Light Source Technologies for indoor & outdoor lighting

LoNNe
ES1204
Loss of the Night Network

Lighting Training School
4-11 October 2015, Berlin

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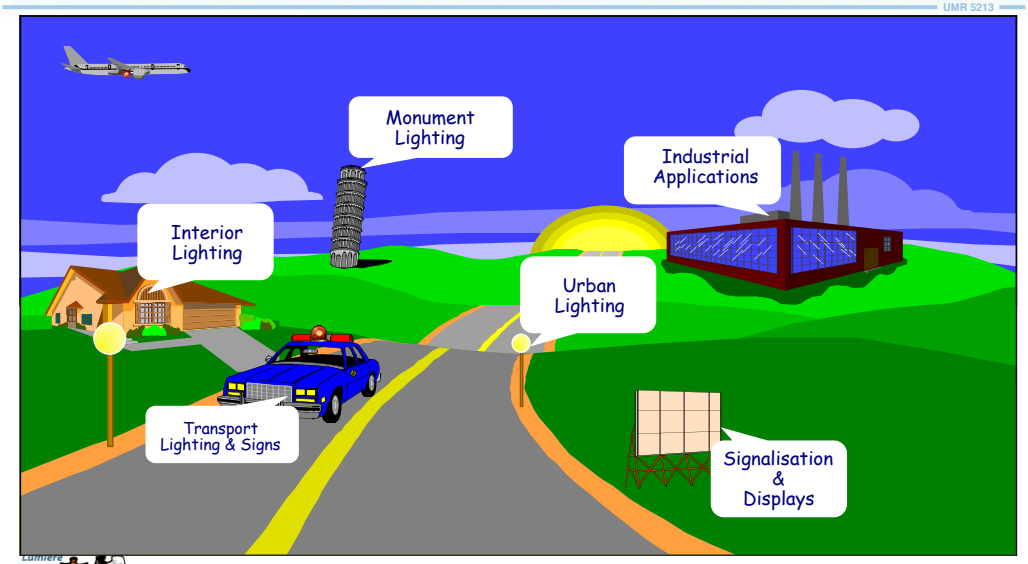
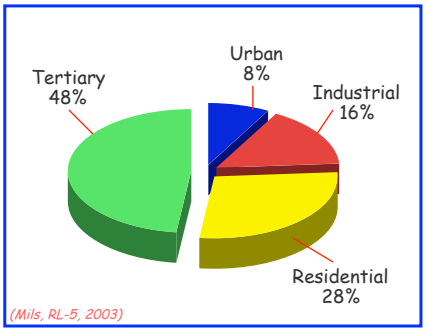
Light sources are everywhere !



Actual situation

- 33 billion lamps operate every day
- 3 140 TWh electricity consumed per annum (inc. losses)
- 16%-19% of worldwide electricity production
- 3% of primary energy used every year for lighting



(Mils, RL-5, 2003)

- ✓ 12% France
- ✓ 9% Germany
- ✓ 21% USA
- ✓ 34% Tunisia
- ✓ 86% Tanzania

Sustainable Development

Full production of FR + IT

200 billion Euros per annum (Europe)

- 1 890 million tonnes of CO_2 per year
- 80 tonnes Hg-contaminated wastes collected in France every week
- Light pollution of skies

Tomorrow ? (2030)...

- 6.5 billion people live on earth (2006) → 8.0 billions (2030) (1.2% growth/annum)
- 1.5 billion without connection to electrical grid (2003) → 1.0 billion (2030)

5 billion people use 2 650 TWh par year
Average energy used for lighting: 430 kWh/person/annum

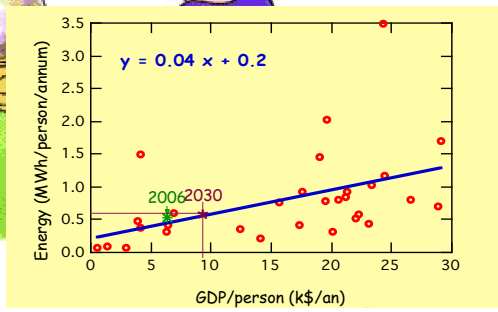
- 6.3 k$ average annual GDP / person (2006)
- 4% annual average GDP growth rate (2006)

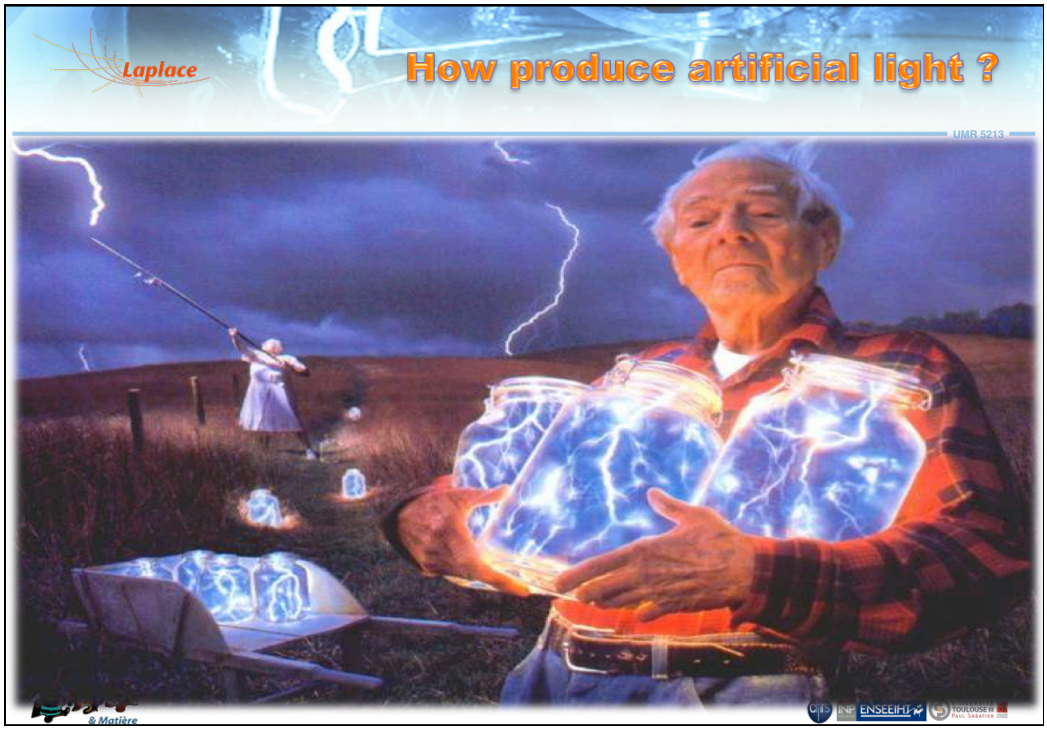
Average 680 kWh/person/annum for 7 billion people in 2030

4800 TWh in 2030

or

1,8 times more energy need...

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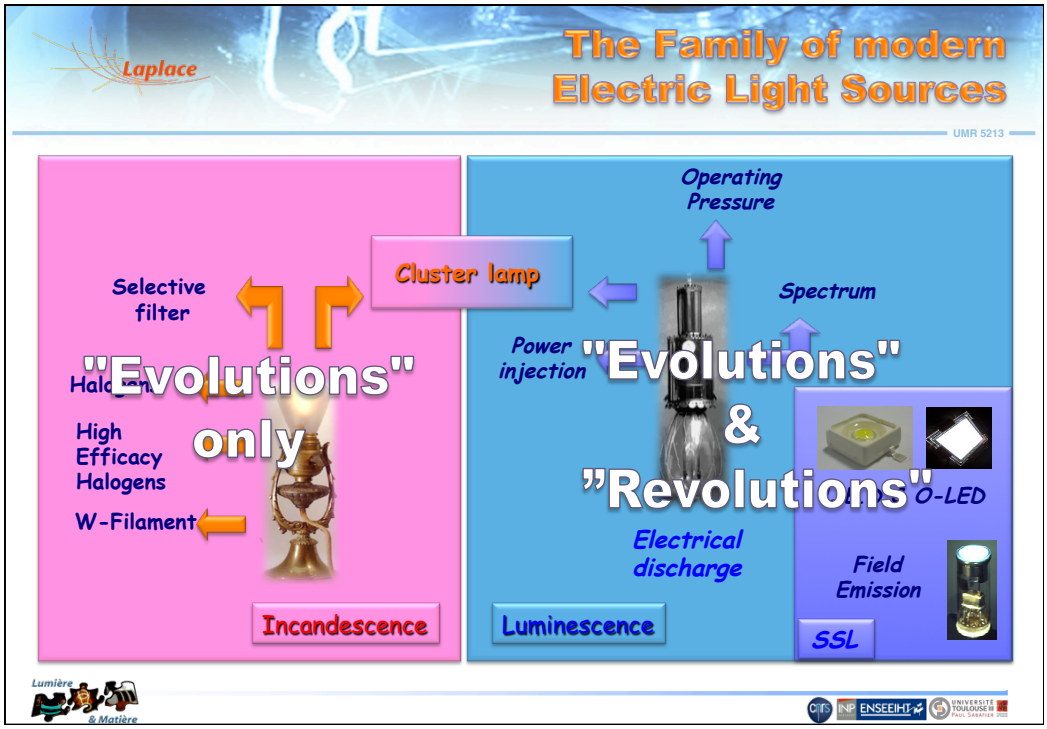
How produce artificial light ?
UMR 5213
& Matière
ENSEEIHT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The Family of modern Electric Light Sources
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Selective filter
Halogen
High Efficacy Halogens
W-Filament
"Evolutions" only
Incandescence
Cluster lamp
Operating Pressure
Spectrum
Power injection
"Evolutions" & "Revolutions"
Electrical discharge
Luminescence
O-LED
Field Emission
SSL
Lumière & Matière
ENSEEIHT

