

Solid State Lighting Annex: Lessons Learned Bringing LEDs to Market

Programmes and Policies Report

Energy Efficient End-Use Equipment (4E)
International Energy Agency

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**IEA 4E Solid State Lighting Annex
Lessons Learned Bringing LEDs to Market:
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This report was prepared by the Solid State Lighting Annex Operating Agent, with input from the SSL Annex Management Committee and SSL Annex Experts. The authors wish to thank the Management Committee and Annex Experts for providing all the information used in this report. The authors also wish to thank Kathryn Conway for her review and copy/edit to improve the readability of the text. This report is the deliverable for the SSL Annex's Task 5.

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About the IEA 4E Solid State Lighting Annex: The SSL Annex was established in 2010 under the framework of the International Energy Agency's Energy Efficient End-use Equipment (4E) Implementing Agreement to provide advice to its member countries seeking to implement quality assurance programmes for SSL lighting. This international collaboration was established by the governments of Australia, Denmark, France, Japan, The Netherlands, the Republic of Korea, Sweden, United Kingdom and the United States of America. Further information on the 4E SSL Annex is available from: <http://ssl.iea-4e.org/>

About the IEA Implementing Agreement on Energy Efficient End-Use Equipment (4E) is an International Energy Agency (IEA) Implementing Agreement established in 2008 to support governments to formulate effective policies that increase production and trade in efficient electrical end-use equipment. Globally, electrical equipment is one of the largest and most rapidly expanding areas of energy consumption which poses considerable challenges in terms of economic development, environmental protection and energy security. As the international trade in appliances grows, many of the reputable multilateral organisations have highlighted the role of international cooperation and the exchange of information on energy efficiency as crucial in providing cost-effective solutions to climate change. Twelve countries have joined together to form 4E as a forum to cooperate on a mixture of technical and policy issues focused on increasing the efficiency of electrical equipment. But 4E is more than a forum for sharing information – it initiates projects designed to meet the policy needs of participants. Participants find that pooling of resources is not only an efficient use of available funds, but results in outcomes which are far more comprehensive and authoritative. The main collaborative research and development activities under 4E include:

- The Electric Motor Systems Annex (EMSA)
- The Mapping and Benchmarking Annex
- The Solid State Lighting Annex (SSL)
- The Electronic Devices and Networks Annex (EDNA)

Current members of 4E are: Australia, Austria, Canada, Denmark, France, Japan, Korea, The Netherlands, Switzerland, Sweden, UK and USA. Further information on the 4E Implementing Agreement is available from: www.iea-4e.org

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Executive Summary

Lighting is an essential part of everyday life. Lighting extends the working day, enabling people to work in enclosed dwellings, offices and factories where natural light is absent. The right lighting improves our quality of life and enhances the productivity of our workforces. However, lighting consumes energy and material resources in the manufacturing and operation of lighting products. As economies grow and populations expand, demand for lighting increases, as does power consumption. According to the United Nations, lighting accounts for approximately 15% of all global electricity consumption (UNEP, 2016). According to the International Energy Agency (2016), deployment in energy efficient lighting has been particularly impressive. The dramatic price declines for LED lighting led to estimated electricity savings of 120 terawatt-hours. This is equivalent to over half of the growth in global electricity generation in 2015.

Illumination products using light emitting diodes (LEDs) as the primary light source have the potential to provide high quality, energy efficient lighting that surpasses the performance of conventional technologies while offering lower life-cycle costs. In certain markets and applications, LED lamps and luminaires are the mainstream choice. For example, LED products are the most common choice for new outdoor and street lighting applications.

Test results show wide variation in the performance and quality of LED illumination products. Many LED products exceed performance and market forecasts but some exhibit problems such as colour shift, flicker, or significantly shorter life or lower efficacy than claimed. Low-quality products undermine consumer confidence and have the potential to delay LED market growth. Poor performance also reduces anticipated energy and environmental benefits. Knowledge of LED technologies and applications evolves with new standards and testing methods and with research into the impacts of LEDs on human physiology and health, the environment and energy.

Lessons Learned

The purpose of this report is to provide policy makers with examples and a summary of how IEA 4E SSL Annex member countries' have introduced and promoted LED illumination products in their respective markets. No one-size-fits-all policy or programmatic model applies globally. This report highlights key policy and programme tools that have supported and sustained the development of markets for high-quality, energy-efficient LED products.

Across all the critical segments of the supply chain, government policies and energy-efficiency programmes can play an important role in raising awareness of the opportunities with LEDs, while helping to build demand for energy-efficient products. Market transformation efforts can include both voluntary and mandatory actions.

IEA 4E Annex member governments support and recommend a portfolio of policies and programmes to grow and sustain the market for high quality, energy efficient LED illumination products. Common programme elements include:

- Quality assurance mechanisms, including market monitoring and performance testing
- Tailored communication approaches for consumers and businesses
- Manufacturer support
- Incentive approaches for consumers and businesses

Cooperation and knowledge sharing between national governments, industry, energy efficiency programmes, local government stakeholders and non-profit organisations can ensure that high efficiency and quality products dominate the lighting market and deliver associated energy savings and other benefits.

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Acronyms and Abbreviations

4E	Energy Efficient End-use Equipment
ADEME	Agency for Energy and Environment (France)
ASEAN	Association of South East Asian Nations
CCT	correlated colour temperature
CIE	Commission Internationale de l'Éclairage (International Commission on Illumination)
CRI	Colour Rendering Index
EC	European Commission
EDNA	Electronic Devices and Networks Annex
eceee	European council for an energy efficient economy
EMSA	Electric Motor Systems Annex
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IESNA	Illuminating Engineering Society of North America
LED	light emitting diode
lm	lumen
RoHS	Reduction of Hazardous Substances
SSL	solid state lighting
UK	United Kingdom
USA	United States of America
W	watt

1 Introduction

1.1 Background

Lighting is an essential part of everyday life. Lighting extends the working day, enabling people to work in enclosed dwellings, offices and factories where natural light is absent. The right lighting improves our quality of life and enhances the productivity of our workforces. However, lighting consumes energy and material resources in the manufacturing and operation of lighting products. As economies grow and populations expand, demand for lighting increases. Lighting accounts for approximately 15% of all global electricity consumption (UNEP, 2016)¹. According to the International Energy Agency (IEA, 2016), deployment in energy efficient lighting has been particularly impressive. The dramatic price declines for LED lighting led to estimated electricity savings of 120 terawatt-hours. This is equivalent to over half of the growth in global electricity generation in 2015.²

Lighting energy consumption can be reduced without compromising lighting quality, through the application of energy-efficient LED illumination products. This report gives examples and identifies some lessons learned from SSL Annex member countries' introduction of LED lighting into their respective markets.

