International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

NIST

26e CGPM
Versailles
13-16 novembre 2018

Measurement Challenges for Efficient Sustainable Lighting Technologies

Yoshi Ohno

President, International Commission on Illumination (CIE)
(National Institute of Standards and Technology, USA)

Other Delegates from CIE:

Kathryn Nield, General Secretary of CIE
Peter Blattner, President-Elect, Director of CIE Division 2
Tony Bergen, Secretary of CIE Division 2

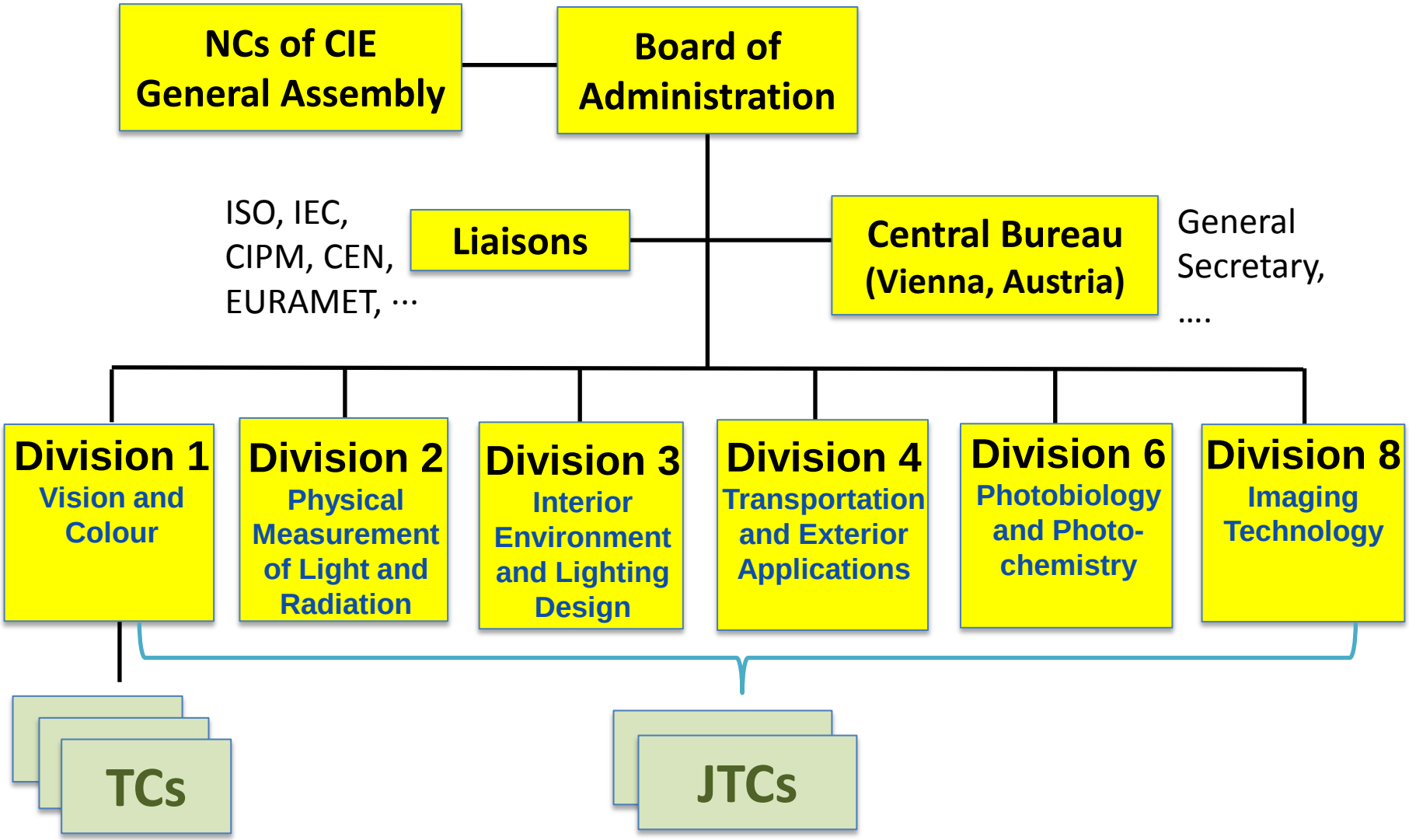
OUTLINE

- ❑ Overview of CIE
- ❑ Solid State Lighting and measurement challenges
- ❑ Challenges in other aspects of SSL
- ❑ CIE's work for future photometry

Overview of CIE

- **Established in 1913**
- **International scientific body** in the area of light and lighting, with ~1500 experts (scientists, standardization officers, lighting engineers, lighting designers, ...)
- **International standardizing body** in the area of light and lighting, recognized by ISO, IEC, and CIPM
- Participation from NMIs, test and measurement laboratories, universities, research institutes, industry,…
- **37 National Committees** and 3 associate National Committees – covering all continents
- ~ 120 **Technical Committees**
- More than 30 publications (technical reports, standards, technical notes) during the past 4 years

Structure of CIE



Overview of CIE
Board of Administration 2015 – 2019

Officers

President	Dr Yoshi Ohno (US)
President-Elect	Dr Peter Blattner (CH)
VP Technical	Dr Erkki Ikonnen (FI)
VP Publications	Prof. Ronier Luo (GB)
VP Standards	Ad de Visser (NL)
VP	Dr Grega Bizjak (SI)
VP	Prof. Yiping Cui (CN)
VP	Prof. Y. Nakamura (JP)
VP	Dr L. Whitehead (CA)
Secretary	Teresa Goodman (GB)
Treasurer	Richard Distl (DE)
General Secretary	Kathryn Nield (Central Bureau)

Division Directors

Div 1	Dr Youngshin Kwak (KR)
Div 2	Dr Peter Blattner (CH)
Div 3	Dr Jennifer Veitch (CA)
Div 4	Dr Dionyz Gasparovsky (SK)
Div 6	Dr John O'Hagan (GB)
Div 8	Po-Chieh Hung (JP)

MoU between CIE and CIPM

AGREEMENT BETWEEN THE
INTERNATIONAL COMMISSION ON ILLUMINATION
AND THE
INTERNATIONAL COMMITTEE FOR WEIGHTS AND MEASURES
2007

Director of the
International Bureau of Weights
and Measures
for the Committee

Date: 2 April 2007

Andrew Wallard

President of the
of the International Commission on
Illumination
for the Commission

Date: 2 April 2007.