Definitions
Luminous & energetic efficacies

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Photometric quantity (lm/W)

$$\text{Luminous efficacy} = \frac{\text{Luminous Flux}}{\text{Absorbed power}}$$

$$\eta = \frac{\kappa \int_{360nm}^{780nm} P(\lambda)V(\lambda)d\lambda}{P_{in}}$$

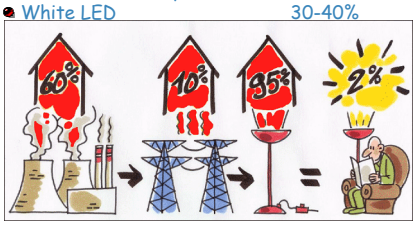
	(lm/W)
Incadescent lamps	12-14
High efficacy halogen lamps	20-25
Compact fluorescent lamp	65
Linear Fluorescent lamp (T5)	110
Ceramic metal halide lamp	70-150
Sodium low-pressure lamp	200
White LED (@ 25°C)	130
Firefly	180

Radiometric quantity (%)

$$\text{Energetic Efficacy} = \frac{\text{Radiative power}}{\text{Absorbed power}}$$

$$\varepsilon = \frac{\int_0^{\infty} P(\lambda)d\lambda}{P_{in}}$$

Linear Fluorescent lamp	20-25%
Incandescent lamp	2- 5%
White LED	30-40%



Definitions:
Colour Temperature (T_{cp})

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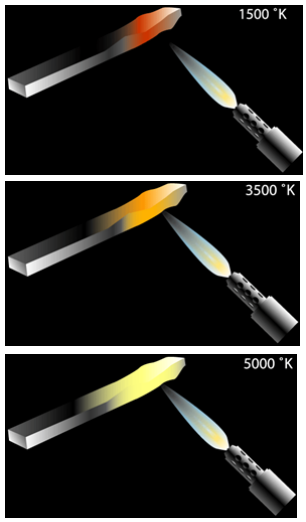
The colour temperature of a source is given by the surface temperature of a black body producing light with similar colour appearance.

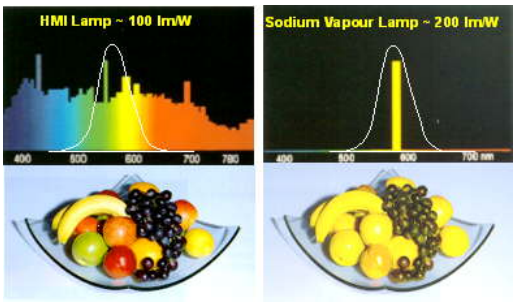
A "warm" light corresponds to a color temperature below 3300 K.

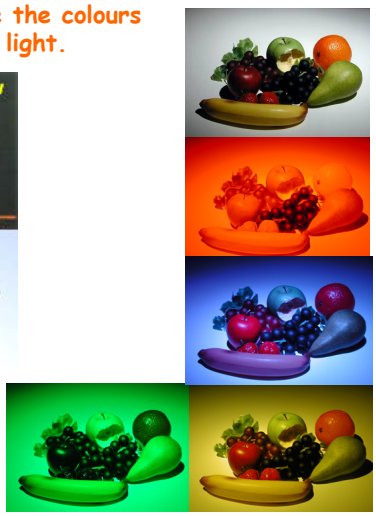
From 5000 K, a light source is referred as "cold" light.



Definitions: Colour Rendering index (CRI or R_a)

Indicates the ability of a light source to reproduce the colours with fidelity compared to a reference white light.





100 = IRC maximum.

0 = No colour visible.

A variation of 5 points is perceptible by humans

$0 < IRC < 100$

Part I - The legacy technology: Discharge Lamps

Plasma - Energy Converter

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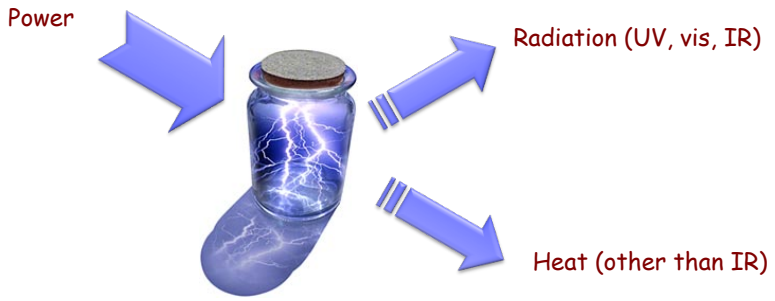
Electrical power injected in a plasma…



…is turn into radiation and heat by the plasma

Discharge lamp families

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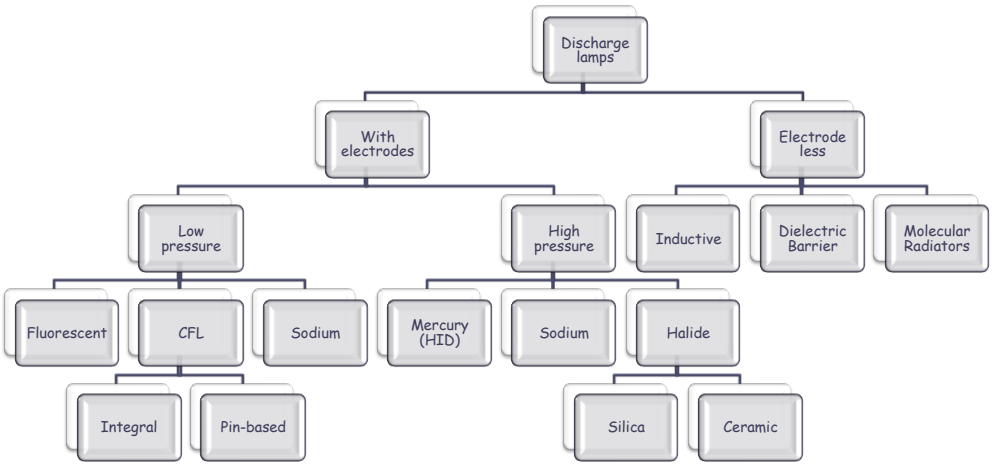
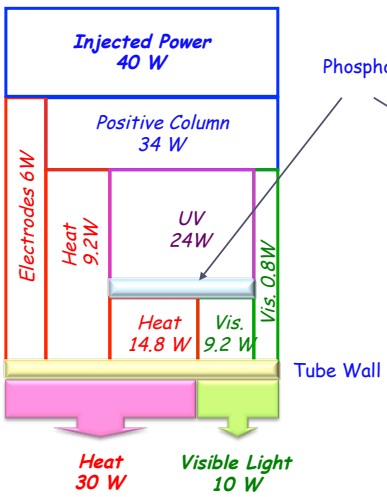


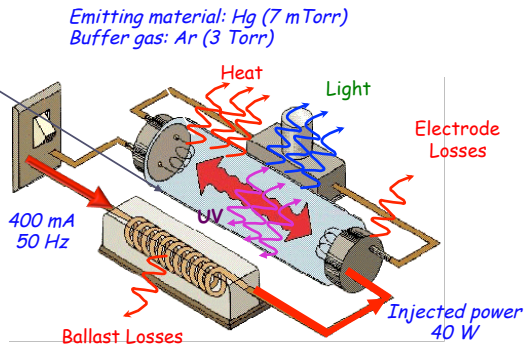
Low pressure lamps

- Fluorescent Tubes (FL)
- Compact Fluorescent Lamps (CFL)
- Low Pressure Sodium (LPS)

RoHS

Fluorescent lamp operation





Energetic efficacy ~25 %

Existing technologies

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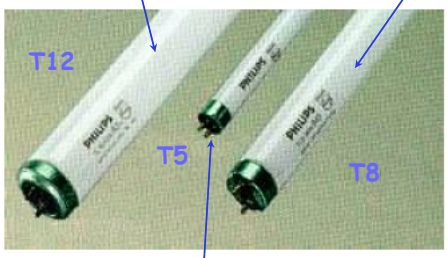
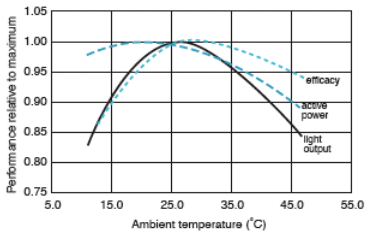
Diametre 38 mm
Luminous Efficacy = 40 - 65 lm/W
MagnetBallast EM
Hallophosphates
Produit en déclin

Diamètre 26 mm
Efficacité lumineuse = 80 à 95 lm/W
Ballast EM ou Eln
Hallophosphates ou triphosphores
Produit mature



Diamètre 16 mm
Efficacité lumineuse = 95 à 105 lm/W
Ballast Eln
Triphosphores
Produit en expansion

Forte sensibilité à la température ambiante



Éclairage intérieur

Spectrum & Colour Temperature

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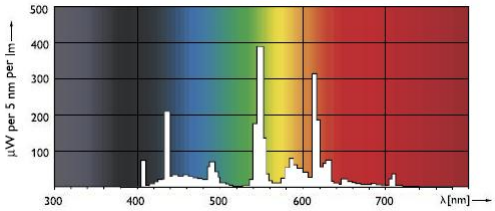

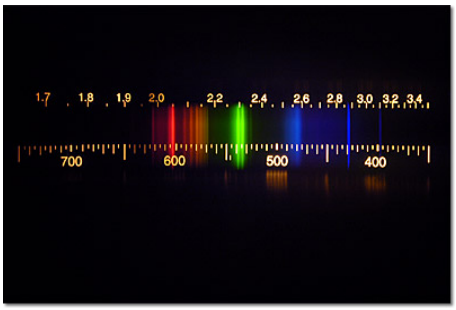

Compact Fluorescent Lamps (CFL)

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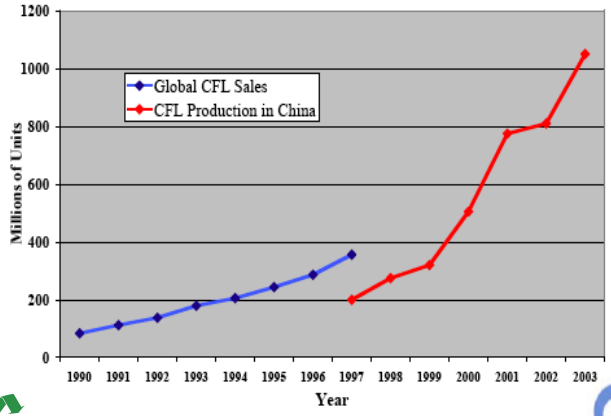
Application: Indoor Lighting

- Slow warm-up
- Sensitive to ambient temperature
- Sensitive to mains voltage variation
- Sensitive to ON/OFF cycling
- Contains mercury



A large choice...

