

# (Lighting and) Solid-State Lighting: Science, Technology, Economic Perspectives

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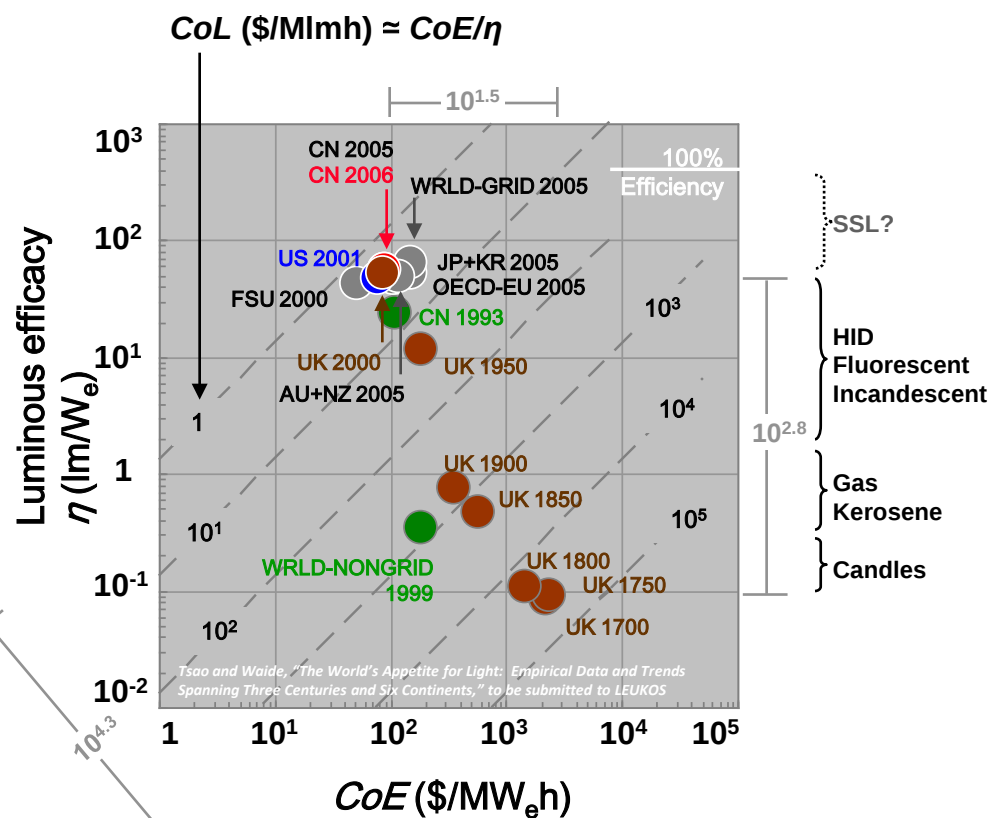
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Night arrives between Europe and Africa; digital composite of archived images taken by several Earth-orbiting satellites and ocean-faring ships; courtesy of NASA; <http://apod.nasa.gov/apod/ap030324.html>

