Australia | Page 54: ©The Climate Group

---

## THE CLIMATE GROUP

The Climate Group is an independent, not-for-profit organization working to inspire and catalyze leadership for a Clean Revolution: a low carbon future that is smarter, better and more prosperous. For all.

Founded in 2004, The Climate Group has operations in Australia, China (Beijing and Hong Kong), Europe, India and North America.

---

### The Clean Revolution Partners:

Please visit [TheCleanRevolution.org](http://TheCleanRevolution.org) for our latest list of Clean Revolution Partners.

---

**Lead Partner:** Philips Lighting

---

**Strategic Partners:** Suzlon, Swiss Re

---

### International Leadership Council:

(Chair) Rt. Hon. **Tony Blair**; HSH Prince **Albert II**, Sovereign Prince of Monaco; **Dr. Sultan Al Jaber**, CEO, Masdar; **Mr. Clesio Balbo**, President, Balbo Group; **Mr. Sunil Bharti Mittal**, Chairman and Group CEO, Bharti Group Enterprises; **Mr. Thor Björgólfsson**, Chairman and CEO, Novator; **Sir Richard Branson**, Chairman and Founder, Virgin Group; **Lord John Browne**, MD, Riverstone LLC; **Premier Jean Charest**, The Province of Québec; **Mr. John Coomber**, Member of the Board of Directors, Pension Corporation; **Mr. Marc de Jong**, General Manager of Professional Luminaires, Philips Lighting; **Dr. Susan Hockfield**, President, Massachusetts Institute of Technology; **Dr. JJ Irani**, Director, Tata Steel Limited; **Mr. Wang Jianzhou**, Chairman and CEO, China Mobile; **Lady Barbara Judge**; **Mr. Patxi Lopez**, President, Basque Country; **Mr. Idan Ofer**, Chairman of the Board, Israel Corporation; **Mr. Boudewijn Poelmann**, Chairman of the Board, Novamedia; **Mr. Anthony Pratt**, CEO, Pratt Industries; **Hon. Mike Rann**, Former Premier of South Australia; **Mr. Jim Rogers**, Chairman, President and CEO, Duke Energy Corporation; **Mr. Alan Salzman**, CEO and Managing Partner, VantagePoint Venture Partners; **Mr. Vinod Sekhar**, President and Group Chief Executive, The Petra Group; **Dr. Zhengrong Shi**, Chairman of the Board and CEO, Suntech; **Dr. Andrew Steer**, Special Envoy for Climate Change, the World Bank; **Mr. Tulsi Tanti**, Founder, Chairman and Managing Director, Suzlon Energy Ltd; **Mr. Steve Westly**, Managing Director, The Westly Group; **Mr. Zhang Yue**, Chairman and CEO, Broad Group; **Mr. Niklas Zennström**, Founder, Zennström Philanthropies

---

### The Clean Revolution Advisory Board:

**Paul Simpson**, Chief Executive Officer, Carbon Disclosure Project; **Professor Dadi Zhou**, emeritus Director General, Energy Research Institute; **Josh Suskewicz**, Principal, Innosight; **Oswaldo Lucon**, Energy Advisor, Government of São Paulo; **John Elkington**, Executive Chairman, Volans Ventures Ltd; **Jennifer Morgan**, Director, Climate & Energy Program, World Resources Institute; **Jarl Krausing**, Team Leader, Global Climate Policy, International Finance Corporation

---

**Campaign Partners:** Carbon Disclosure Project, The World Bank, UN Global Compact

---

**Campaign Supporter:** Global Carbon Capture and Storage Institute

**Contact:**

The Climate Group, London  
 Second Floor, Riverside Building  
 County Hall  
 Belvedere Road  
 London  
 SE1 7PB  
 United Kingdom

Tel: +44 (0) 20 7960 2970  
 Fax: +44 (0) 20 7960 2971

TheClimateGroup.org

Feedback and requests for information  
 should be sent to: [info@theclimategroup.org](mailto:info@theclimategroup.org)

Follow [Twitter.com/ClimateGroup](https://twitter.com/ClimateGroup) for daily  
 #CleanRevolution news