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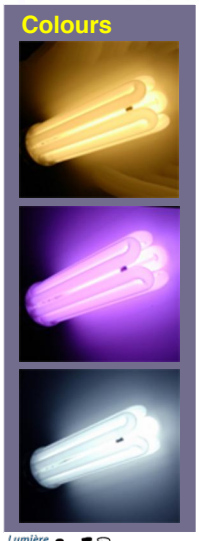

- Luminous efficacy affected
- Lifespan affected
- Warm-up time affected
- Dimming is complex

Equivalence GLS-CFL

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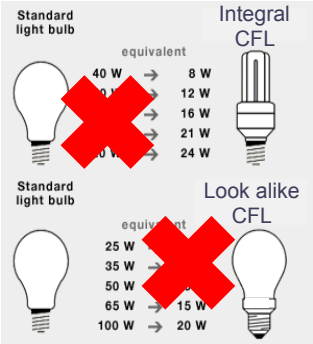
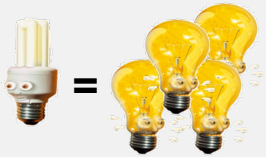


- Power can't be used as indicator
- Luminous flux is just an indicator
- Human eye is sensitive to brightness nor to flux neither to illuminance

A clear incandescent lamp is 150-200 times brighter than a CFL with the same luminous flux



Proposed equivalence: 1 : 4

10 W CFL → 40 W Incand.
15 W CFL → 60 W Incand.
25 W CFL → 100 W Incand.

Low pressure sodium (LPS, SOX, SO/H, SOI)

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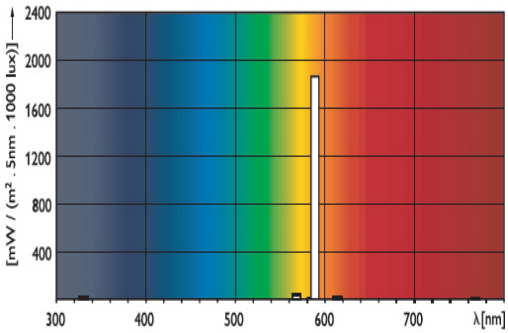
- Power: 18 - 180 W
- Lum. Efficacy: 98 - 200 lm/W
- Energetic Effic.: 40%
- Life span: 12 000 - 14 000 h
- CRI: N/A
- T_{cp}: 1 700 - 1 800 K
- Warm-up time: 15 min

DECLINING MARKET

SOX 36W

exempt RoHS

Application: road lighting



Distribution spectrale MASTER SOX-E 36W

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Universal

High Pressure lamps

- Mercury High Intensity Discharge lamp (HID)
- High Pressure Sodium lamp (SHP)
- Metal Halide lamps (MHL)

exempt
RoHS

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HP-Hg Lamps (HID)

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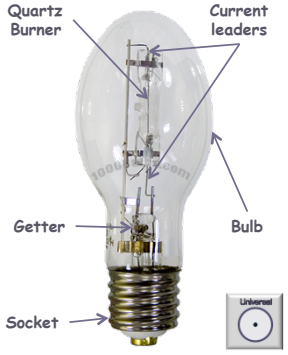
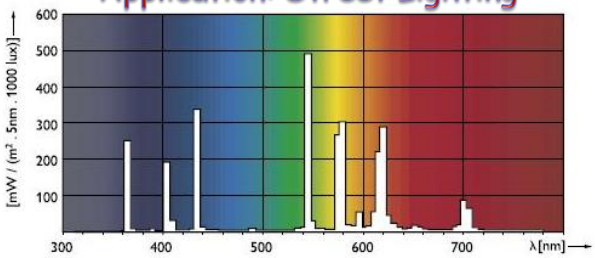
DECLINING MARKET – Forbidden in 2014



Application: Street Lighting



Distribution spectrale de la lampe BTC Riviéra 250W
(Lampe MAZDA ECLAIRAGE)

- Power: 50 - 400 W
- Lum. Efficacy: 25 - 50 lm/W
- CRI: 15 - 60
- T_{cp}: 3000 - 5500 K
- Life Span: 7000-20000 h

Diverses formes

Integrated reflector (PAR)

"black" light

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HP Sodium Lamps

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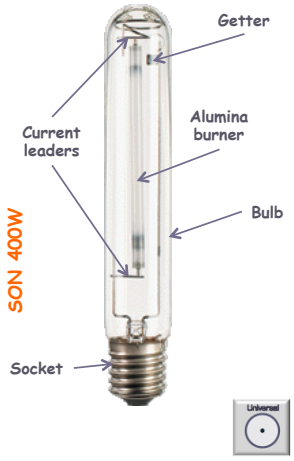
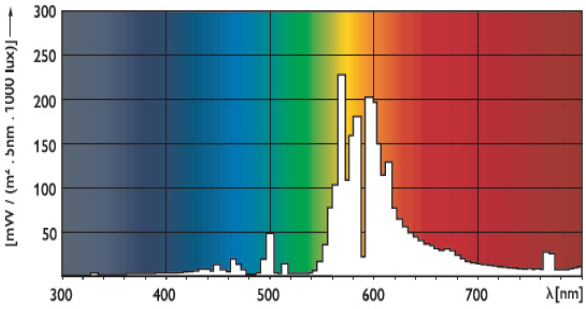


Street Lighting

- Power: 35 - 1000 W
- Lum. Efficacy: 55 - 120 lm/W
- CRI: 30 - 65
- T_{cp}: 2000 - 2300 K
- Life span: 7000-25000 h
- Warm-up lag: 3 - 5 min



Distribution spectrale de la 250W

Pressure, colour & luminous efficacy

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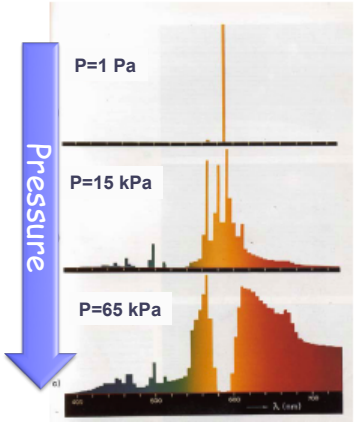
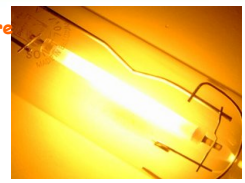
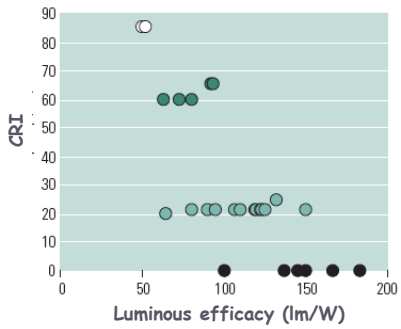


Spectrum broadening increases with pressure

Light turns to "white" and CRI increases

Luminous efficacy decreases





Metal Halide lamps (Silica tube)

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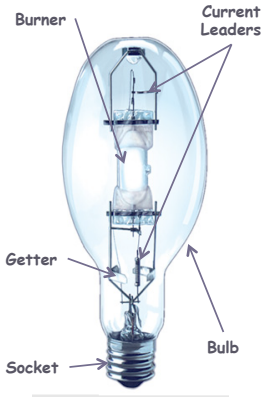
Outdoor/sport Lighting

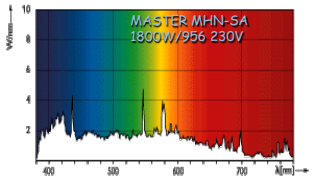


Philips: MASTER MHN-LA

Philips: MASTER MHN-SA

Philips: MASTER White CDO-TT 100W E40

- Power: 50 - 2000 W
- Lum. Efficacy: 54 - 120 lm/W
- CRI: 65-93
- T_{cp}: 3 700 - 6 100 K
- Life span: 4 000 - 8 000 h
- Warm-up lag: 5-10 min



Low Life Span
Limited colour stability

Cearmic Metal Halide Lamps (C-MHL)

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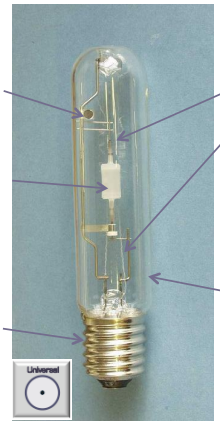
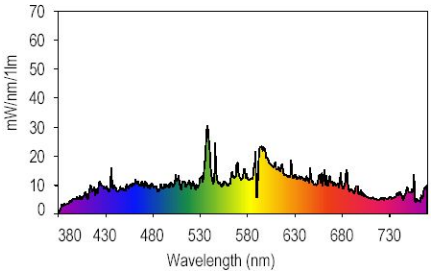
City and Indoor Lighting



GE constantcolor « NumeLiTe »

- Power: 20 - 400 W
- Lum. Efficacy: 70 -150 lm/W
- CRI: 86 - 95
- T_{cp}: 3000 - 4500 K
- Life span: 7000-16000 h
- Warm-up lag: 3-5 min
- Controlled Dimming possible

Spectral Power Distribution 4200 K



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Part II - The new technology: Light Emitting Diodes

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Novel light sources...