1.2 Purpose

This document is intended to inform and encourage policies and programme approaches that support market uptake and supply of high quality and energy efficient LEDs. Careful planning combined with the right mix of market transformation policies and programmes can support and stimulate uptake of high quality, energy-efficient LED product. Lessons learned from the market introduction missteps of a prior efficiency innovation, compact fluorescent lamps, should help to ensure faster and more favourable market uptake of LED illumination products (Sandahl, 2006).³ Governments and efficiency programmes can play an important role in raising supply chain awareness of efficiency opportunities with LEDs, helping to build demand and stimulate supply for highly efficient and quality products.

The original member countries of the IEA 4E SSL Annex were: Australia, Denmark, France, Republic of Korea, The Netherlands, Sweden, United Kingdom (UK) and United States of America (USA). Together with China as a Participating Technical Expert, these countries have decades of experience with lighting market transformation. This report organises and summarises the SSL Annex member countries' experiences with LED illumination product market development. It includes examples of national-level policy and programmatic approaches, lessons learned and references.

¹ UNEP. 2016. En.lighten: Efficient lighting for developing and emerging countries. Paris, France: United Nations Environment Programme. Accessed on 7 Dec 2016: <http://www.enlighten-initiative.org/>.

² International Energy Agency. 2016. Energy Efficiency Market Report 2016: Digital Snapshot. Paris, France. Accessed on 7 Dec 2016: <http://www.iea.org/eemr16/>.

³ Sandahl, L., et al. 2006. *Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market*. Richland, WA, USA: Pacific Northwest National Laboratory. Accessed on 7 Dec 2016: http://www1.eere.energy.gov/buildings/publications/pdfs/ssl/cfl_lessons_learned_web.pdf

1.3 Scope and Method

This report focuses on policies and programmes at the national, regional or international level that promote increased market adoption of LED illumination products for on-grid applications. Most of the examples are from or are supported by IEA 4E SSL Annex member countries. This report draws upon interviews conducted with IEA 4E SSL Annex members plus presentations and reports shared by SSL Annex members at member expert meetings.

1.4 Policy and Programme Models

IEA 4E SSL Annex member countries have employed different policy and programme approaches and elements at different times, as appropriate for each market and its stage of development. Their activities helped to accelerate the rate of market development, change consumer preferences and behaviour and achieve strategic policy goals. Table 1 categorises examples and policies described in this report. Figures 1 to 3 show how several countries have organized their market transformation activities.

Table 1. Categories of Market Transformation Activities

Policy Category	Examples
Market research and communication	<ul style="list-style-type: none"> • Behavioural and human factors research • Education and awareness-raising • Baseline studies, market modelling and tracking tools, and, analysis and reports • Labelling and certification programmes • Supply chain and retailer partnerships to promote efficient purchasing
Industry support and public-private partnerships	<ul style="list-style-type: none"> • Research and development of roadmaps and funding, especially for companies transitioning to LED technology • Technology innovation clusters and manufacturing ecosystems • Standards and testing development • Recognition programmes • Industry associations • Design guidance (by application)
Quality assurance, supporting policies and financing	<ul style="list-style-type: none"> • Regional and international cooperation • Incentives (training, economic development zones and tax incentives) • Policies (economic development programmes, climate change mitigation, green buildings and infrastructure) • Regulations (utility demand-side management; energy efficiency mandates for appliances and buildings; and, electrical and environmental safety requirements) • Minimum energy performance standards (MEPS) • Performance specifications and guidelines, including High Energy Performance Specifications (HEPS) • Monitoring, verification and enforcement programmes • White certificate schemes -setting procurement specifications
Incentives for end users and purchasers	<ul style="list-style-type: none"> • Financial incentives (such as rebates) for consumers and businesses • Bulk purchasing information, guidance and groups • Upstream/downstream incentives in retail or commercial distribution chains • Green public procurement schemes and criteria

When considering a market transformation programme, it is important to consider the level of government that will be implementing the market transformation policy or programme. For example, national level

governments may focus on initiatives like minimum energy performance standards (MEPS), labelling schemes, building codes and public buildings. State-level governments may focus on white certificate schemes, major roads, regional initiatives, green procurement and public buildings. Municipal and local-level governments may look at local subsidy schemes, transport facilities and outdoor lighting, green procurement and public buildings.

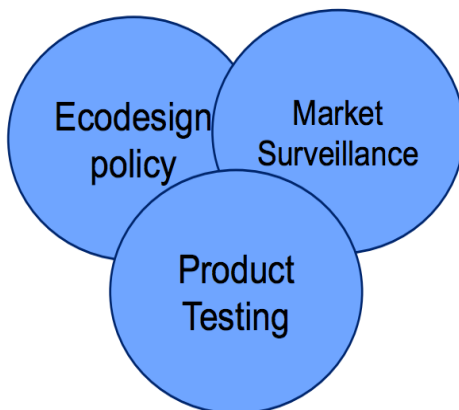


Figure 1. Organisation of Expert Teams for Resource Efficient Products (Sweden)

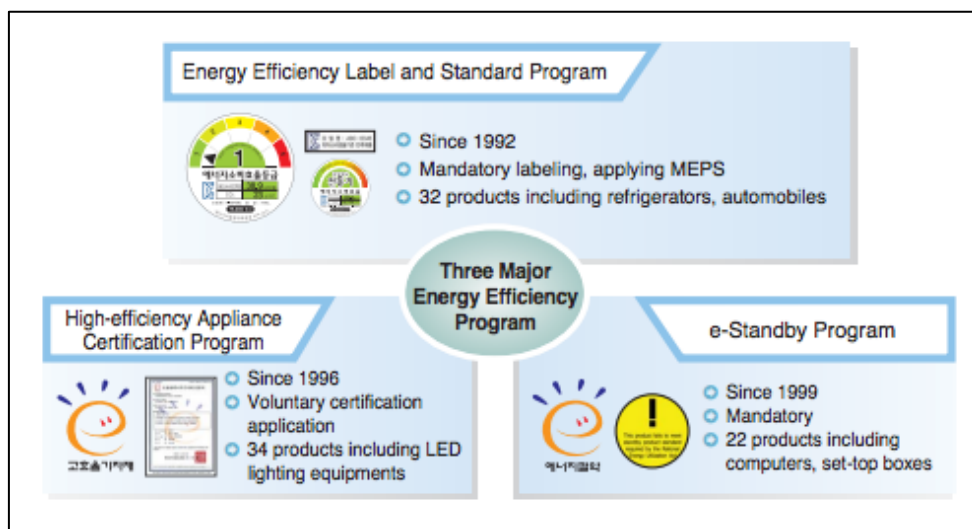


Figure 2. Three Programs to Promote LED Lighting (Korea)⁴

⁴ Republic of Korea, Ministry of Knowledge Economy and Korea Energy Management Corporation. n.d. *Korea's Energy Standards & Labelling: Market Transformation*. Accessed on 7 Dec 2016: http://www.kemco.or.kr/nd_file/kemco_eng/KoreaEnergyStandards&Labeling.pdf