# Artificial Lighting and Human Productivity

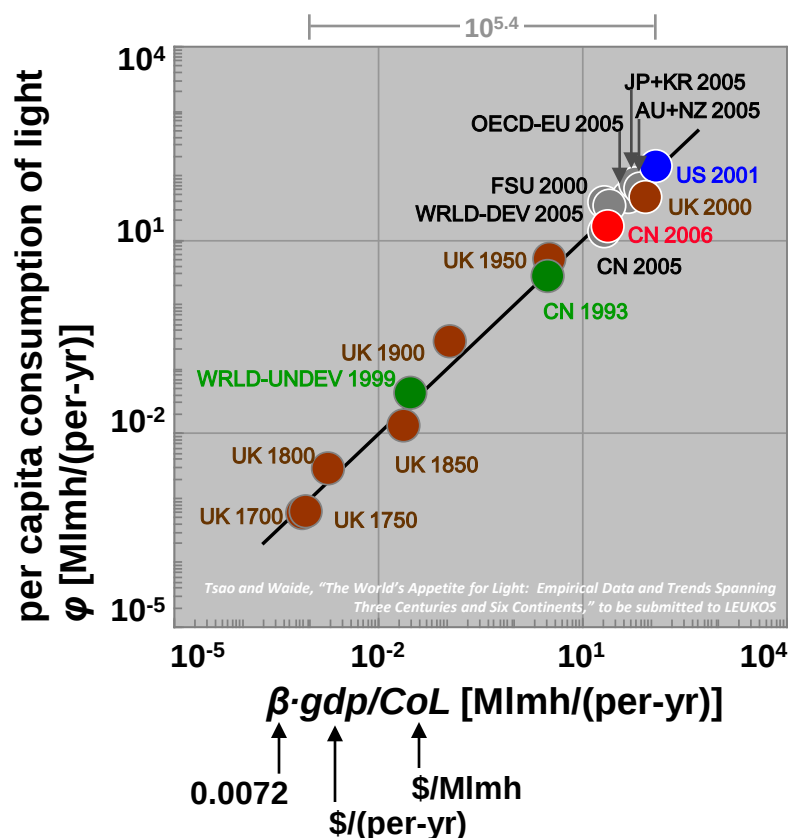
## Efficiency



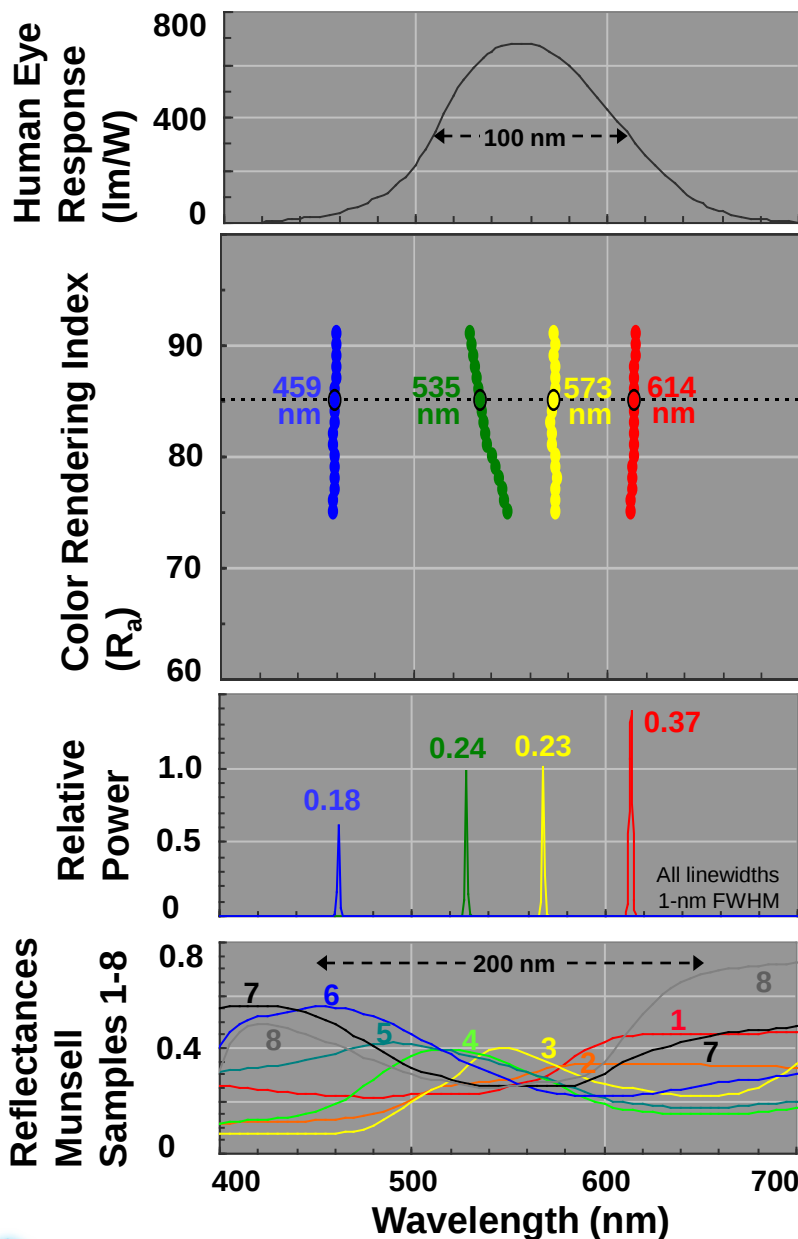
## Consumption

$0.72\% = US\$440B / US\$60T$

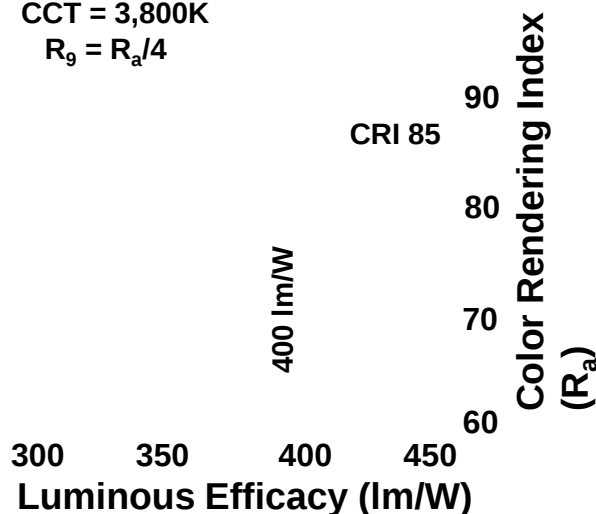
$6.5\% = 1 TW_c / 16 TW_c$



# Characteristics of “100%-Efficient” Lighting

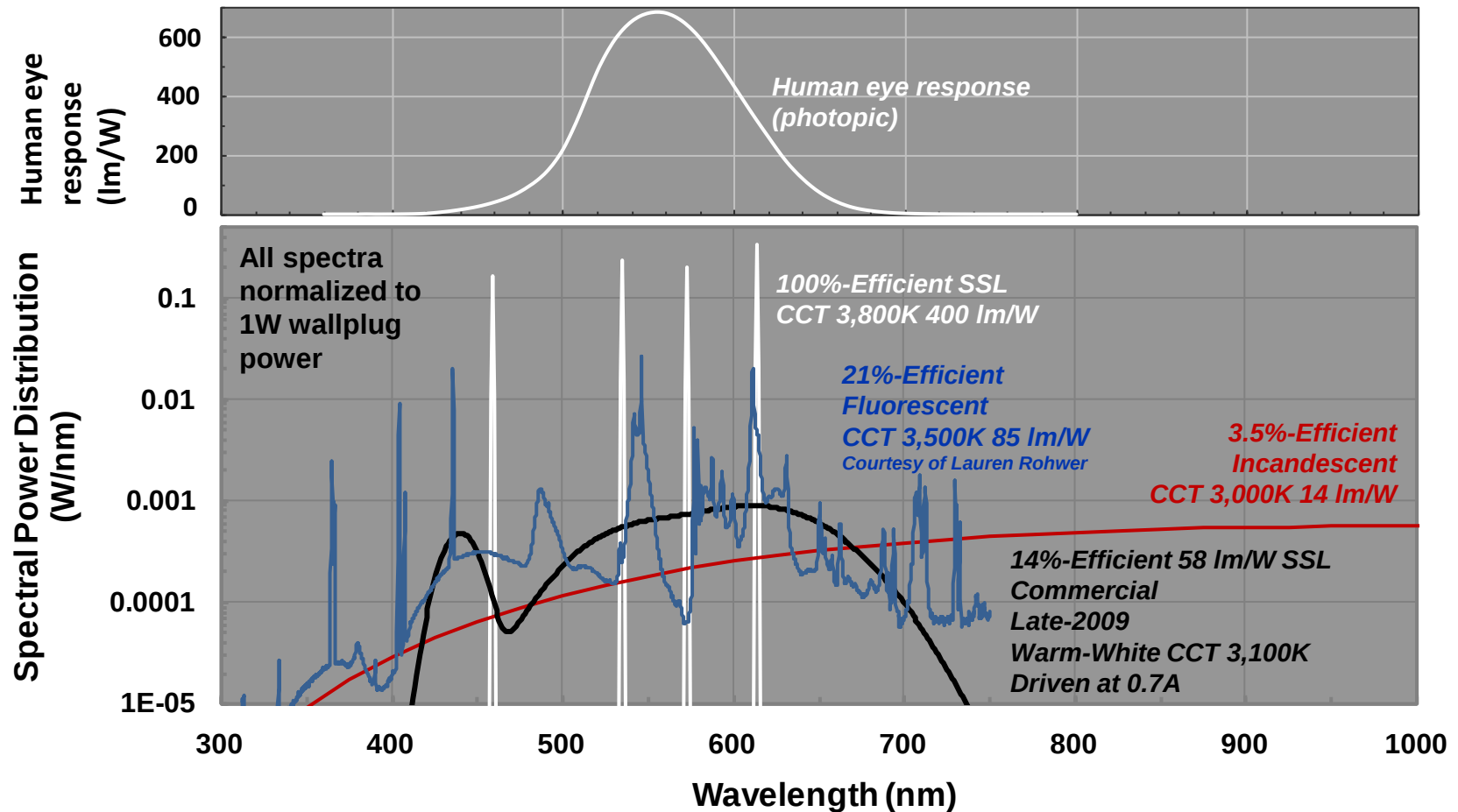