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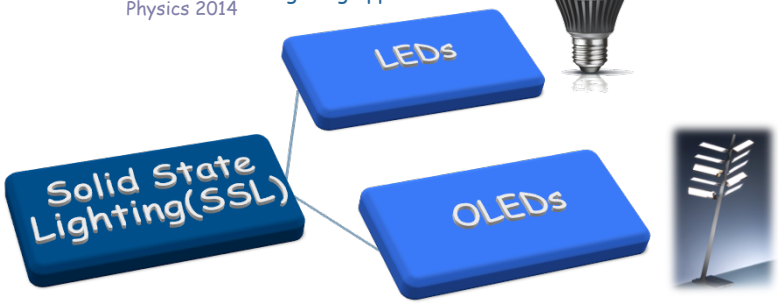
Physics 2014

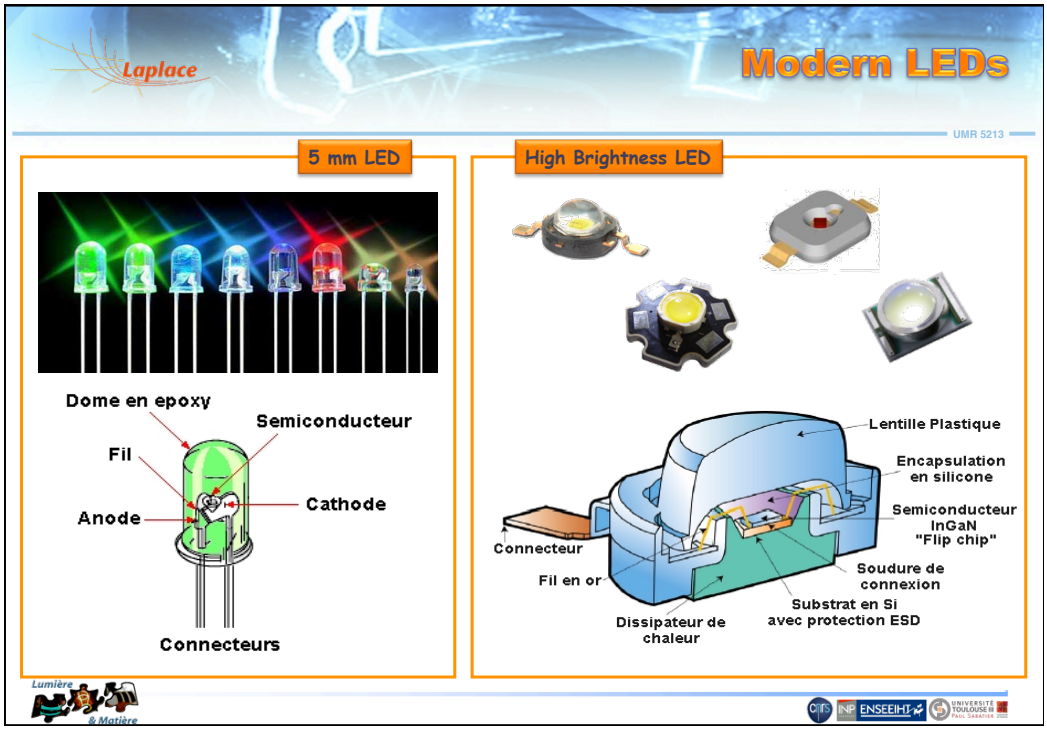
Discovering electrolulinescence 1907
1st coloured LED 1962
1st white LED 1995
Lighting applications 2000



Chemistry 2000

Discover current conducting polymers1977
1st OLED (thin film) 1987
Lighting applications2010

Lumière & Matière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Modern LEDs
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5 mm LED
High Brightness LED
Dome en epoxy
Semiconducteur
Fil
Anode
Cathode
Connecteurs
Lentille Plastique
Encapsulation en silicone
Semiconducteur InGaN "Flip chip"
Connecteur
Fil en or
Soudure de connexion
Substrat en Si avec protection ESD
Dissipateur de chaleur
Lumière & Matière
ENSEEIHT

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LED's advantages
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True,
but are these advantages enough?
High luminance
Excellent saturated colors
High luminous efficacy
High conversion efficacy
Small dimensions & light weight
Robust
Multi-chip
Robust
Power = 50W
Colour = White
Lumens = 1800 lm
CCT = 6500 K
Lumière & Matière
ENSEEIHT

LEDs produce only pure colours

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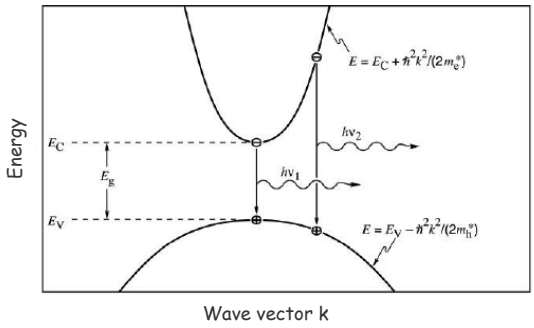
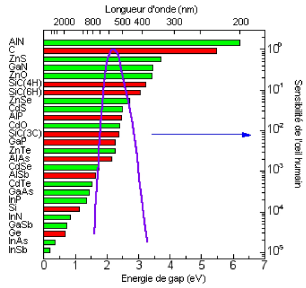


- An LED is nearly monochromatic
- Spectral width is very small
- The colour changes with junction temperature



$$\Delta E_{FWHM} = 1{,}8 k_B T \qquad \nu_{max} = \frac{E_g}{h} + \frac{k_B T}{2h} = \frac{c}{\lambda_{max}}$$

Producing white light (1)

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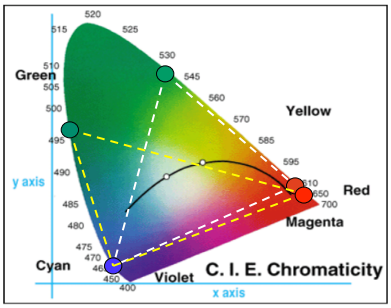
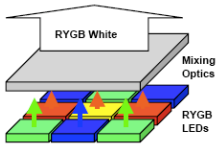
1. Colour mixing (RGB or more)



- Limited gamut
- Unacceptable colour temperature
- Low Colour Rendering Index (CRI)
- Important optical losses
- Non-intuitive control



Producing white light (2)

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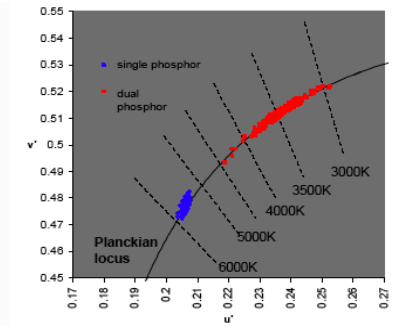
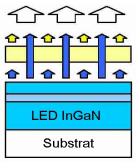
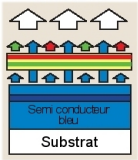
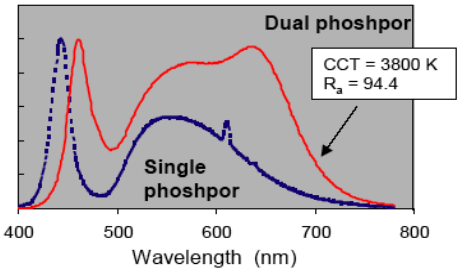
2. Mixing Blue + Yellow







- Low conversion efficacy
- Yellow "Hallo" effect
- Bad CRI (at least with B-Y mixing)
- Unpleasant colour temperature



Producing white light (3)

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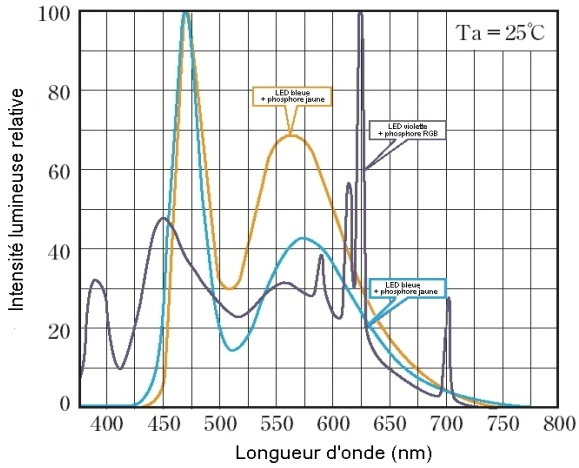
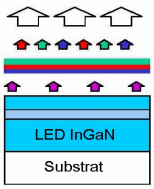
3. UV-LED + Phosphors





- Colour is depending on phosphor
- Nice CRI
- Moderate efficacy

- UV solarisation of plastic parts
- Low UV power

Luminous efficacy increases and price decreases

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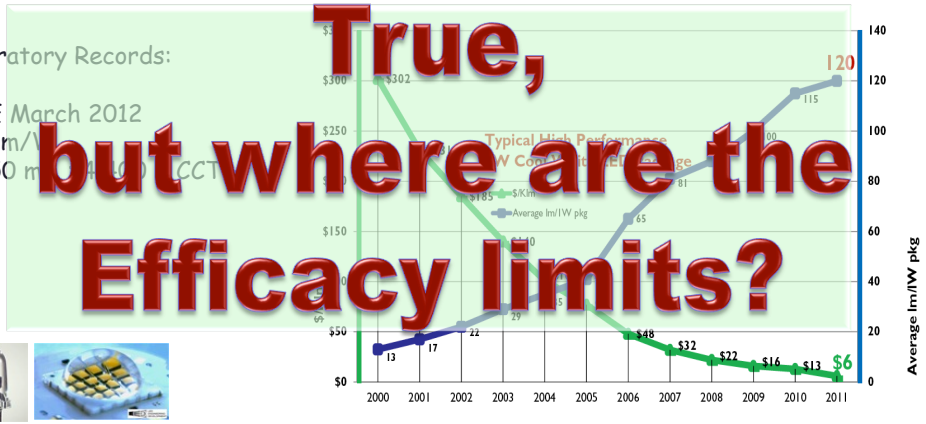
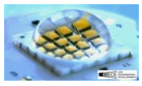
Laboratory Records:

CREE March 2012
276 lm/W
@ 350 mA 4100 CCT



True, but where are the Efficacy limits?