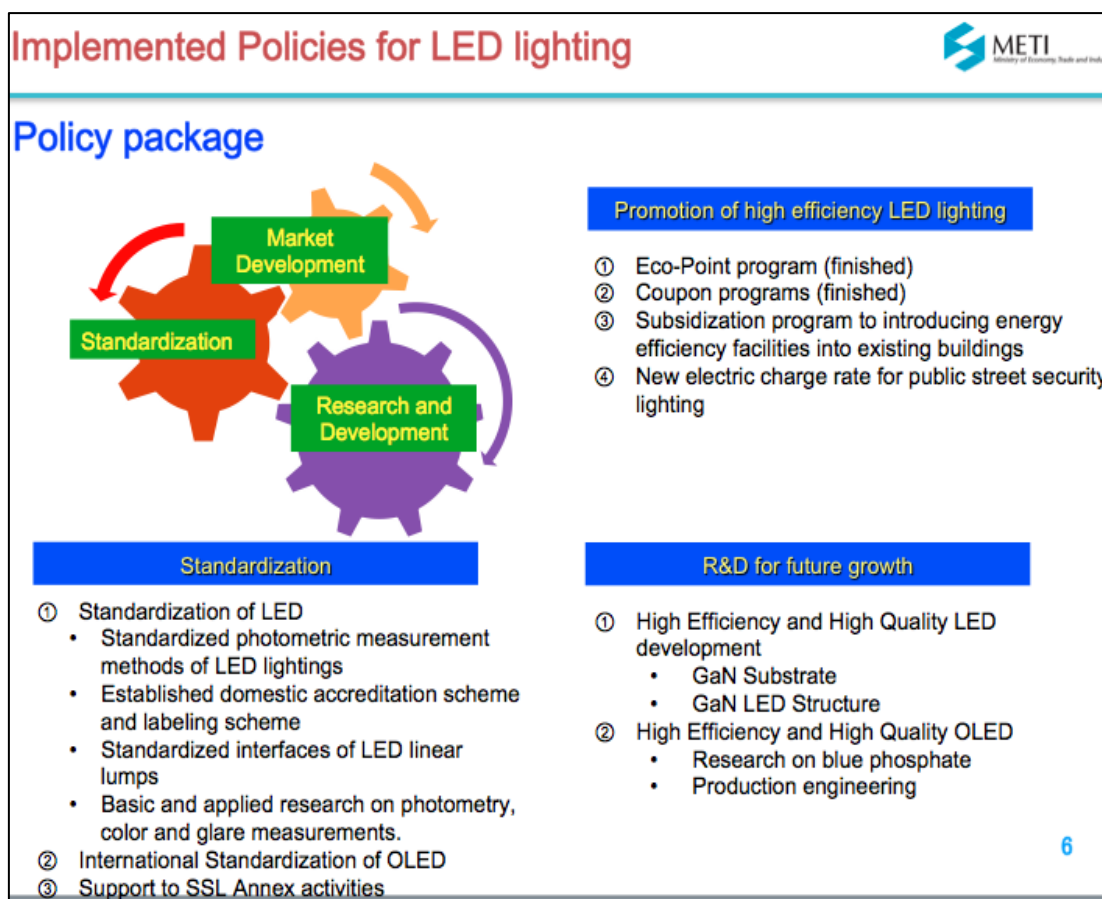


Figure 3. Policies to Promote LED Lighting (Japan)

1.5 Promoting High Quality LED Lamps and Luminaires

In November 2016, the IEA 4E SSL Annex published voluntary quality and [performance tiers](#) for seven product categories that address product attributes such as colour, lifetime, power, and efficacy⁵. Additionally, the quality and performance tiers include a requirement for maximum “dominant light frequency” for which a spreadsheet is provided for calculating the Fourier Series. These product performance tiers were agreed upon by IEA SSL Annex members. The tiers can be utilised by government, non-profit and donor agencies when designing programmes and policies. They can also be utilised by programme designers to reduce the costs of writing specifications and to harmonize local specifications and programmes with those of larger markets, national, regional and/or international. Use of the tiers is entirely voluntary; and, the tiers are not recognised as international standards.

⁵ IEA 4E SSL Annex. 2016. *Product Performance*. Accessed on 7 Dec 2016: <http://ssl.iea-4e.org/product-performance>.



Figure 4. Performance Tiers and Spreadsheet for Dominant Light Modulation Frequency

Table 2 lists some of the performance criteria for these tiers. Given the diversity of applications, not all of the parameters apply to all categories of products.

Table 2. LED Lamp and Luminaire Quality Criteria in the IEA 4E SSL Annex Tiers

Criteria	Parameters and Metrics
Efficacy	Total luminous flux, active power, luminous efficacy (lm/W)
Life	Lumen maintenance, minimum rated lamp lifetime, endurance test (cycle on-off)
Colour	Colour rendering index, colour maintenance, correlated colour temperature, chromaticity coordinates and tolerance
Operation	Luminous intensity distribution, lag start time, dimmer compatibility, power factor, harmonic distortion
Light and Health	Dominant light modulation and frequency modulation (%) (including flicker effects); photobiological risk group (blue light and UV hazard)
Environment	Warranty duration; RoHS compliance; recyclable content (%)

The performance characteristics and parameters for high quality LED illumination products continue to evolve. Most IEA 4E SSL Annex member countries invest in research and development knowledge programmes. IEA 4E SSL Annex members collaborate with research and industry partners to continue to explore and create knowledge to enable the manufacture of high quality LEDs, considering energy, environmental and health-related dimensions⁶.

Public Funding for Lighting Research

France's energy agency, [ADEME](#), through its Investments for the Future program, sponsors research on smart lighting technology for buildings and cities (including sensors, controls and RF/optical data links) and on the possible health impacts of blue light.

[The Joint Research Centre](#) (JRC) of the European Commission (EC) conducts efficient lighting studies, publishes reports and convenes [conferences](#) that support market transformation throughout Europe. Topics include purchasing and usage behavior, modeling, sustainable production and materials research.

⁶ See, for example, Bertoldi, P., ed. 2016. *Proceedings of the 9th International Conference Improving Energy Efficiency in Commercial Buildings and Smart Communities*. Accessed 7 Dec 2016: <https://ec.europa.eu/jrc/en/publication/9th-international-conference-improving-energy-efficiency-commercial-buildings-and-smart-communities>.

Also, ADEME. 2016. *Smart Grids: First results from French demonstrators*, and, *Investments for the Future*. Accessed 7 Dec 2016: <http://www.ademe.fr/en/smart-grids-first-results-from-french-demonstrators> and <http://www.ademe.fr/en/investments-for-the-future>

2 Quality Assurance

Rapid development and increased market penetration of LED illumination products presents technology and application challenges that include:

- Potential for exaggerated performance claims by unscrupulous and/or ill-informed suppliers
- Questions over how to define and test for LED lifetime and reliability
- Limitations on the application of existing colour metrics
- Potential benefits, implications and risks for human health (e.g., blue light, flicker, glare)
- Interoperability and capacity issues with existing and future illumination, lighting control and communication systems
- Smart lamps and the unstructured expansion of multiple services (e.g., light, sound, WiFi, vision, security)

Quality assurance programmes can help ensure that the full benefits of LED illumination will be realized. Approaches include promoting the sale and procurement of high quality products, setting minimum performance levels for general sales and procurement programmes, compatibility testing and reporting, and/or supporting monitoring, verification and enforcement through independent performance testing and third-party reporting.