- Liaison from CIE to CCPR: Division 2 Director (P. Blattner)
- Liaison from CCPR to CIE: Y. Ohno
- **CIPM is responsible for the units**
- **CIE is responsible for defining action spectra** (including spectral luminous efficiency functions)
- Consult together on issues of **quantities and units and metrology for optical radiation**

CIE is also an **observer in CCU**
(K. Nield, P. Blattner)

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Light-Emitting Diodes (LED)

History of LED

1907 Electroluminescence (from SiC) was discovered by H. J. Round (UK).


Henry Joseph Round

1955 - 1961 Infrared LEDs developed

1962 Red LED invented by Nick Holonyak (USA)


Nick Holonyak

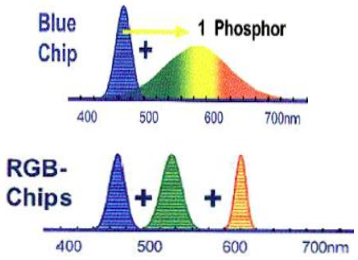
1962 Yellow LED invented by George Craford (USA)


George Craford)

1994 Blue LED (InGaN) invented by S. Nakamura, H. Amano, and I. Akasaki (Japan).


2014 Nobel Prize

White LED possible



Solid State Lighting (LED Lighting)

Incandescent

10~ 15 lm/W
(lumen / watt)

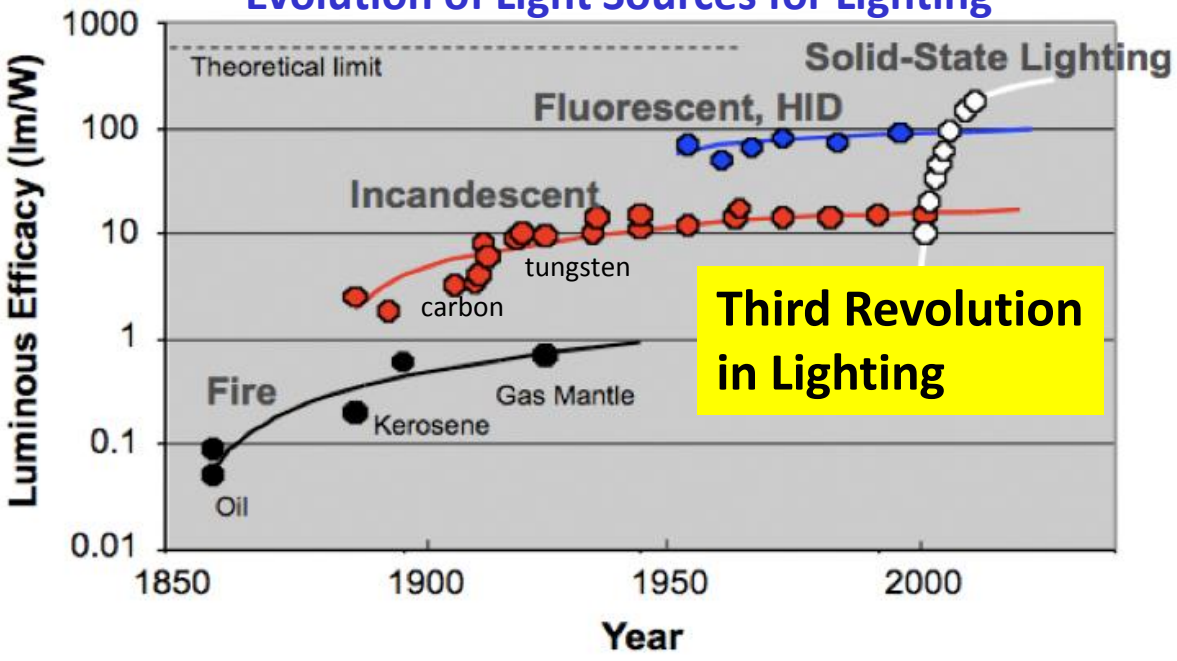
Fluorescent

50~ 90 lm/W

Solid State (White LEDs)

Potential 300 lm/W

Evolution of Light Sources for Lighting



- High energy efficiency
- Long life
- Instant start
- Easy on/off control, dimming