These are the limits

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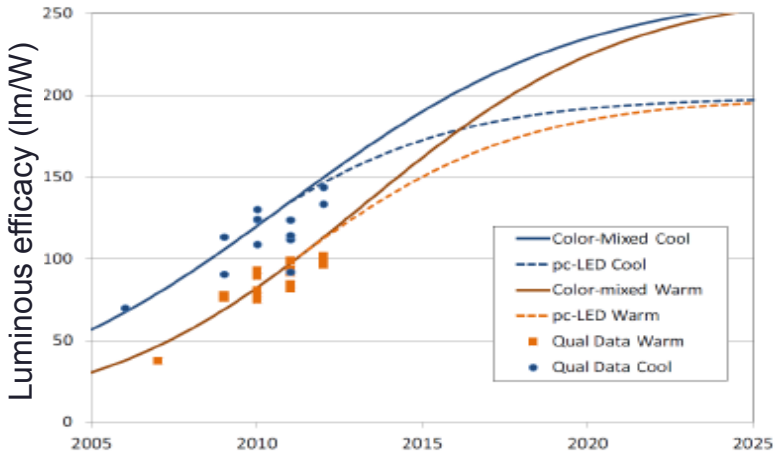

Solid-State Lighting Research and Development Multiyear Program Plan for 2012; prepared for: Lighting Research and Development, Building Technologies Program, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, April 2012

Temperature affects seriously LEDs

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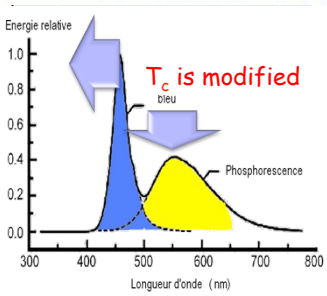
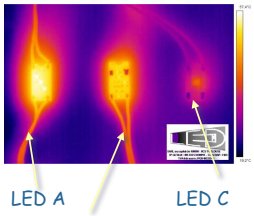
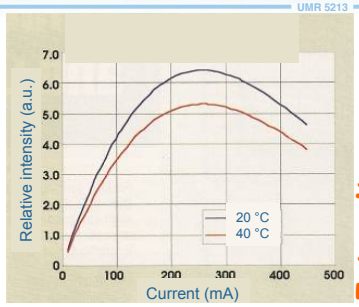
Spectrum

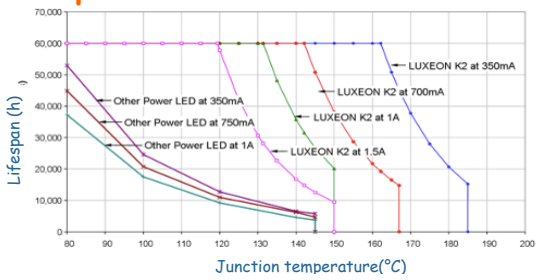




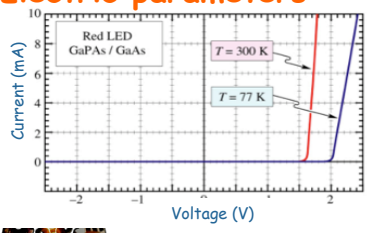


Intensity

Lifespan



Electric parameters



LEDs aren't cold !!!

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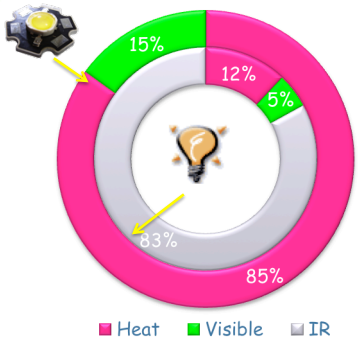
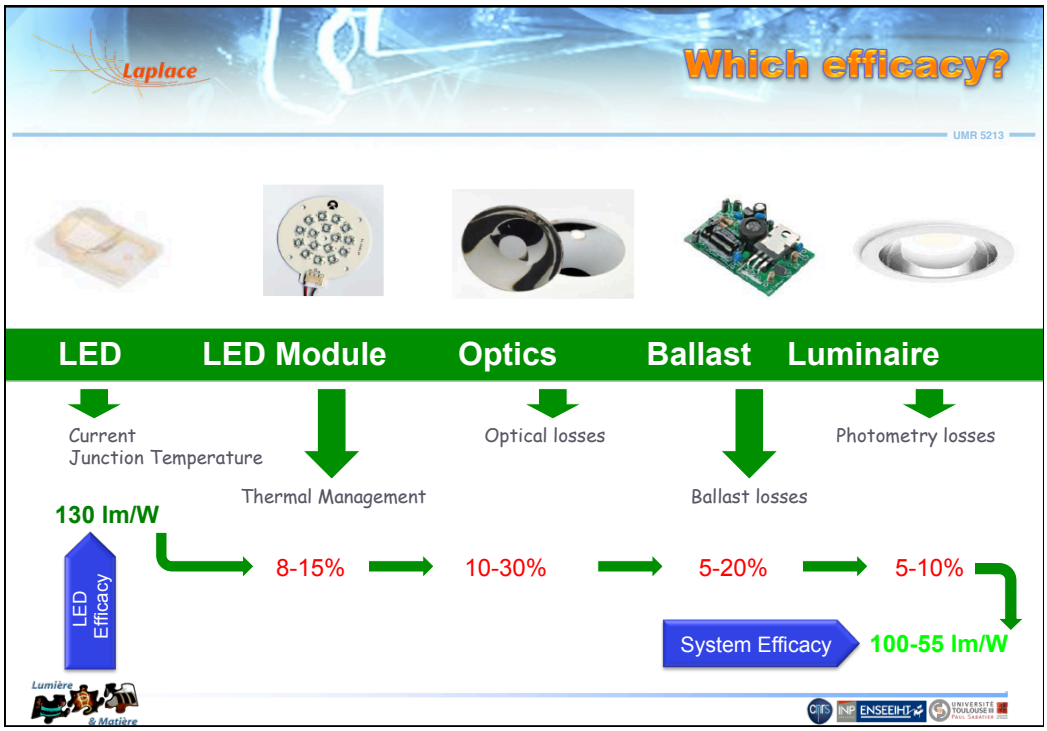


For evacuating conducted heat a sink in need

Increasing power leads to more heat to evacuate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Which efficacy?
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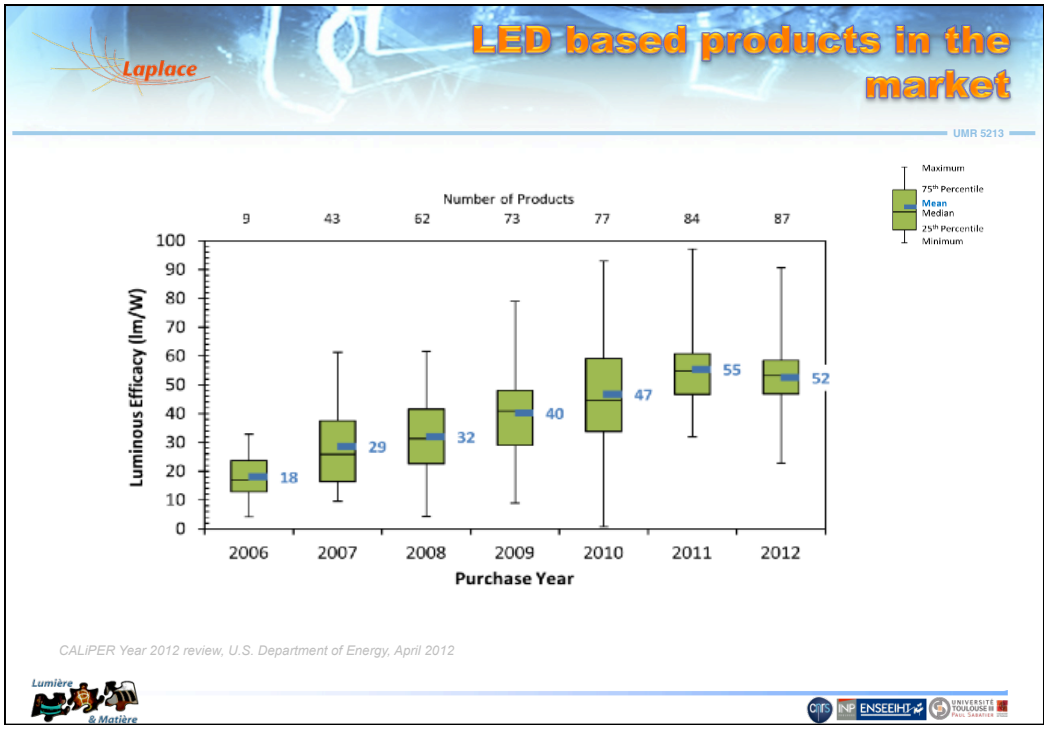
LED
LED Module
Optics
Ballast
Luminaire
Current
Junction Temperature
Thermal Management
Optical losses
Ballast losses
Photometry losses
130 lm/W
LED Efficacy
8-15%
10-30%
5-20%
5-10%
System Efficacy
100-55 lm/W
Lumière & Matière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LED based products in the market
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Number of Products
9
43
62
73
77
84
87
Maximum
75th Percentile
Mean
Median
25th Percentile
Minimum
Luminous Efficacy (lm/W)
100
90
80
70
60
50
40
30
20
10
0
18
29
32
40
47
55
52
2006
2007
2008
2009
2010
2011
2012
Purchase Year
CALiPER Year 2012 review, U.S. Department of Energy, April 2012
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At system level, quality is a major concern!