2.1 Minimum Efficiency Performance Standards (MEPS)

History suggests that if consumers have negative experiences with poor quality products, they may subsequently have negative associations with all similar products, including LED illumination products (Goebes, 2014).⁷ To avoid or mitigate the risk of market spoiling some governments may establish minimum efficiency performance standards (MEPS) for categories of LED illumination products. For success, the MEPS should be developed in consultation with a wide range of stakeholders, including: business and industry representatives, academic experts, labour unions, professional associations, central and local governments and civil society organisations.

- **Ecodesign Directive for Energy-Related Products (European Union):** In 2009 the European Commission established obligatory minimum efficiency performance standards for lamps (bulbs) sold in all EU-member countries ([ecodesign requirements](#)).⁸ In 2013, associated [lighting product labelling requirements](#) (that cover LED lamps and modules) came into effect.⁹
- **Product Registry Database (Australia):** In combination with their MEPS programme, Australia runs a product registry database¹⁰ which enables upfront scrutiny of products and supports compliance activity. It provides a track record of all the products offered in the market which helps to monitor natural market progress and government programmes. At the time of this printing, Australia is actively working to establish MEPS for LED products, and the product registry database will provide an excellent resource for reviewing the MEPS once they are established.

⁷ Goebes, M.D. et al. 2014. LED Program Strategies: Synthesizing Recent Research. *ACEEE 2014 Proceedings*. Accessed on 7 Dec 2016: <http://aceee.org/files/proceedings/2014/data/papers/5-1080.pdf>

⁸ See relevant lighting regulations on the European Commission website. Accessed on 7 Dec 2016: <http://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products/lighting>

⁹ *ibid.*

¹⁰ Australia's product registry database: http://reg.energyrating.gov.au/comparator/product_types/

- **Top Runner Standards (Japan):** The [Top Runner](#) program established mandatory performance and labelling standards for manufacturers and importers of LED lamps¹¹. Japan established two product categories, with luminous efficacy requirements based on correlated colour temperature. The law also requires that product packaging contains minimum information including total luminous flux (lumens), watts, lamp colour and the name of Japanese accredited testing laboratory. Through these standards, Japan aims to reduce by at least 50% its electric lighting consumption by the end of fiscal year 2017.
- **General Service Lamps Backstop Standard (USA):** The Energy Policy and Conservation Act, as amended, requires that, effective beginning January 1, 2020, the U.S. DOE shall prohibit the sale of any general service lamp that does not meet a minimum efficacy standard of 45 lumens per watt. (See section 42 U.S.C. 6295(i)(6)(A)(i)-(iv))

2.2 LED Performance Guidelines and Specifications

Governments can accelerate early market adoption by promoting, specifying and purchasing high-performing LED illumination systems. Procurement programmes for high quality lamps for government-owned or -leased facilities and buildings demonstrate and can evaluate new and high-performing products. These activities also facilitate a market price reduction due to bulk procurements as well as providing experience to lighting designers and electrical contractors while providing feedback to manufacturers and distributors. Establishing voluntary, common guidelines or minimum performance criteria for LED illumination products and systems also supports other public or private sector stakeholders through shared experience and information tools. For example, local professional groups often meet to tour facilities and meet managers who operate new installations; this peer-to-peer knowledge exchange is highly valuable for all parties.

Green procurement projects also support a government's public image and accountability. Green initiatives show support for energy efficiency policies, create demand for innovative businesses and technologies and demonstrate prudence with operating cost and maintenance budgets. Large procurements of efficient products (such as municipal street lighting systems or LED upgrades for government-owned buildings) can be financed through issuance of public bonds and the involvement of energy service companies (ESCOs). The IEA reports that in 2015, "green bond" issuances rose to USD\$42 billion, with energy efficiency being their second largest investment target, at 20% of total.¹²

Many IEA 4E SSL Annex members seek economic and trade benefits by minimising the number of and differences between minimum efficiency performance levels for the same global categories of lighting products. Harmonisation minimises compliance costs to governments (and manufacturers/suppliers) for market transformation programmes and policies. When requirements can be harmonised, costs of preparing specifications and monitoring quality can be reduced.

Procurement quality assurance examples include:

¹¹ METI. 2015. *Top Runner Program*. Accessed on 7 Dec 2016: www.enecho.meti.go.jp/category/saving_and_new/saving/data/toprunner2015e.pdf

¹² IEA. 2016. *Energy Efficiency Market Report 2016: Digital Snapshot*. Paris, France. Accessed on 7 Dec 2016: <http://www.iea.org/eemr16/>.

- **LED Green Procurement (France):** [RATP](#), the transport authority of Paris, replaced 250,000 lighting units, covering more than 300 km of newly lit metro platforms and station corridors. It was the first public transport network of its size to be fully equipped with LEDs in all passenger areas¹³.
- **Procurement of Efficient LEDs (Republic of Korea):** The government set a goal of 60% national deployment of LEDs by 2020. By 2014, all public organisations had to replace more than 50% of their lighting equipment with LED products. By 2018, Seoul plans to convert all lighting to LEDs in government buildings¹⁴. All public organisations must specify high-efficiency certified products when making purchases through the public procurement services.
- **Street Lighting Guidance (Australia):** Australia and New Zealand have a minimum efficiency performance standard requirement to phase out mercury-based lamps. Numerous best practice guides are available from governments, manufacturers and professional associations to assist local government bodies with information on how to choose and specify high efficiency replacements, many of which are now LED illumination systems. The guides emphasise luminous efficiency, system design and appropriate spacing¹⁵. In 2016, Australia issued a smart-controls LED street lighting roadmap and a street lighting specification for use by municipal/local governments and networks.¹⁶ Australia is also working on an energy-efficient design specification for LED lighting which will be largely based on the European standard EN 13201-5:2015, *Road lighting. Energy performance indicators*.
- **Federal Energy Management Program (USA):** The Federal Energy Management Program (FEMP) in the USA provides acquisition guidance for the purchase of energy-consuming products, including light bulbs. Federal agencies are required by law to purchase Energy Star-qualified or FEMP-designated products when feasible. The FEMP guidance for light bulbs refers to the corresponding Energy Star product specification¹⁷.

2.3 Market Monitoring, Verification and Enforcement

Governments monitor markets by collecting sales data, import/export data, manufacturer test data and surveying instore stock of products. Governments also purchase lamps from their national markets and verify performance via testing. They enforce measures for compliance and support the effectiveness of policies and programmes. For a rapidly developing technology such as LEDs, a key strategy to understanding markets and conducting surveillance is engaging and working with industry stakeholders.