Huge Energy Savings Potential

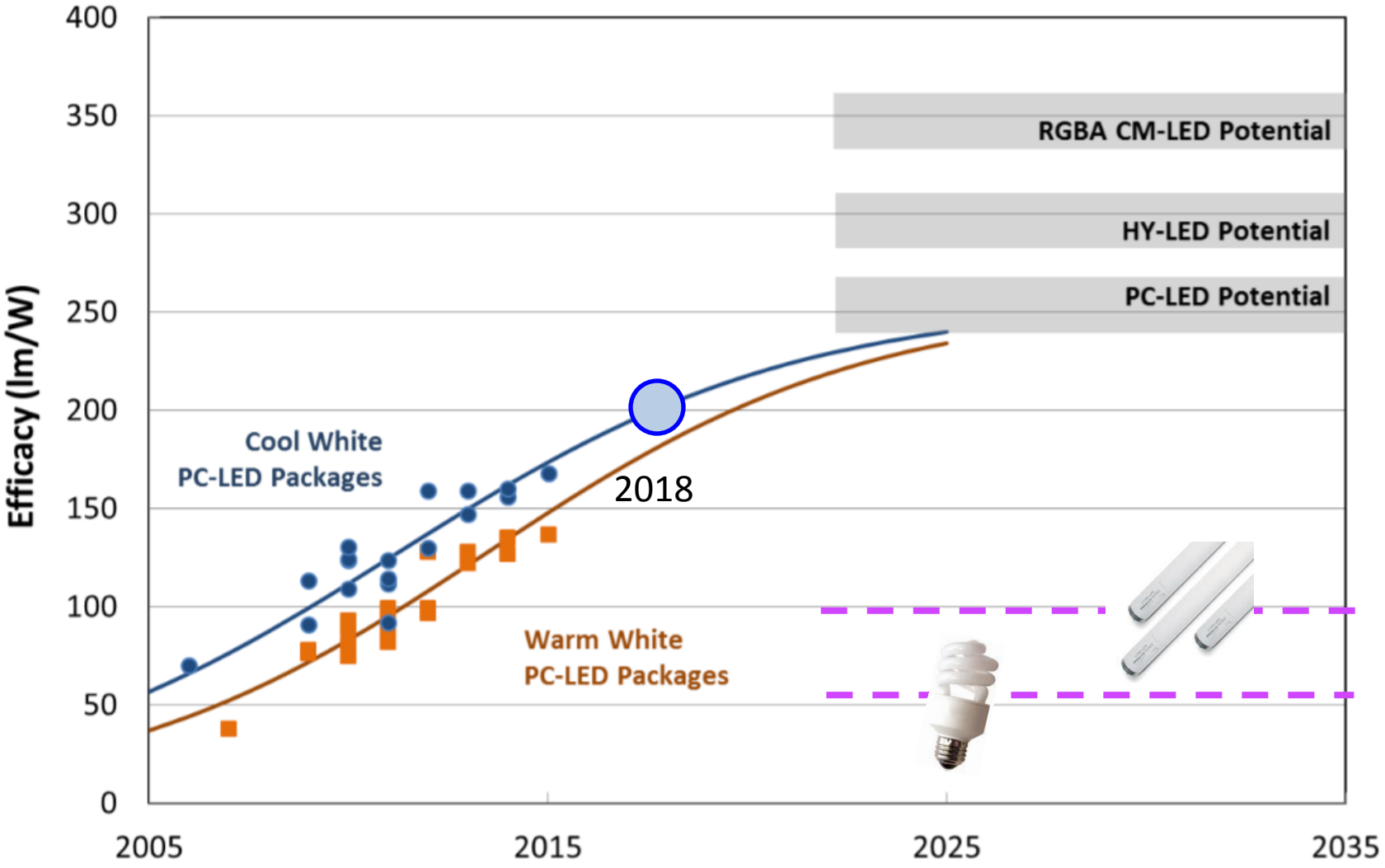
Lighting consumes ~20 % of electricity

~8 % of total energy

(statistics of USA)

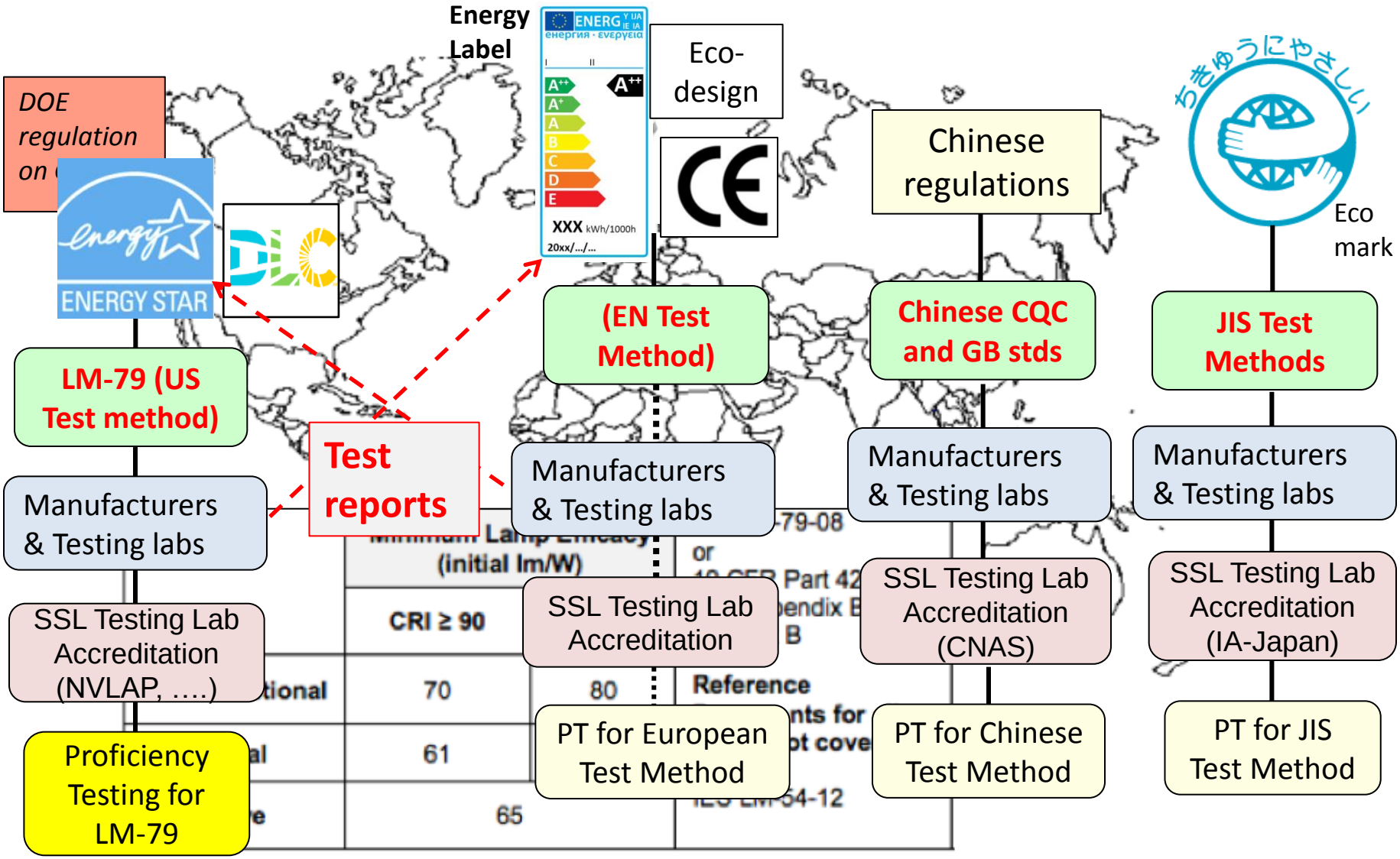
Improvement of luminous efficacy of LED lighting products by 1 % will save electrical energy of value 4 billion Euro /year globally.