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- Bad system integration
- Bad thermal management
- Low quality passive components
- Bad wiring & electrical hazard risks
- Unacceptable harmonic distortion
- Photo-colorimetric problems & flicker
- False statements & wrong declarations

NAME OF PUBLICATION	PLACE OF PUBLICATION	DATE OF PUBLICATION
FINANCIAL CHRONICLE	NEW DELHI	28,JULY 2014

Poor quality imports give India a bad experience of LED lamps

S SHYAMALA
Chennai

LED technology is considered the way forward in lighting but low-cost and inferior-quality imported products are severely harming the segment, say industry players.

India needs to urgently formalise product standards and boost local production to popularise the product, they say.

"Customers have had a lot of bad experience because of poor Chinese imports. Industry players through ELCOMA (electric lamp and component manufacturers association) have been pushing for BIS standards for LED products. Earlier, CFLs took that route and it helped curb sales of poor-quality goods. We should follow the same path on LEDs," said Arun Gupta, managing director of NTL Electronics, a Noida-based lighting components maker.

According to Frost & Sullivan, the LED lighting industry in India earned revenues of over $142.8 million in 2012 and it is expected to reach $1.2 billion in 2018.

BULLISH MARKET: The LED lighting industry in India earned revenues of over $142.8 million in 2012

The growing interest in energy-efficient technology, green buildings and the urge to reduce energy bills have lent momentum for the B2B and B2C LED market in India.

Gupta said Indian consumers have burnt their fingers by buying cheap imported products. LED product failures have been high and, hence, the adoption continues to be low.

The huge reliance on LED imports as well as finished lighting products is a critical challenge for India, as insufficient demand is discouraging local manufacturers.

Government agencies such as the ministry for renewable energy and the bureau of energy efficiency have been trying to raise awareness of the benefits of LED technologies and even distributing free solar LED lanterns in some villages.

"It is a chicken-and-egg story. Manufacturers will produce locally when there is enough demand; customers will buy more when there is enough supply. The critical inflection point may come when prices go down further," says Rajesh Kocchar, president of TISVA, the lighting brand of Usha International.

"For example, an LED lamp now costs Rs 500. The cost needs to go down by half to be affordable for the masses. LEDs will then achieve the expected growth in India," Kocchar said.

shyamalasethuraman@mydigitalfc.com

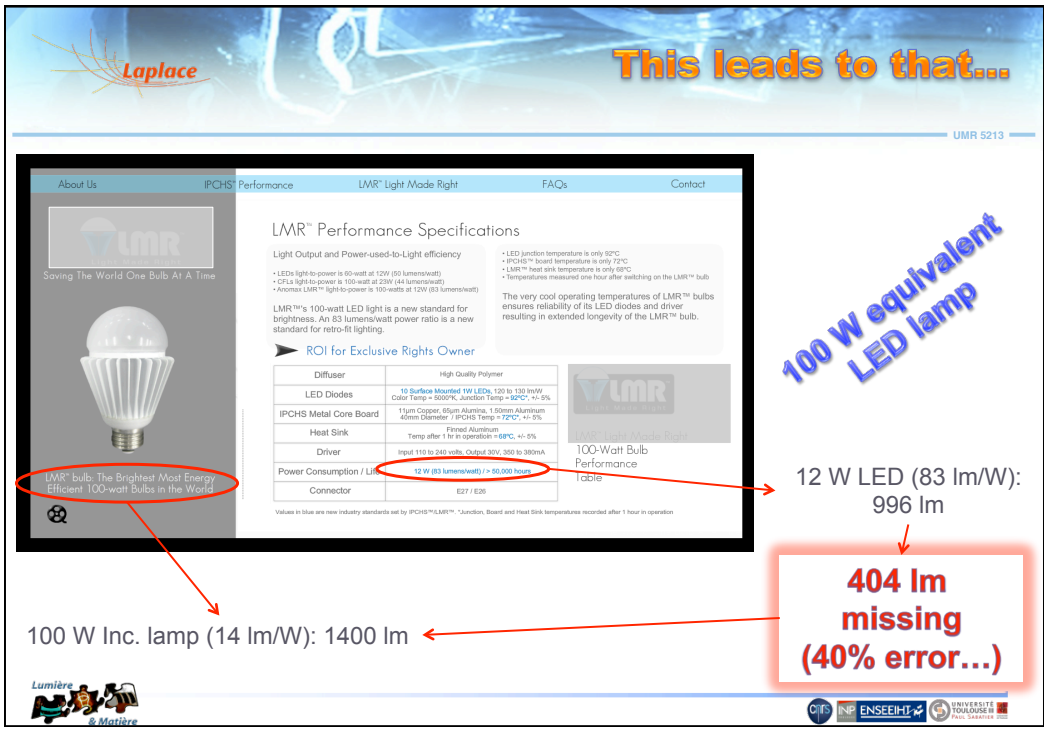
The huge reliance on LED imports as well as finished lighting products is a critical challenge for India

The market becomes mature...

Actual status of world's standardization...

The No. 1 enemy of the LED is the unscrupulous salesman!

000247


Laplace
This leads to that...
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About Us
IPCHS Performance
LMR Light Made Right
FAQs
Contact
Saving The World One Bulb At A Time
LMR Performance Specifications
Light Output and Power-used-to-Light efficiency
ROI for Exclusive Rights Owner
LMR bulb: The Brightest Most Energy Efficient 100-watt Bulbs in the World
100-Watt Bulb Performance Table
100 W equivalent LED lamp
12 W LED (83 lm/W): 996 lm
404 lm missing (40% error...)
100 W Inc. lamp (14 lm/W): 1400 lm
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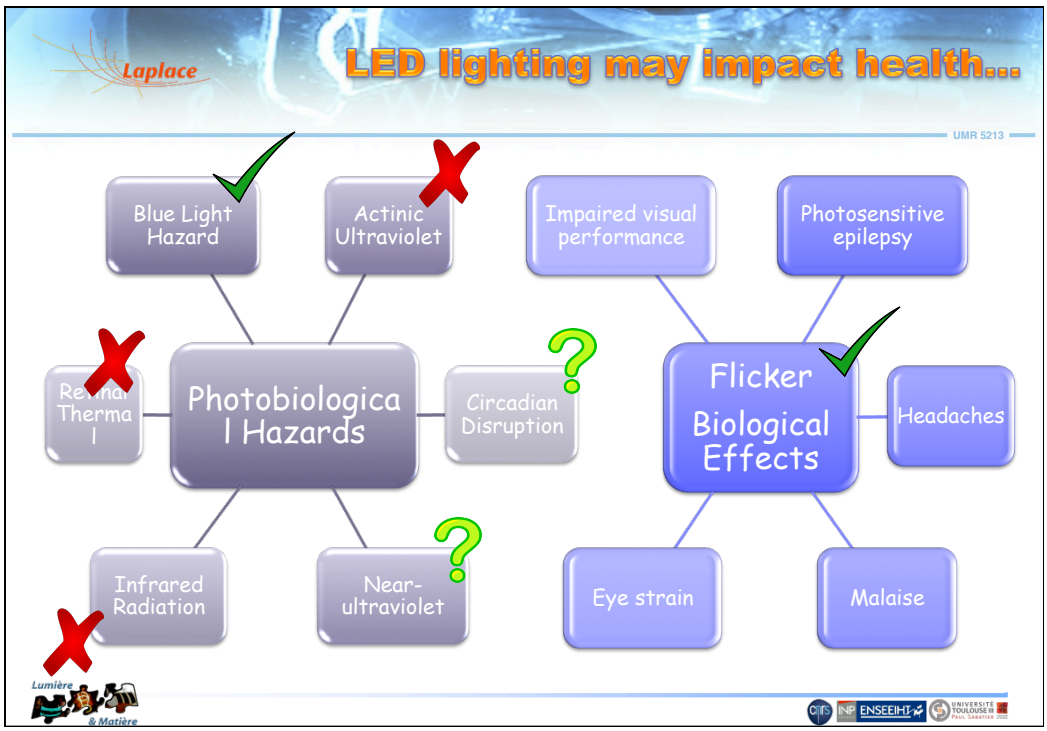
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LED lighting may impact health...
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Blue Light Hazard
Actinic Ultraviolet
Impaired visual performance
Photosensitive epilepsy
Retinal Thermal
Photobiological Hazards
Circadian Disruption
Flicker
Biological Effects
Headaches
Infrared Radiation
Near-ultraviolet
Eye strain
Malaise
Lumière & Matière