¹³ RATP. 2016. Accessed on 7 Dec 2016: http://www.ratp.fr/en/ratp/r_76407/led-lighting-for-ratp-metro-and-rer-stations/ and http://www.ratp.fr/en/ratp/v_151980/ratp-becomes-the-worlds-first-transport-network-fully-equipped-with-leds/print/

¹⁴ ChinaHong. n.d. All municipal government office of Seoul plans to use LED lighting in 2018. Accessed on 7 Dec 2016: <http://www.chinahong.org/news/18.html>

¹⁵ The Energy Efficiency Council (EEC). 2016. Australian Energy Efficiency Policy Handbook. Accessed 7 Dec 2016: <http://www.eec.org.au/policy-advocacy/handbook>.

¹⁶ The Australian street light report issued Dec 2016: <http://www.lites.asia/news-and-events/news/slsc-roadmap>

¹⁷ The USA example references: <https://energy.gov/eere/femp/purchasing-energy-efficient-light-bulbs> and https://www4.eere.energy.gov/femp/requirements/laws_and_requirements/energy_star_and_femp_designated_products_procurement_requirements

Governments can take a lead role or work collaboratively to test products for compliance with requirements or to support voluntary measures. For example, the European Union market surveillance requirements place most responsibilities on national governments¹⁸.

- **Verification Testing (Australia, Denmark, Sweden, and USA):** These countries regularly test products available in their markets to ensure that lighting products comply with standards and labelling requirements. Verification testing ensures that consumers receive products that reflect the expected level of performance and energy savings based on advertised claims. The data from verification testing can also help inform policy makers when establishing or updating standards.

Market monitoring and product testing:

Price and performance expectations for LED illumination products should be regularly checked, as evidenced by a [2015 study](#) compiled by the Swedish Energy Agency, Belgian Ministry, CLASP and eceee, which concluded that, “LED products are introduced into the European market at much lower prices and much better performance levels than the European Commission anticipated in June 2013... approximately 50% of the LED lamps purchased and tested for this study already exceed the 2016 price and performance levels that were anticipated by the Commission, and one model available on the European market in 2014 already exceeds the anticipated 2018 level on efficacy and the 2020 level on price.”

- **Collaborative, regional laboratory capacity building and training (Australia, China and others):** Supported by the Australian government, the Global Environment Facility and the United Nations, the en.lighten initiative conducted the [Southeast Asia and Pacific Monitoring, Verification and Enforcement Project](#) to develop lighting laboratory testing capacity and knowledge. Illumination engineering experts delivered training on photometric measurements, colorimetry, uncertainty evaluation, lighting distribution and calibration of integrating spheres. Participants conducted market benchmarking exercises for efficient lamps and discussed results at *lite.asia* meetings¹⁹. A series of best practice guides was published²⁰ and under the Association of South East Asian Nations (ASEAN) SHINE initiative, the governments are collaborating in a regional LED testing project that is evaluating over 100 different LED lamps across ASEAN.
- **Commercially Available LED Product Evaluation and Reporting (USA):** Launched in 2006, the [CALiPER](#) LED product testing program relies on reports from accredited test laboratories, using industry-standard test procedures. To support purchasers and end-users, it intends to discourage inaccurate LED performance claims and help manufacturers identify product performance that could be improved. The test results and analysis are also used to support the development of standards and test procedures. Numerous reports and analyses are available.²¹
- **Rapid Alert System (Europe):** This enforcement scheme enables quick exchange of information between all the European countries and the European Commission. Public authorities identifying

¹⁸ For updates, see the EC webpage, “[The implementation of market surveillance in Europe.](#)” Also see eceee summaries of recent testing at: <http://www.eceee.org/all-news/press/2015/test-report-confirms-rapid-development-of-LED-lamps> and <http://www.eceee.org/all-news/news/news-2015/2015-03-17a>.

¹⁹ <http://www.lites.asia/>

²⁰ UNEP. 2015-2016. MVE best practice guides. Accessed 7 Dec 2016: <http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx>

²¹ U.S. DOE CALiPER website: <http://energy.gov/eere/ssl/caliper-testing>.

dangerous lighting products can require: recalls of the product from end users; withdrawal of the product from the market; and, destruction of the product²².

- **Sharing Test Data (SSL Annex; Europe ADCO):** Governments can cooperate through the sharing of test results between countries. In the SSL Annex, the member countries have compiled and share a product database that spans several years and tracks not only the current products in members' markets, but also the trend and technology improvements over time. In Europe, the 28 member states all participate in an "Administrative Cooperative" (ADCO) around major legislative directives, including one for Ecodesign and Energy Labelling. Within this ADCO, the governments share their test results, report any issues and provide resources to enable better policy-making.
- **New Import Codes for LED Products (Australia):** With the rapid introduction of LED lighting into many new applications and markets, the globally harmonised system for tracking trade between countries had difficulty classifying these products. In Australia, the government moved to establish new statistical import codes to provide better data, and help track the market evolution of LED lighting relative to other technologies more accurately. For more information, visit the March 2017 issue of the lites.asia newsletter.²³

²² EU Rapid Alert System for dangerous non-food products. Accessed 7 Dec 2016:

http://ec.europa.eu/consumers/consumers_safety/safety_products/rapex/index_en.htm

²³ Lites.asia article on new LED import codes: <http://www.lites.asia/news-and-events/news/hs-led-codes>

3 Communication Tools

LED-related communication and education strategies differ depending on the target audiences, which could include consumers, professional purchasers and supply chain actors. Government and trade partner information campaigns help consumers make informed, energy efficient choices at the point of purchase. Campaigns can provide web-based resources such as searchable databases of qualified or certified products, fact sheets, lighting design guides, advertisements, videos and other collateral materials. These shared resources introduce locally-appropriate and harmonised information and reduce communication costs throughout the distribution chain.

3.1 Product Certification, Labelling and Information Programmes

Labelling programmes can be an element of, or compliment to, certification schemes and communications campaigns. Labels can be endorsement labels oriented to consumers, such as [ENERGY STAR®](#) in the USA, or categorical labels like the Australian [Energy Rating E3](#)²⁴ or the European energy label offering label classes that vary with the level of efficiency. Labels support professional stakeholders and commercial lighting markets.