White LED lm/W improvements

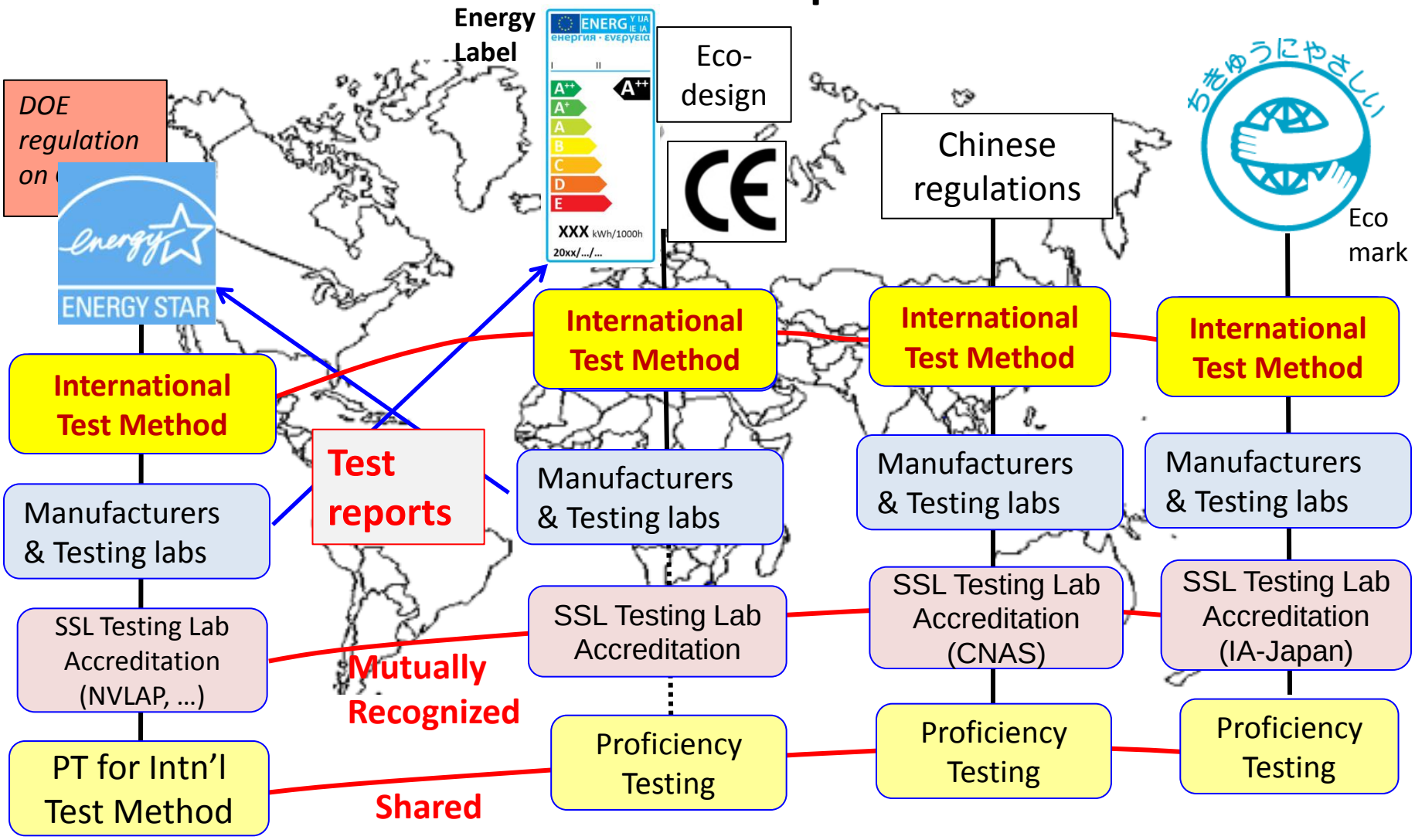


http://www.energy.gov/sites/prod/files/2015/02/f19/craford_innovation_sanfrancisco2015.pdf

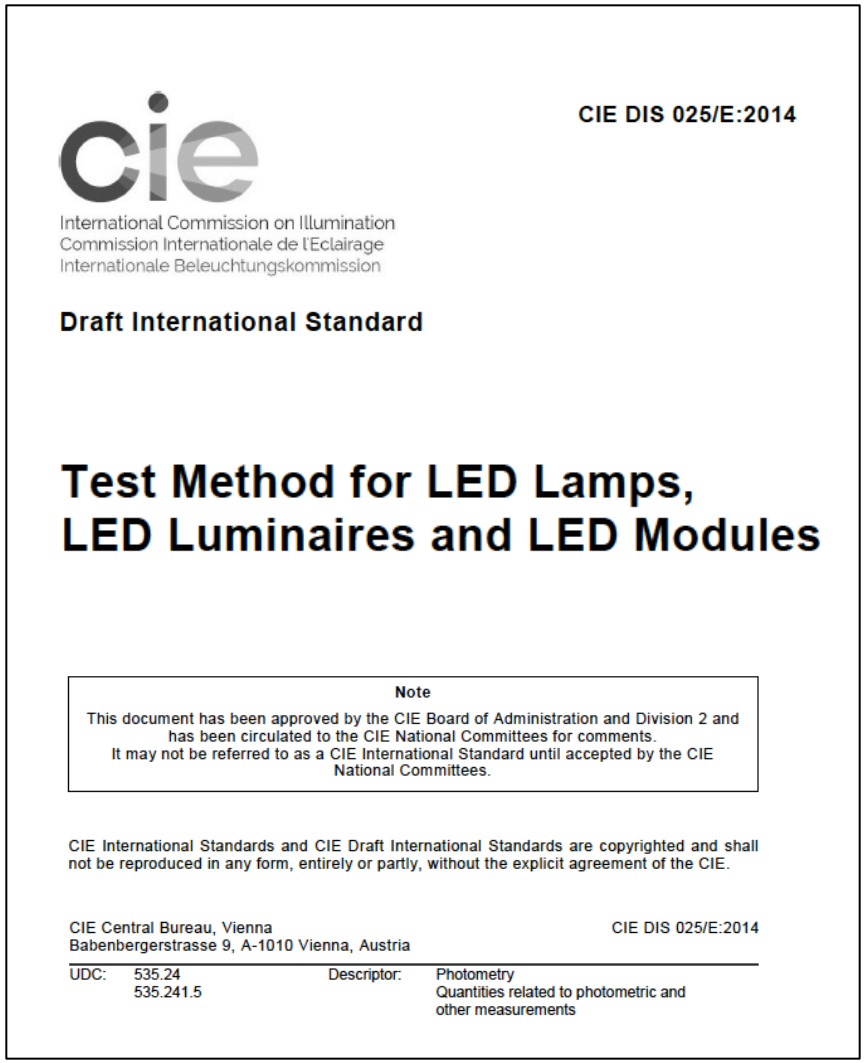
Needs for international harmonization of test methods and accreditation



Future Goal toward free trade and commerce for SSL products



CIE S 025:2015



CIE DIS 025/E:2014

International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

Draft International Standard

Test Method for LED Lamps, LED Luminaires and LED Modules

Note

This document has been approved by the CIE Board of Administration and Division 2 and has been circulated to the CIE National Committees for comments.
It may not be referred to as a CIE International Standard until accepted by the CIE National Committees.