**The Clean Revolution Network:****OUR MEMBERS**

**Corporations:** Alstom; Arup; Better Place; Bloomberg; Broad Group; BT Group PLC; CBRE Group; CECEP (China Energy Conservation and Environmental Protection Group); China Mobile; Cisco; CLP Holdings Limited; Dell, Inc.; Deutsche Bank; Duke Energy; EN+ Group; GE Capital Finance Australasia Pty Ltd; Goldman Sachs; Greenstone Carbon Management; Hanergy Holdings Group; Hewlett Packard; HSBC Holdings plc; IWC Schaffhausen; Johnson Controls; JP Morgan Chase; Landsea; Munich Re; News Corporation; Nike; Origin Energy; PassivSystems; Philips Lighting; Procter & Gamble; Smith Electric Vehicles; Standard Chartered Bank; Suntech; Suzlon; Swire Pacific; Swiss Re; Taobao; The Coca-Cola Company; TNT; VantagePoint Venture Partners; Veolia Environment; Visy

**Governments\*:** The Province of KwaZulu-Natal; The Province of Manitoba; The Province of Ontario; The Province of Québec; The Region of Brittany; The Region of Catalonia; The Region of Île-de-France; The Region of Jämtland; The Region of La Réunion; The Region of Rhône-Alpes; The Region of the Basque Country; The Scottish Government; The State of Baden-Württemberg; The State of Bavaria; The State of California; The State of New York; The State of North Rhine-Westphalia; The State of Quintana Roo; The State of São Paulo; The State of South Australia; The State of Upper Austria; The Welsh Assembly Government

\*All of our government members are also members of the States and Regions Alliance

**Cities:** Greater London Authority; The City of Adelaide; The City of Chongqing; The City of Guiyang; The City of Haldia; The City of Hangzhou; The City of Kashgar; The City of Kolkata; The City of Mumbai; The City of New York; The City of Quezon; The City of Sydney; The City of Thane; The City of Tianjin; The City of Toronto; The City of Wuhan

**AFFILIATES OF THE STATES AND REGIONS ALLIANCE**

The Province of British Columbia; The Province of Guangdong (China Redesign Partner); The Province of New Brunswick; The Province of Nova Scotia; The Province of Prince Edward Island; The Province of South Holland; The Province of the Western Cape; The Region of Aragon; The Region of Fatick; The Region of Flanders; The Region of Jämtland; The Region of Poitou-Charentes; The Region of Tuscany; The Region of Wallonia; The Region of Wielkopolska; The State of Baja California; The State of Burgenland; The State of Campeche; The State of Carinthia; The State of Coahuila; The State of Connecticut; The State of Durango; The State of Hidalgo; The State of Jalisco; The State of Maine; The State of Michoacán; The State of Morelos; The State of New South Wales; The State of Nuevo León; The State of Penang; The State of Queensland; The State of San Luis Potosí; The State of Selangor; The State of Sonora; The State of Tabasco; The State of Västra Götaland; The State of Vermont; The State of Victoria; The State of Western Australia; The Territory of Nunavut; The Territory of the Northwest Territories; The Territory of Yukon

**PHILANTHROPIC SUPPORTERS**

As a charity with no regular government funding and to ensure our continued independence, we look for financial support from like-minded grant-makers who appreciate the scale of the challenge ahead of us and the time-limited nature of an effective response. Our current philanthropic supporters include the **Dutch Postcode Lottery**, **Esmée Fairbairn Foundation**, **The Prince Albert II of Monaco Foundation**, **Tellus Mater Foundation** and **Zennström Philanthropies**.

We are also pleased to collaborate on specific projects and initiatives with the following organizations: **New Cities Foundation**; **NRG4SD**; **One Foundation** and the **United Nations Development Program**.

All the views in the report are those of The Climate Group and do not necessarily reflect those of our partners, members or advisors.







FOR MORE INFORMATION, PLEASE VISIT:  
[TheCleanRevolution.org](http://TheCleanRevolution.org) | [TheClimateGroup.org](http://TheClimateGroup.org)