- **Energy Label (China):** In 2005 China introduced a mandatory, categorical labelling programme to transform the Chinese market towards more efficient appliances. By 2014, the programme covered twenty-nine products in five categories, including thousands of LED illumination products.²⁵
- **High Efficiency Appliance Certification (Korea):** The Korean Energy Agency manages the voluntary High Efficiency Appliance Certification Program, to provide subsidies and incentives to increase the market for LED traffic lights, lamps, recessed and fixed LED fixtures and LED security lighting.²⁶ LED manufacturers or importers apply for certification through this programme by submitting their products to government-sponsored testing facilities. If a product meets or exceeds established performance thresholds, the test agency issues a report confirming that the product is certified. The Korean Energy Agency also inspects the manufacturing facilities of domestic and foreign manufacturers. Evaluation criteria include areas such as production capabilities and scalability, quality control regimes, and follow-up customer services.
- **ENERGY STAR® (USA):** The voluntary [ENERGY STAR®](#) program differentiates the highest-performing products, allowing consumers to quickly identify appropriate, energy-saving LED products through a trusted government programme. It has both commercial and residential lighting components, with searchable databases of qualified products. ENERGY STAR provides its

²⁴ “The Equipment Energy Efficiency (E3) program is a cross jurisdictional program through which the Australian Government, states and territories and the New Zealand Government collaborate to deliver a single, integrated program on energy efficiency standards and energy labelling for equipment and appliances.” Accessed 7 Dec 2016: <http://www.energyrating.gov.au/about>

²⁵ Yu, Y., et al. 2015. *Consumer Comprehension of the China Energy Label and Household Appliance-using Habits in China*. Accessed on 7 Dec 2016: <http://kms.energyefficiencycentre.org/publication-report/consumer-comprehension-china-energy-label-and-household-appliance-using-habits>.

²⁶ Republic of Korea, Ministry of Knowledge Economy and Korea Energy Management Corporation. n.d. *Korea’s Energy Standards & Labeling: Market Transformation*. Accessed on 7 Dec 2016: http://www.kemco.or.kr/nd_file/kemco_eng/KoreaEnergyStandards&Labeling.pdf

market partners with extensive support and materials customized for retail, online and business-to-business sales channels.²⁷

- **LED Lighting Facts (USA):** “[LED Lighting Facts](#)” showcases products from manufacturers who commit to testing products and reporting performance results according to industry standards.”²⁸ The LED Lighting Facts program maintains an online database with detailed information of nearly 55,000 LED products, and provides a label for manufacturers to report product performance results of verified products.
- **Lampguiden (Sweden, Denmark, Australia and New Zealand):** The [lamp guide](#) smart phone application²⁹ helps promote LED products to consumers, showing energy and financial savings over a 10 year period – the typical lifetime of an LED lamp. The tool also offers lighting design guidance for specific rooms. An update to the smartphone app was recently prepared and rolled out in Australia and New Zealand.³⁰
- **QR Code (China):** To help reach end-use customers, China National Institute of Standards (CNIS) developed a national voluntary appliance label whereby manufacturers could add a [QR code](#) to the existing Chinese Energy Label. The QR code is scanned via smart phone, giving consumers access to product data for efficiency level and functionality.³¹
- **Dimmer Database (Australia):** Policy makers working on MEPS for LED lamps have found there can be some compatibility issues between new LED lamps and older dimming technologies and low-voltage transformers. The Australian government is therefore developing a compatibility database which will be based on actual testing and will help consumers identify which products can be used in their homes.

3.2 Training Retailers to Improve Communications

The point-of-sale is a critical point in the consumer purchase decision process. Retailers and shop-floor sales representatives often serve as on-site advisors to consumers, finding efficient LED lamps that would fit into their fixtures and satisfy their requirements in terms of quality and brightness. Governments can partner with retailers to promote high efficiency products to consumers.

- **Lighting Design Training Manual (Australia):** Specialist lighting and major hardware stores were identified as key players and partners to educate homeowners contemplating new lighting systems for renovations or major refurbishments. The specialist lighting retailer training package consists of a retailer guide, a suite of residential case studies (including residential houses and

²⁷U.S. EPA, 2015. *National Awareness of ENERGY STAR® for 2014: Analysis of 2014 CEE Household Survey*. Washington, DC: Office of Air and Radiation, Climate Protection Partnerships Division. Accessed 7 Dec 2016:

https://www.energystar.gov/sites/default/files/asset/document/National_Awareness_of_ENERGY_STAR_2014_v6_508_1.pdf

²⁸U.S. DOE LED Lighting Facts website. Accessed 7 Dec 2016: <http://www.lightingfacts.com/>.

²⁹Lamp Guide. <http://www.energimyndigheten.se/energieffektivisering/hemmet/belysning/lampguiden/>

³⁰The smartphone app is available from the Australian government: <http://www.energyrating.gov.au/apps>

³¹Ye, L. *et al.* 2015. *Appliance Labeling for the 21st Century: Introducing QR code for the China Energy Label*. www.cnis.gov.cn

apartments), designed to help retailers support their customers in selecting energy-efficient lighting solutions that meet their needs.³²

- **Pilot test of a retailer e-training program (Denmark):** The government developed a short lighting training programme to enable retailers to better guide and provide advice to their customers.³³ The first iteration of the training was too long and technical. With feedback, it was shortened to 10 minutes and enhanced with graphics and narration. A short quiz asked retail staff about what they had learned, to reinforce the content. Also, even when communication materials were provided free-of-charge, not all retailers used the materials or placed them appropriately. Members suggested engaging retailers individually to customize the types of promotional materials and strategies to the retailers' stores and needs. An updated version of the Danish Energy Agency's tool was prepared for normal household use and posted on municipal and electric utility websites. This tool has been successfully used by tens of thousands of customers across Denmark.

3.3 Initiatives for Professional Lighting

Working with suppliers to the professional lighting market requires a different approach than that used for the consumer markets. During construction or refurbishment of commercial, public or institutional buildings, lighting engineers or designers prepare lighting designs, specify the equipment and take care to satisfy building, safety and appliance regulations.

Governments sponsor professional training, accreditation programmes, and lighting design awards, work with local partners including municipalities and universities, develop demonstration projects and deliver information campaigns via professional journals and trade expositions.

- **Street Lighting Training Programme (France):** For a decade, ADEME has sponsored an education programme for specifiers and installers of public street-lighting. The 3-day programme includes design and energy efficient technologies such as LEDs. Participants have contributed to a steady increase in LEDs street lighting installations in France³⁴.
- **Small Retailer LED Education (Denmark):** The Danish Energy Agency commissioned a savings potential study. Although small retail applications offered good potential, retailers lacked the necessary technical knowledge to capture the savings potential. The Agency re-purposed

Communicating performance concerns: Prior to 2013 the European ecodesign directive for lighting products did not include quality criteria. The Swedish Energy Agency was concerned about quality issues with LEDs and with the risk that consumers would become dissatisfied with LED illumination products. LED lifetime, was a special interest, since no standard test methods were available for lifetime testing. The Agency therefore focused early communications and training to municipalities and professional purchasers on warranty issues, encouraging them to specify products with five to seven year warranties. They also reminded stakeholders about consumer product protection laws.