CIE Central Bureau, Vienna
Babenbergerstrasse 9, A-1010 Vienna, Austria
CIE DIS 025/E:2014

UDC: 535.24
535.241.5
Descriptor: Photometry
Quantities related to photometric and other measurements

- **International test method** for LED lamps, LED luminaires, and LED modules
- Developed by TC 2-71 (Ohno chair) with **40 members from 20 countries**. Took 4 years.
- Intended for use in SSL **regulations** and for **testing laboratory accreditation.**
- Joint work with CEN TC169 WG7, that produced a harmonized std:

> EN 13032-4 Lighting Applications — Measurement and presentation of photometric data of lamps and luminaires — Part 4: LED lamps, modules and luminaires

- Test method for European region.

Capacity Building for the Industry

CIE Tutorial and Practical Workshop on LED Lamp and Luminaire Testing to CIE S 025

(1) PTB, Germany, Nov. 2015

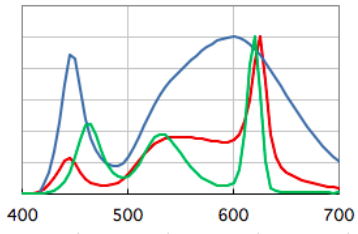
(2) METAS, Switzerland, May 8-11, 2017

(3) VNISI, Moscow, Russia, Nov. 5-7, 2018

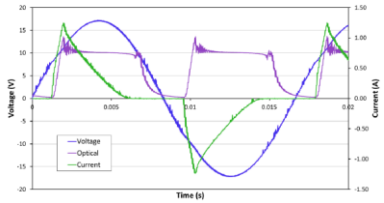
CIE Tutorial and Expert Symposium on Measurement Uncertainties in Photometry and Radiometry for Industry, Vienna, Austria, Sep. 2014

Measurement challenges for LEDs, LED lamps and LED luminaires

- **Variety of products** (components to lamps, luminaires)
- **Sensitive to temperature** (ambient temperature, air movement)
- **Large drift of output** (~20 %) during stabilization



- **Dissimilar spectral distributions**
- **Sensitive to AC power supply characteristics** (impedance, harmonic distortion, power meter error)

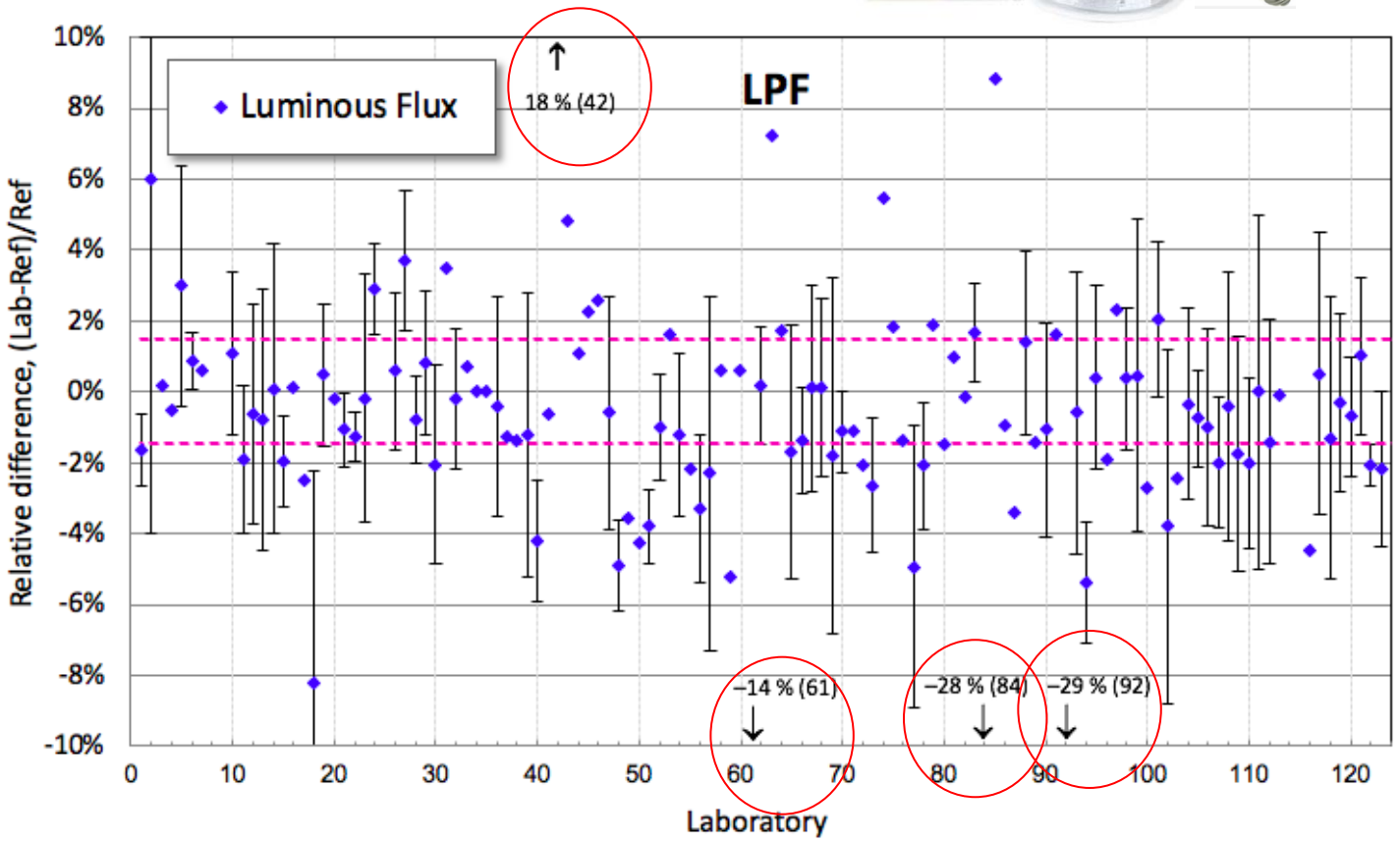


- There are **many quantities** (total luminous flux, luminous efficacy, luminous intensity distribution, active power, colour quantities … in regulations)
- **Uncertainty evaluation** is difficult for many industry laboratories (particularly for color quantities).