CCT = 3,800K  
 $R_g = R_a/4$



*J.M. Phillips, et al, “Challenges to Ultra-Efficient SSL”, Laser & Photonics Reviews (2007).  
 Calculations based on white LED simulator 5-3 (Y. Ohno, NIST).*

# Efficiencies of Actual Lighting Technologies



# Anatomy of State-of-Art Commercial SSL

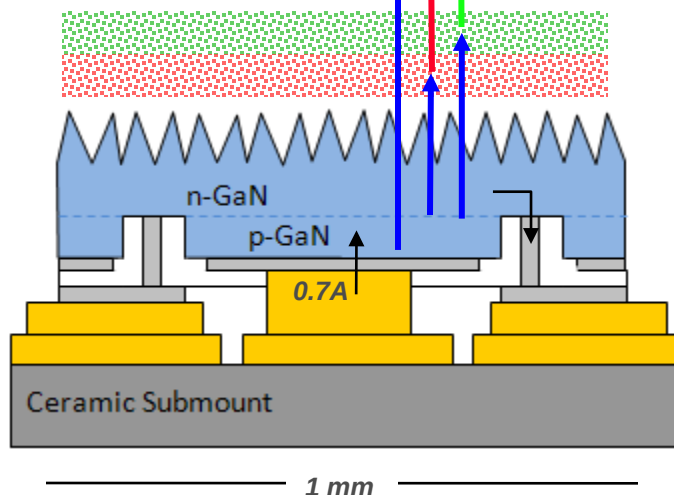
$\varepsilon$  = 14%  
 $\eta$  = 58 lm/W  
 CRI = 85  
 CCT = 3,100K



Spectral 78%

Phosphor/Package 54%  
Internal quantum effic 90%  
Stokes deficit 76%  
Scattering/absorption 80%

Blue LED 33%  
Joule 85%  
IQE at low power 70%  
Droop at high power 70%  
Light extraction 80%