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Blue Light Hazard effects
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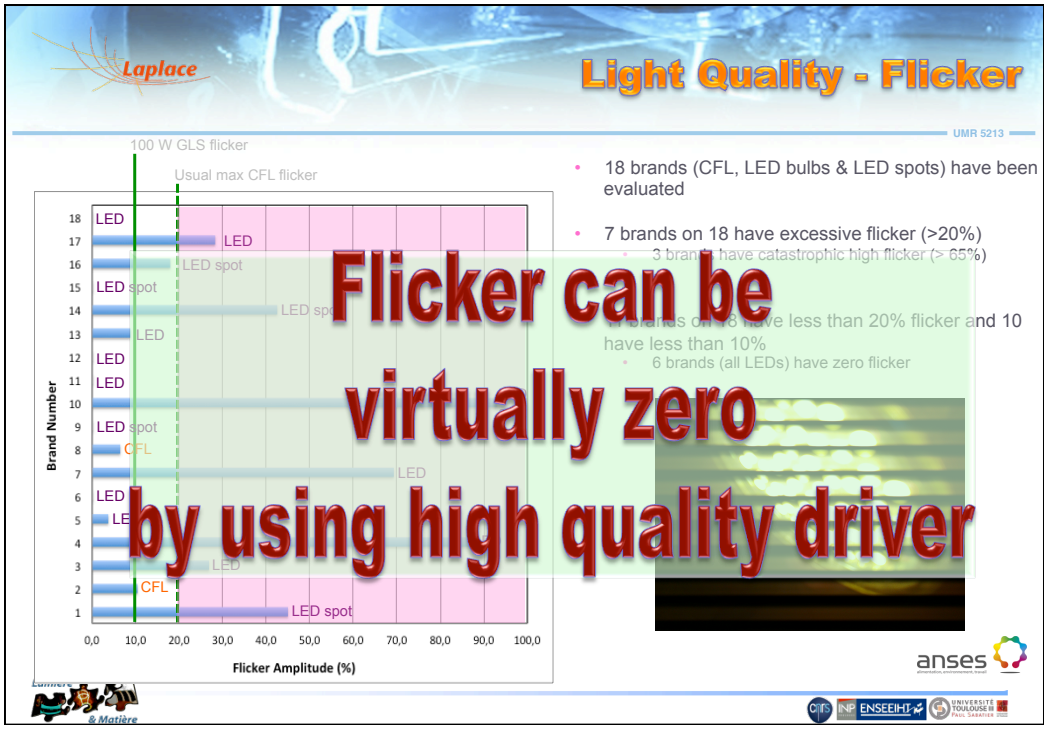
Some LEDs have luminance higher than 10⁶ cd/m²…
(Sun: 1.6x10⁹ cd/m²)
anses
Blue light hazard can be avoided by increasing distance from the light source
Impact on Retina
prolonged exposure
LED (3000K)
1
0,5
0
400nm
500nm
600nm
700nm
Single-die blue LED
Radiant flux of 0.5 W
Maximum permissible exposure time is between 15 s and 20 s
Exposure limit
Exposure time (s)
Lumière & Matière
ENSEEIHT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Light Quality - Flicker
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100 W GLS flicker
Usual max CFL flicker
Brand Number
Flicker Amplitude (%)
0,0
10,0
20,0
30,0
40,0
50,0
60,0
70,0
80,0
90,0
100,0
LED
LED spot
CFL
• 18 brands (CFL, LED bulbs & LED spots) have been evaluated
• 7 brands on 18 have excessive flicker (>20%)
• 3 brands have catastrophic high flicker (> 65%)
• 11 brands on 18 have less than 20% flicker and 10 have less than 10%
• 6 brands (all LEDs) have zero flicker
Flicker can be virtually zero by using high quality driver
anses
Lumière & Matière
ENSEEIHT

Laplace

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OLEDs - Organic Light Emitting Diodes

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Laplace

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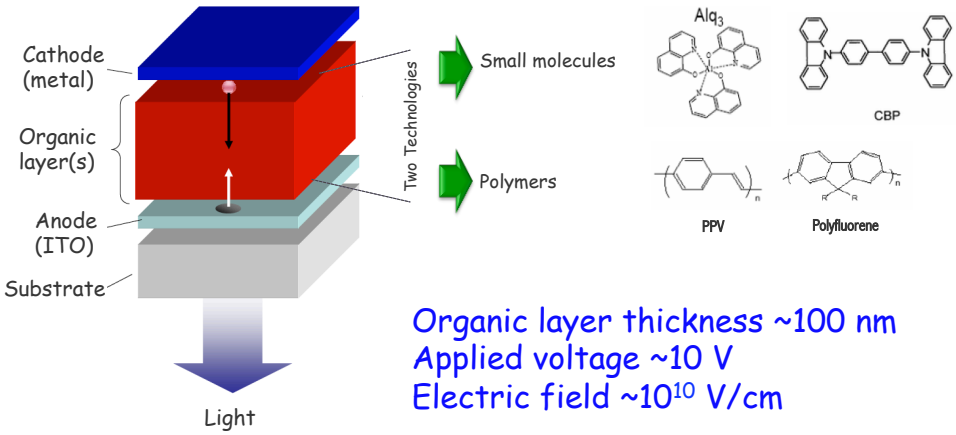
To a practical way...

An OLED is based on a stack of organic semi-conductors



Organic layer thickness ~100 nm
Applied voltage ~10 V
Electric field ~10^{10} V/cm

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What is an OLED?

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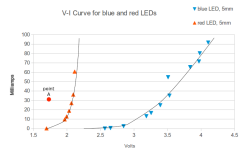
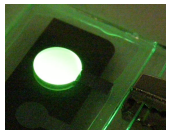
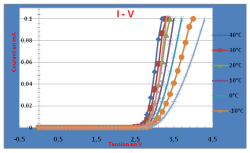
An OLED is a Light Emitting Diode based on organic semi-conductors



- Inorganic semi-conductor junction
- AC rectifier character due to PN junction
- Excitons (e^--holes) are delocalised in the crystal: Energy bands
- Electrical mobility decreases with temperature
- Doping is necessary for getting free carriers
- Hetero-structures are limited due to crystal mesh mismatch
- Almost monochromatic emission linked to the energy gap

LED





- Organic semi-conductor stack
- AC rectifier character due to work function difference between the two electrodes used for the carrier injection
- Excitons (e^--holes) are localized to single molecule
- Electrical mobility increases with temperature but stays very low
- Doping is not necessary for getting free carriers: they are injected from electrodes
- Structures choices are almost unlimited
- Large emission covering visible spectrum (molecular bands, mixing…)

OLED

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All colours are possible!

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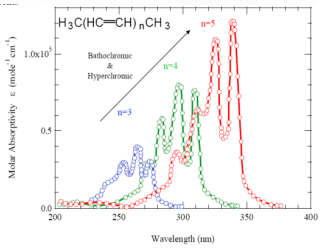
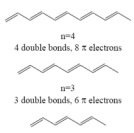
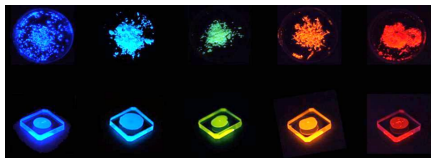
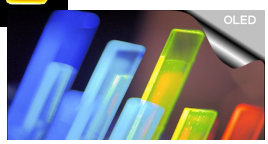
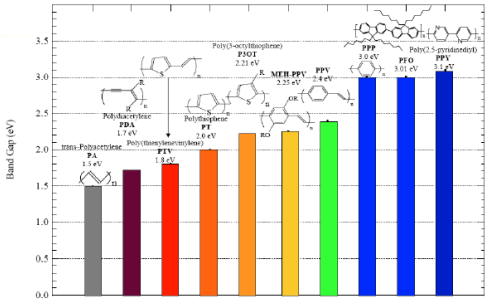


Ref. D. L. Pavia, G. M. Lampman, G. S. Kriz, Introduction to Spectroscopy, 2nd ed. (Saunders College Publishing, 1996), p.289









Ref. N. C. Greenham and R. H. Friend, Solid State Physics 49, 1 (1995) p.13; A. Monkman et al., Phys. Rev. Lett. 8, 1358 (2001)

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OLED Avantages

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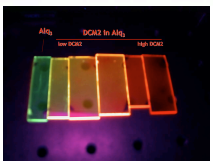
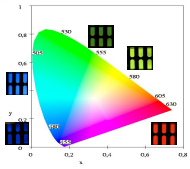
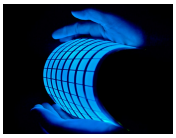
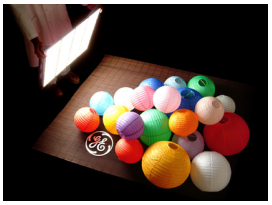
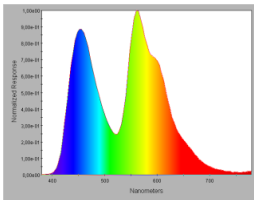
- All colours are possible (no green gap)
- High colour quality (saturation)
- High CRI (molecular bands)
- High luminous efficacy
- Lambertian intensity distribution
- Long lifespan
- Low temperature drift
- Excellent mechanical behaviour (Flexible, bendable…)
- Extremely light and thin
- Easy to produce at low cost (R2R)
- Low carbon footprint
- Dimmable

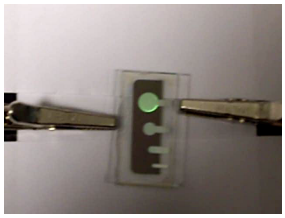












How we obtain white OLEDs?