Worldwide Interlaboratory Comparison of Measurements of LED lamps (110 Labs)

(IEA 4E SSL Annex, IC 2013)

An example data

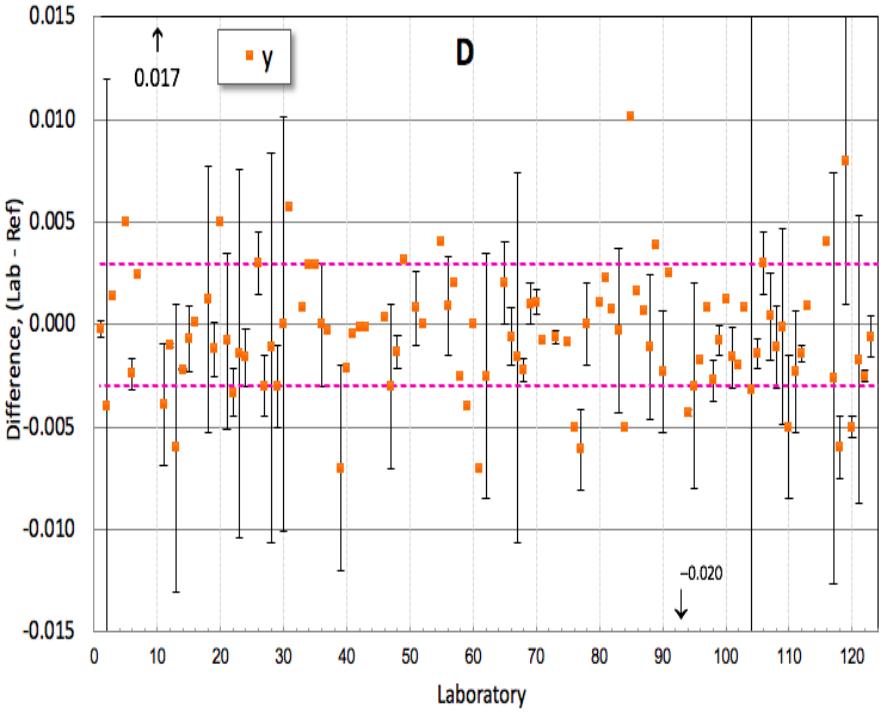


Ref. *IC 2013 Final Report* at http://ssl.iea-4e.org

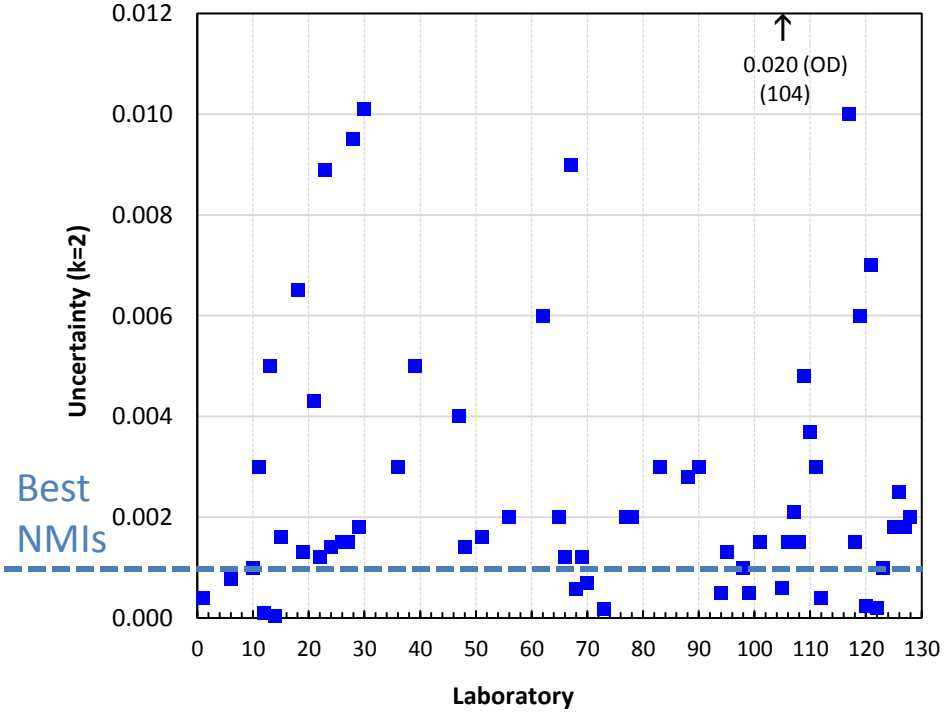
Worldwide Interlaboratory Comparison of Measurements of LED lamps (110 Labs)

(IEA 4E SSL Annex, IC 2013)