³² Australian retailers guide: <http://www.energyrating.gov.au/document/lighting-retailer-training-guide-0>

³³ Danish programme: <http://sparenergi.dk/forbruger/el/energimaerkning-apparater/eus-energimaerkning/spoergeskema-om-belysning>

³⁴ See, for example, the city lighting projects coordinated by Citelum, a subsidiary of the French electric utility, EDF. Accessed on 7 Dec 2016: <http://www.citelum.com/news-service/smart-lighting>.

previously developed educational content to specifically address this stakeholder audience.³⁵

- **Municipal Solid-State Street Lighting Consortium (USA):** Cities, electric utilities and other parties join the [Consortium](#) to share experiences and technical information.³⁶ A knowledge base of field experience and market data helps members purchase and implement high-quality, energy-efficient LED lighting. Members develop and receive information on Consortium tools and resources via a website, newsletter and meetings. Tools include model specifications, financing guides, evaluated demonstrations and market analyses.
- **Training Guide: The Basics of Efficient Lighting (Australia):** Australia developed a training manual on LED lighting to help installers and contractors work with LED lighting. The “Basics of Efficient Lighting” reference manual is a joint initiative of the E3 Program and the National Electrical and Communications Association (NECA). It introduces the basic concepts of light and lighting, and explores the key requirements of a lighting system and what standards need to be met. It also explains what is meant by sustainability and energy efficiency and how good lighting design can contribute to these.³⁷
- **Illuminating Engineering Society of Australia and New Zealand (Australia):** Governments of Australia and New Zealand have sponsored energy efficient lighting design awards and efficient lighting product design awards. Both awards were required to meet specific lighting quality aspects of design before being eligible for consideration in the energy efficiency award.

³⁵ The Danish retail campaign included 800 shops with use of an LED calculation tool:

<http://sparenergi.dk/erhverv/vaerktoejer/skift-til-led> The national campaign is described at:

<http://www.mynewsdesk.com/dk/energistyrelsen/pressreleases/energistyrelsens-led-konsulenter-besoeger-800-nye-butikker-1856310>

³⁶ U.S. DOE, Municipal Street Lighting Consortium website: <http://energy.gov/eere/ssl/doe-municipal-solid-state-street-lighting-consortium>

³⁷ Australian resources for retailers and installers: <http://energyrating.gov.au/retailers-tradies> Note that at the time of publication of this report, the resource guide is being updated to better incorporate LED lighting.

4 Promoting LED Lamps with Incentives

Based on interviews with IEA 4E SSL Annex members, in 2015 LED illumination was gaining market traction primarily in public (street lighting) and commercial-based applications. More recently however, North America has seen sales of LED A-line lamps surge to 32.4% of the market in third quarter 2016, and posting a 124.2% increase in shipments compared to 3Q 2015³⁸. Short-term incentives in the form of coupons, rebates or bulk purchases can help to promote initial uptake of LED products, as they did in North America.

4.1 Domestic Sector

- **Utility Rebates (Canada and USA):** State and provincial regulators require many electric utilities to conduct demand-side management programs. For local LED lighting incentives, users can search the Database of State Incentives for Renewables & Efficiency® ([DSIRE](#)), which also includes policies by state. Some regions offer incentives and qualified product information via collaborative efforts, such as the bilingual and searchable list developed by the [DesignLights Consortium](#). As the North American market matures, experience shows that lighting product incentives are most economically applied prior to the point-of-sale, “upstream” in the distribution chain.³⁹
- **LED Lamp Promotion (France):** With the support of EDF, the national electric company, and municipalities, France provided one million LED lamps at no cost, primarily to low-income households, as an [initiative for the environment](#)⁴⁰. Municipalities selected the households to receive the lamps.
- **State-based White Certificate Schemes (Australia)** Electricity distributors in the state are required by contract to purchase a predetermined number of white certificates in the open market each year created by approved certificate providers (including certificates from installation of qualified energy efficient lighting products).

4.2 Professional Sector

- **Tax Incentives for High Efficiency LEDs (Japan):** In 2011, Japan introduced a tax incentive scheme for energy load reduction, to reform the energy supply structure and contribute to emissions goals. In 2013, small businesses could apply either a 30% depreciation deduction or a 7% tax exemption for installing high efficiency LEDs in more than 90% of their luminaires. The Ministry of Economy, Trade and Industry (METI) partnered with the Japan Lighting Manufacturing Association, which was responsible for coordinating with manufacturers and the construction industry to approve applications, review documents and issue certificates to confirm tax benefits.
- **Enhanced Capital Allowances (UK):** This UK government scheme allows businesses to improve cash flow through accelerated tax relief by encouraging investments in energy saving plant or

³⁸ NEMA data for LED A-line lamp sales: <https://www.nema.org/news/Pages/LED-A-Line-Lamp-Shipment-Increase-in-Third-Quarter-of-2016.aspx>

³⁹ Consortium for Energy Efficiency. 2015 Overview of Residential Lighting Programs in the United States and Canada. Accessed 7 Dec 2016: <https://library.cee1.org/content/cee-2015-residential-lighting-program-overview/>

⁴⁰ Government of France. 2015. La loi de transition énergétique est publiée: Ségolène Royal appelle les citoyens à s'en saisir. 15 August 2015. Accessed 7 Dec 2016: <http://www.developpement-durable.gouv.fr/La-loi-de-transition-energetique,44347.html>

machinery.⁴¹ The Carbon Trust maintains and specifies a list of approved, energy saving products or systems in its [Energy Technology List](#), a register of products that may be eligible for 100% tax relief.

⁴¹ UK. Enhanced Capital Allowances and Carbon Trust Energy Technology List. Accessed 7 Dec 2015: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/376179/ECA763_Lighting.pdf and <https://www.gov.uk/guidance/energy-technology-list>.

5 Supporting Domestic Manufacturers

SSL Annex members recognised the emergence of LEDs as an opportunity for national business growth and development. Supporting research and the creation of intellectual property fuels future technology innovation. Manufacturing support through measures such as national policies, financial or tax incentives and public programmes are familiar ways to cultivate valuable products.

5.1 Public Investments in LED Industries

Most members of the SSL Annex have invested in LED research and manufacturing to build their domestic industries. For example, public-private partnerships can launch and maintain business incubators to encourage inventors and small- to medium-size enterprises. Also, government-academia research initiatives, incubators and economic development zones may encourage banks and investors to create green technology funds to provide low interest loans or start-up capital.

There are many stages in the LED product supply chain ranging from chip manufacturing through modules, drivers, optical design and assembly and finished products. Companies can plan to compete in any stage of the supply chain, and offer services for business-to-business or business-to-consumer.

- **R&D and financing (Republic of Korea):** Korea offers tax advantages for suppliers who make energy efficiency investments and subsidies for testing fees in support of the Korean high-efficiency certification programmes. Forecasting relatively small profit margins for general indoor lighting products, the government decided to invest in three areas:
 - Creating a new market for LEDs for medical applications;
 - Converting the conventional LED industry to higher-value added businesses;
 - Cultivating a business ecosystem for LED lighting product manufacturing.
- **R&D support (USA):** Since 2000, U.S. DOE has funded numerous LED illumination research and development projects. Multi-year R&D and market roadmaps are developed with input from stakeholders to identify barriers and set milestones. The [roadmaps](#) are available to industry and the public⁴².