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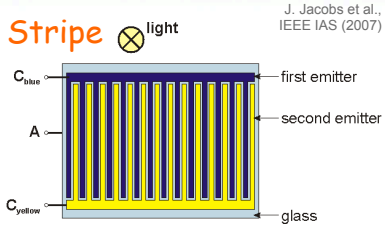
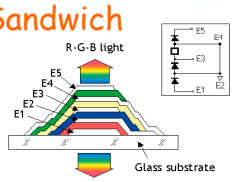
Stripe

J. Jacobs et al., IEEE IAS (2007)

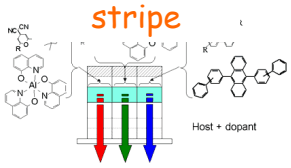


Sandwich

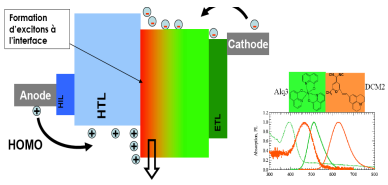


G. Gu et al., J. Appl. Phys. 86,4076 (1999)

Flat dot/ stripe



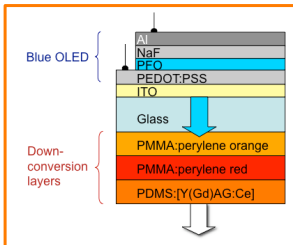
Host/Donor system



YB mix

RGB mix

Down conversion & Colour mixing



A.R. Duggal et al., Appl. Phys. Lett. 80,3470 (2002)

Large spectrum issued from "molecular engineering"

OLEDs & lighting

UMR 5213

1m² OLED panel with luminance of 1 500 cd/m² can give an illuminance of 400 lx in office configuration, without glare

Performance Targets

UMR 5213

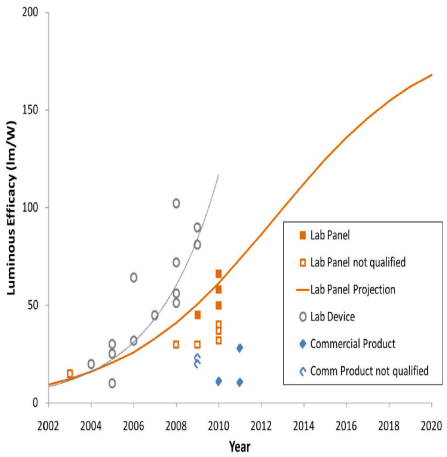
Metric	2012	2013	2014	2015
Efficacy (lm/W)	60	80	100	135
Luminance (cd/m²)	3,000	3,000	–	4,000
L_{70} Lumen Maintenance (1,000 hours)	15	20	30	40
Area (mm)	100 x 100	150 x 150	300 x 300	300 x 300

LG Chem Targets

US DoE Targets

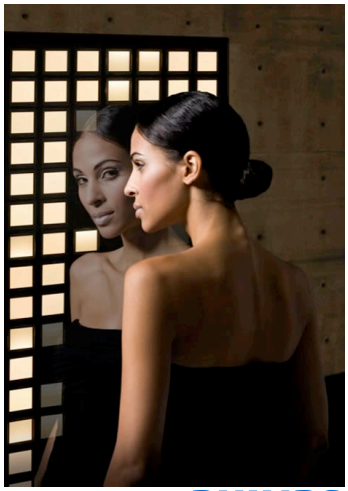
Metric	2013	2015	2018	Goal
LER (lm/W)	320	330	350	360
Internal Quantum Efficiency	85%	90%	90%	90%
Electrical Efficiency	75%	80%	85%	85%
Extraction Efficiency	40%	50%	60%	70%
Panel Efficacy (lm/W)	80	100	120	190
L_{70} Lumen Maintenance (1,000 hours)	15	20	25	30

Note: Projections assume CRI > 85, 2580-3710K; 10,000 lm/m² emittance.

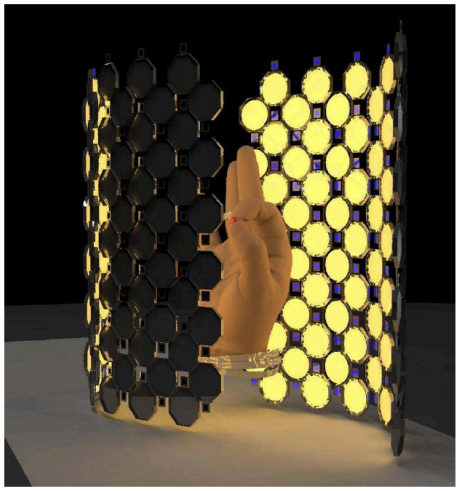


Source: Solid-State Lighting Research and Development Multi-Year Program Plan, DoE Report, 2013 and 2011.

Mood & object Lighting



PHILIPS



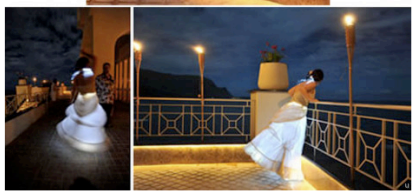
OSRAM

And many other applications...

OLED Christmas tree (General Electric)

OLED wedding dress (Alison Lewis e-Textile)

OLED pillow

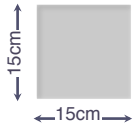


Some real examples (1)

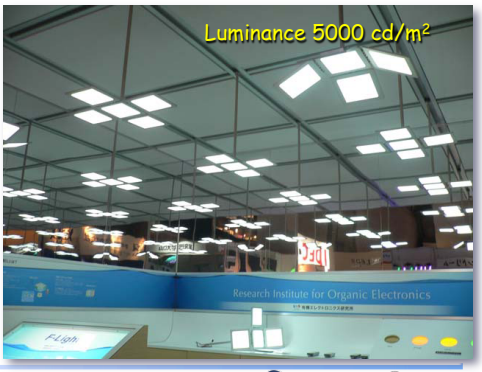
UMR 5213

Yonezawa City (Japon)
OLED Café !

Lighting Fair 2007



RIOE
Research Institute for Organic Electronics



Courtesy J. Kido, 2009

Some real examples (2)

UMR 5213

Lighting Fair 2007

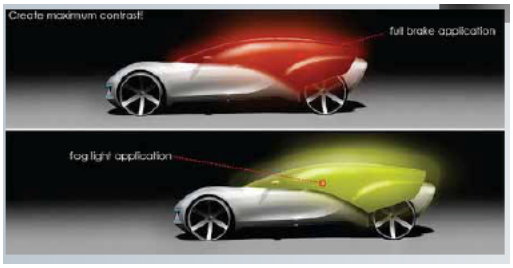
Courtesy J. Kido, 2009

Some real examples (3)

Those gathered at the recent Optic & Photonics Conference in San Diego:
Life span of more than 12,000 hours and a system efficacy of 71 lm/W.
In addition, these OLED lights are completely cool to the touch

Automotive applications

novaled



Applications in transport

Trains

Aircrafts

Laplace
UMR 5213
Lumière & Matière
CNRS INP ENSEEIHT UNIVERSITÉ TOULOUSE III PAUL SABATIER

Laplace

It is easy with electricity !

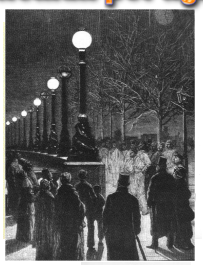
UMR 5213

Electrical Discharge

1809

Sir Humphry Davy

...Human put lighting in a bottle !



Carbon arc (1813)

- Power
- Lifespan
- Complexity
- Reliability

Jablochkoff's candle (1870)

Lumière & Matière

CNRS INP ENSEEIHT UNIVERSITÉ TOULOUSE III PAUL SABATIER

Laplace

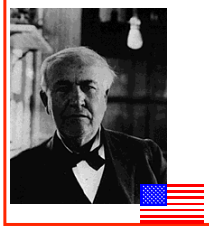
Edison's lamp is coming...

UMR 5213

Incandescence

1878

Carbon Filament Lamp



Thomas A. Edison

1 major inconvenient :
- low efficacy

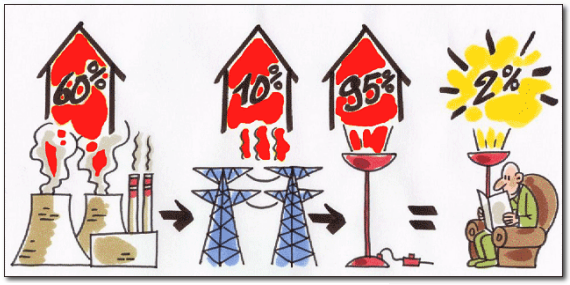
2 strong points:
- easy to produce
- large lifespan

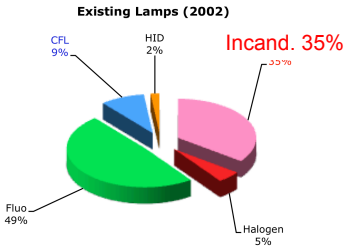
1 visionary inventor:
- "system" vision: from electricity to light

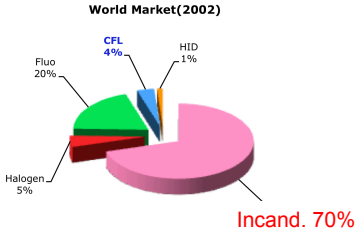
Lumière & Matière

CNRS INP ENSEEIHT UNIVERSITÉ TOULOUSE III PAUL SABATIER

...and disappearing (2010)







- Is production capacity sufficient ?
- Is the consumer ready for the market transformation ?
- What is the social impact ?