Chromaticity y



Reported uncertainty (k=2) for chromaticity y

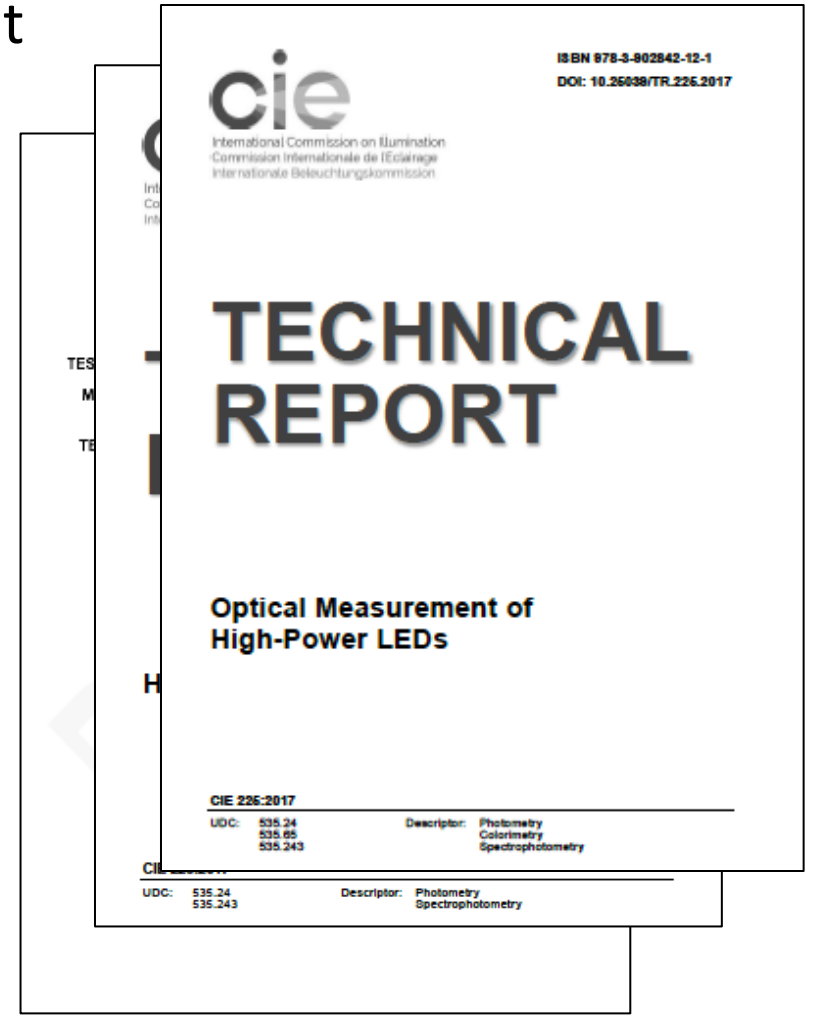


Ref. *IC 2013 Final Report* at http://ssl.iea-4e.org

Other Recent Publications on LED measurement

CIE 226:2017 Optical Measurement of High-Power LEDs

Measure LEDs at a given junction temperature.



CIE 227:2017 High Speed Testing Methods for LEDs

CIE S 025 SP-1 <approval stage> Test Methods for OLED luminaires and OLED light sources

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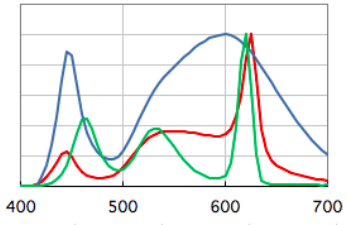
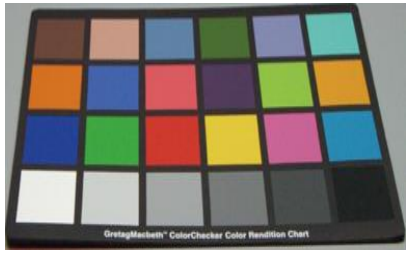
Colour Quality of LED Lighting Sources

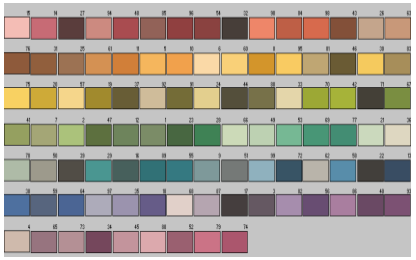


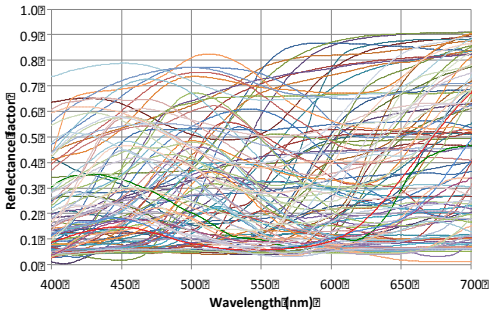


- Variety of Spectra
- New color quality design products

- Existing standard **CIE Color Rendering Index** does not meet the needs for SSL.

- CIE published a new metric: **CIE 2017 Colour Fidelity Index** (CIE 224:2017)

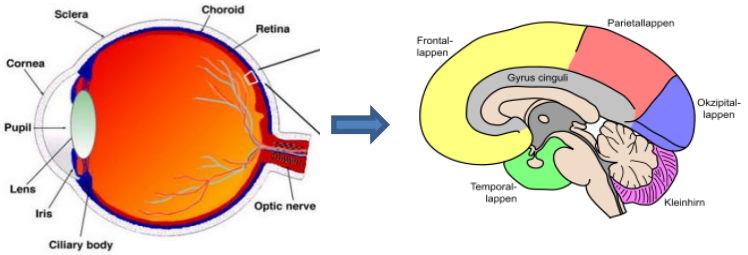




- Work in progress for further metrics.

Non-visual effects of light

Human visual system



Vision (image, colour)

Non-visual effects

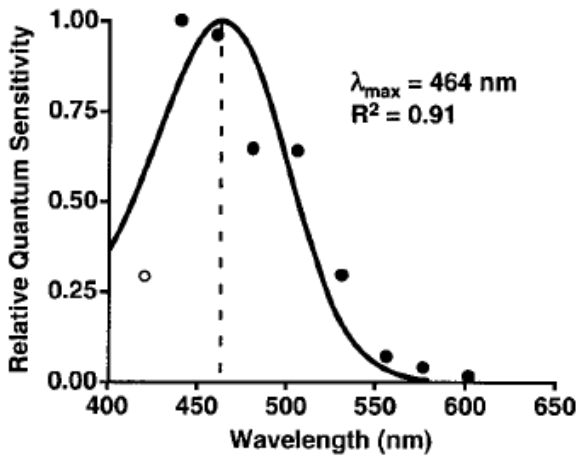
- **sleep-wake (circadian) regulation**
- alertness / comfort
- eye fatigue

5 Photoreceptors

- Cones (L, M, S)
- Rod (scotopic)
- **ipRGC**

(Intrinsically-Photosensitive Retinal Ganglion Cells)

Action spectrum for melatonin suppression



”Healthful Lighting”

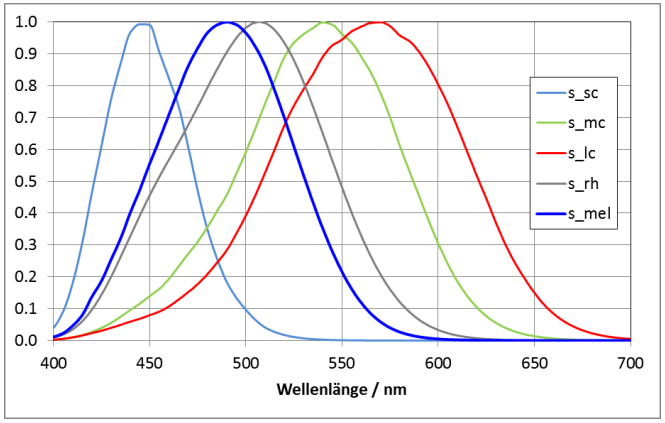
- What light is best for night (for good sleep)?
- What light is best for office work (productivity)?
- How much light is needed for healthful life?