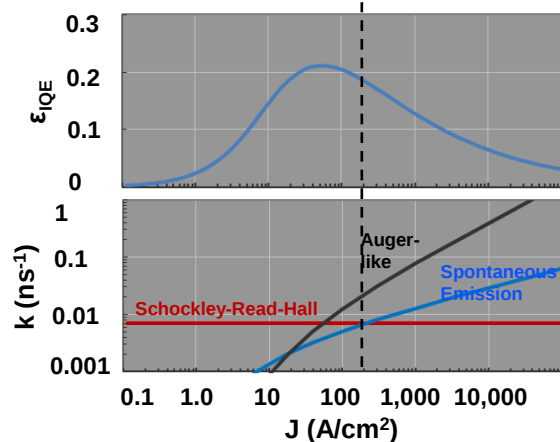


Thin-Film Flip Chip (TFFC)  
 schematic courtesy of Jon Wierer

# Technology Grand Challenges for Luminous Efficacy

## ① Eliminate blue LED droop

Target: 200 A/cm<sup>2</sup>

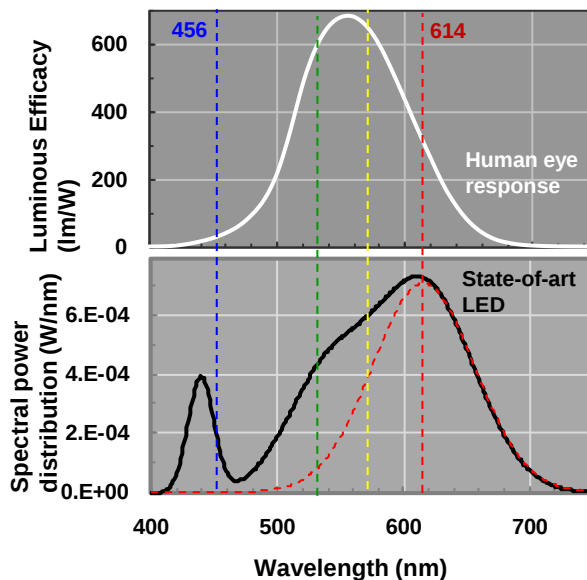


$$\epsilon_{IQE} = \epsilon_{INJ} \cdot \frac{Bn}{A + Bn + Cn^2}$$

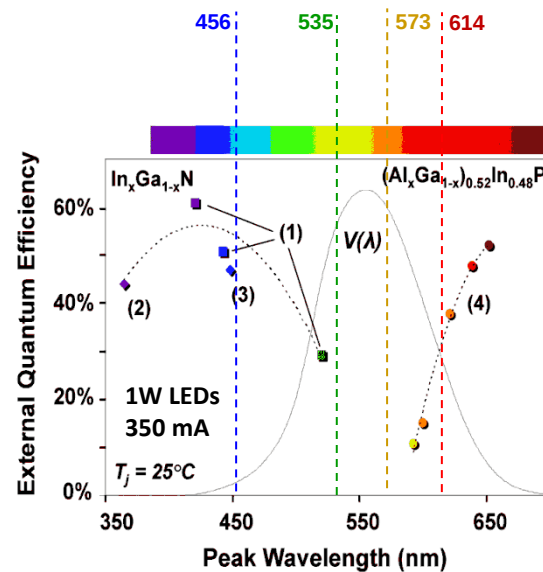
Shockley-Read-Hall      Spontaneous Emission      Auger-like

Rate constants for 510nm LED, after UT Schwarz, "Emission of biased green quantum wells in time and wavelength domain," SPIE Proc 7216, 7216U-1 (2009).

## ② Narrow-linewidth shallow-red color conversion



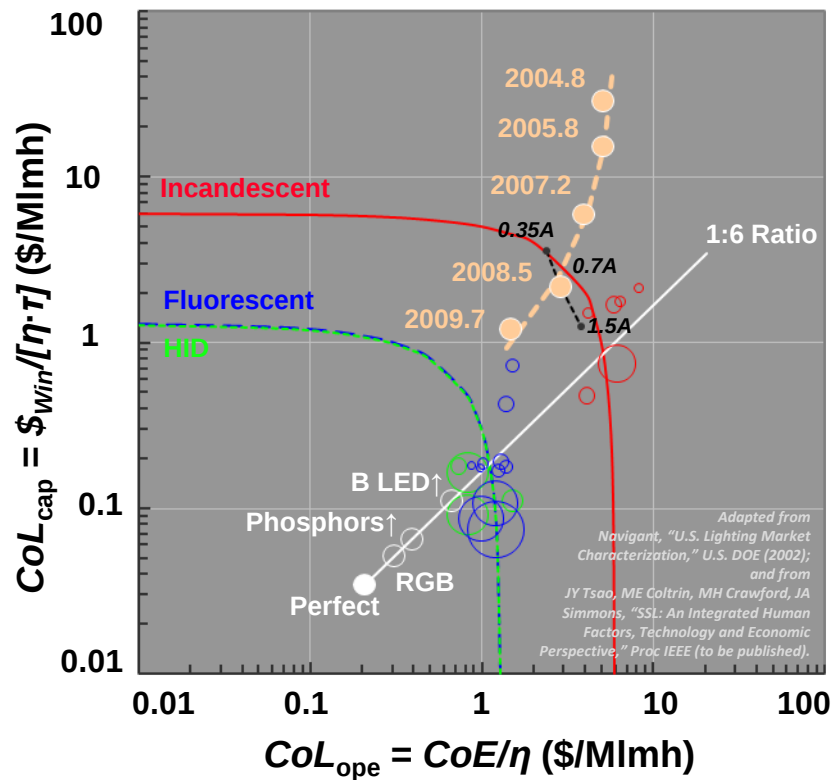
## ③ Fill in the red-yellow-green gap



Courtesy of M. Krames, Philips-Lumileds

# What about Cost of Light?

$CoL_{cap}$  is already  $\sim CoL_{ope}/6$ ,  
so  $\eta$  is the key



2012 may be the beginning  
of "the transition"