5.2 Awards and Programmes to Promote Better Product Performance

Governments can offer recognition to reward innovation. Competitions, prizes and awards can inspire and accelerate LED innovation while helping to raise awareness of the highest quality and energy efficient products within a certain category.

- **Innovation Competitions (USA):** U.S. DOE established the [L Prize](#) competition to spur development of replacement technologies. The L Prize for a 60W incandescent replacement lamp was awarded in August 2011; it included a US\$10 million cash prize and eligibility for government procurement and utility program contracts. The [Next Generation Lighting Systems](#) competition (formerly known as Next Generation Luminaires) encourages innovation and education for the development of next generation lighting systems with a focus on specific lighting applications. Systems are installed in real-world settings and superior performers and areas for improvement are recognized.

⁴² U.S. DOE Solid State Lighting website: <http://www.energy.gov/eere/ssl/technology-roadmaps>.

Competitions: <http://www.lightingprize.org/index.stm> and <http://energy.gov/eere/ssl/design-competitions>.

- **SEAD Global Efficiency Medal and the Global Lighting Challenge⁴³**: The Clean Energy Ministerial sponsors two high efficiency lighting competitions. In 2017, the Super-efficient Equipment and Appliance Deployment (SEAD) initiative's [Global Efficiency Medal](#) will identify and recognize highly energy-efficient industrial and outdoor lighting products. The [Global Lighting Challenge](#), launched mid-2015, is a race to reach cumulative global sales of 10 billion high efficiency, high quality, and affordable advanced lighting products such as LED lamps, as fast as possible. As of late 2016, participants (including the SSL 4E Annex) had achieved one percent of this ambitious goal.

5.3 Support Testing Standards

Governments, manufacturers, illumination engineering societies, laboratories, accreditation bodies, lighting designers and consumer representatives can support and accelerate the creation and use of LED test standards to support high quality, energy efficient products. To do so, they participate in national, regional and international standards-setting organization's committees.

- **Interlaboratory Comparison⁴⁴**: In September 2014, the IEA 4E SSL Annex published a report on an LED lighting product measurement comparison of over 110 lighting test labs. The [Interlaboratory Comparison](#) was designed to support harmonisation of SSL testing around the world and help establish a common proficiency test⁴⁵ for accreditation programmes. The comparison looked at the measured values of luminous flux, luminous efficacy, active power, RMS current, power factor, chromaticity x and y, correlated colour temperature, and colour rendering index.

The IEA 4E SSL Annex is currently launching the 2017 Interlaboratory Comparison (IC 2017) for goniophotometer measurements. IC 2017 is open to all photometric laboratories that use goniophotometers for testing LED lighting products. This new interlaboratory comparison will study the equivalence of different types of goniophotometers, e.g., near-field goniophotometers and far-field goniophotometers, and investigate the measurement variations and the capability of participating laboratories using goniophotometers to measure SSL products.⁴⁶

- **International Standardisation Processes**: The Illuminating Engineering Society (IES) of North America developed a measurement standard for LED lamps in 2008⁴⁷. Many aspects were incorporated into the 2015 global test standard published by the International Commission on Illumination (CIE S 025/E:2015). SSL Annex members encourage countries to sponsor experts to engage with and participate in the international standardisation processes of CIE, the International Electrotechnical Commission (IEC) and other bodies. Support would help local manufacturers understand, embrace and successfully apply international test standards for lighting products, to help protect consumers from poor quality products and to strengthen metrology practices.

⁴³ SEAD Global Medal: <http://www.superefficient.org/Global-Efficiency-Medal/Lighting-Awards>. Global Lighting Challenge: <http://globallightingchallenge.org/>.

⁴⁴ <http://ssl.iea-4e.org/news/2013-ic-final-report>

⁴⁵ Proficiency testing is used to establish whether a lab can be accredited for testing against a specific standard.

⁴⁶ SSL Annex Interlaboratory Comparison: <http://ssl.iea-4e.org/testing-standards/laboratory-comparability>

⁴⁷ IES LM-79-08, "Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products": https://www.nist.gov/sites/default/files/documents/2017/04/05/iesna_lm_79-iesna_lm_79_1.pdf

6 Recommendations and Conclusions

SSL Annex member countries have decades of combined experience with developing markets for LED illumination products; however, no single policy or programmatic model applies globally. Rather, a portfolio of market transformation policy and programme tools can support and sustain markets for high quality, energy efficient products. Governments and energy efficiency programmes can raise awareness of efficiency opportunities and the benefits of LED products, throughout the supply chain. Members' market transformation activities demonstrate that:

- LED illumination products are capturing a growing share of lighting sales globally. LED technology is the preferred choice in certain applications, namely outdoor lighting and public/commercial sector applications.
 - In France, over 50% of newly installed luminaires in non-residential applications are LEDs.
 - In Korean public buildings, LEDs comprise nearly 40% of installed lighting.
 - In the USA, LED lamps for consumer use have more than 32% of A-line lamps sold in the third quarter 2016.
 - In Australia, LED lighting accounts for 15% of residential installed lighting (2016).
 - In the IEA 4E SSL member countries, LED street lighting is rapidly increasing its market penetration.
- The definition of “high quality” LED lighting continues to evolve; it depends on product, application and consumer expectations. The IEA 4E SSL Annex publishes LED minimum performance tiers that can be used as a “benchmark” for quality. Some concerns remain, including:
 - Exaggerated performance claims by some manufacturers/suppliers;
 - How to define and test for LED lifetime and reliability;
 - Limitations on the application of existing colour metrics to LEDs;
 - Colour shift over the lifetime of the LEDs;
 - A need for more research on the physiological effects of colours, intensities and applications of light, particularly human health and photobiological safety;
 - Interoperability and capability issues with existing lighting infrastructure including lighting control systems;
 - Dimming systems and related flicker; and
 - Glare and related complications.
- IEA 4E Annex members support and recommend a portfolio of policies and programmes to grow and sustain the market for high quality, energy efficient LED illumination products. Portfolio elements include:
 - Quality assurance mechanisms including market monitoring and performance testing;
 - Tailored communication approaches for consumers and businesses;
 - Manufacturer support; and
 - Incentive approaches for consumers and businesses.

Cooperation and knowledge sharing between regional trading partners, national governments, industry, energy efficiency programmes, local government stakeholders and non-profit organisations can ensure that high efficiency and quality products dominate the lighting market and deliver associated energy savings and other benefits. As the IEA notes, “Efficiency is the one energy resource all countries possess in abundance.

The world is using only a small portion of the available supply and this must change.”⁴⁸ In many cases, support for developing and deploying LED illumination products constitutes the first step in a rapid market transformation to an energy-efficient economy.

⁴⁸ IEA. *Energy Efficiency Market Report 2016*. Paris, France. Accessed on 7 Dec 2016: <http://www.iea.org/eemr16/>.