Metrology for Non-visual effects of light

CIE Draft International Standard DIS 026: 2018

CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light

- Defines **action spectra for ipRGC** and other 4 photoreceptors, L,M,S-cones, and Rod.



- Defines **quantities** measured with these action spectra **using SI units**:

Response	Index α	Photoreceptor	Photopigment	α-opic action spectrum, $s_\alpha(\lambda)$
S-cone-opic	sc	Short-wavelength cones	S-cone photopsin (cyanolabe)	$s_{sc}(\lambda)$
M-cone-opic	mc	Medium-wavelength cones	M-cone photopsin (chlorolabe)	$s_{mc}(\lambda)$
L-cone-opic	lc	Long-wavelength cones	L-cone photopsin (erythrolabe)	$s_{lc}(\lambda)$
Rhodopic	rh	Rods	Rhodopsin	$s_{rh}(\lambda)$
Melanopic	mel	ipRGCs	Melanopsin	$s_{mel}(\lambda)$

e.g., melanopic irradiance $E_{e,mel}$ = 65.7 mW/m²

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- ❑ Challenges in measuring many other aspects of SSL
- ❑ CIE's work for future photometry

CIE's Work for Future Photometry

"CIE standard Illuminant for LED"

Photometric instruments

Current practice

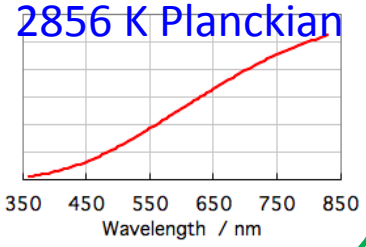
Calibrated against:

Incandescent standard lamps

CIE Source A

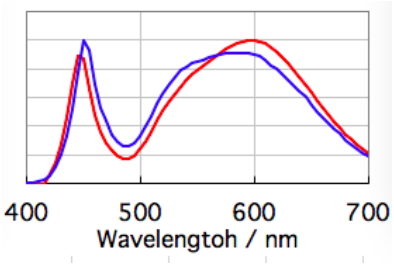
CIE Illuminant A

2856 K Planckian

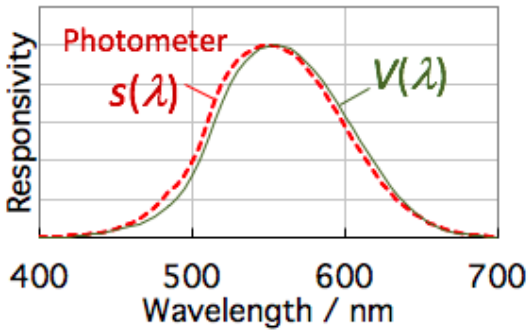


They measure:

LED products



Spectral mismatch errors



CIE's Work for Future Photometry

"CIE Illuminant L"

Photometric instruments

Current practice

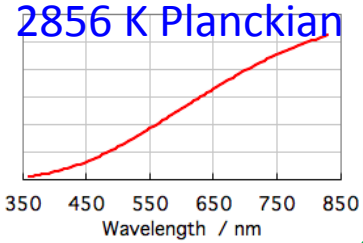
Calibrated against:

Incandescent standard lamps

CIE Source A

CIE Illuminant A

2856 K Planckian

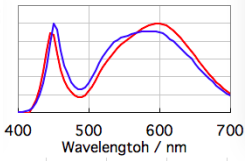


New Practice

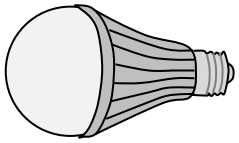
Calibrated against:

They measure:

LED products

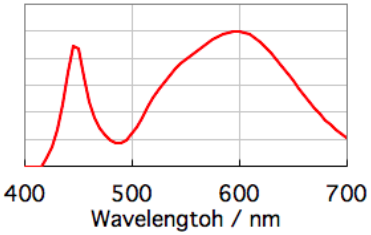


Uncertainties reduced to ~ 1/4



"Source L"

"CIE Illuminant L"



CIE TC 2-90 LED Reference Spectrum for Photometer Calibration

CIE's Work for Future Photometry

Revision of

"Principles Governing Photometry" (BIPM, 1983), and

"Basis of Physical Photometry" (CIE 18.2-1983) (in approval stage)

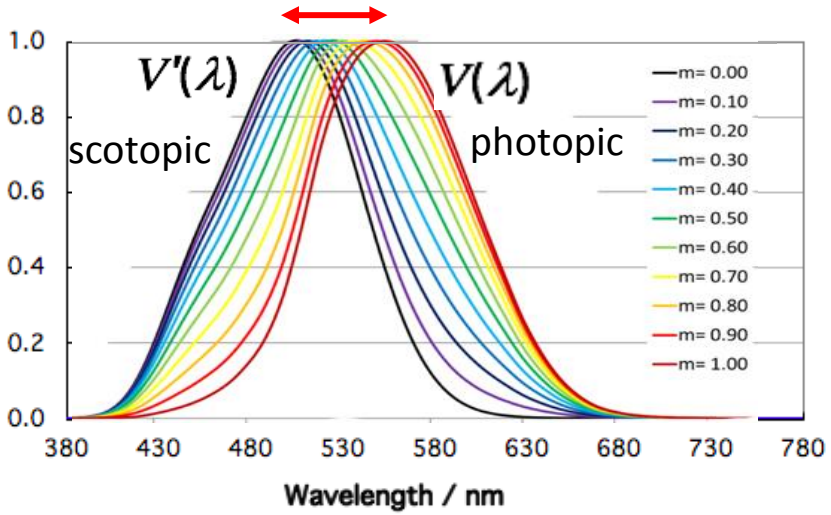
developed by CIE-CCPR Joint TC (JTC-2)

Spectral Luminous Efficiency Function

Scotopic

Mesopic

$V_{mes}(\lambda)$ mesopic, based on CIE 191-2010



Photopic

Very important for LED street/outdoor lighting applications.

Summary

- The revolution in lighting is on-going for huge energy savings globally. CIE supports SSL in **metrology and scientific** aspects.
- There are many other issues (flicker, glare, blue light hazard, connected lighting ..). Further **new standards** are needed for the evolving SSL.
- CIE has **close cooperation** with ISO, IEC, CCPR, IEA and many other organizations. We welcome new countries and other organizations to work together.

THANK YOU

Contact: ohno@nist.gov