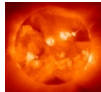


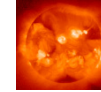
Solid-State Lighting: It's Also About Human Productivity!

Jeff Tsao · Physical Chemical Nano Sciences Center · Sandia National Labs



Full-disk view of the X-ray Sun and was produced by the Yohkoh solar observatory in 1991.
http://en.wikipedia.org/wiki/File:Yohkoh_image.gif

Full moon view from Earth in Belgium, courtesy of Luc Viatour.
http://en.wikipedia.org/wiki/File:Full_Moon_Luc_Viatour.jpg



Bridgelux Helieon Solid-State Lamp.
<http://www.bridgelux.com/products/helieon.html>



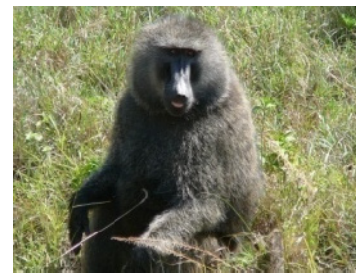
Asaphus species (Trilobite) picture taken by DanielCD.
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Red Lory (Eos bornea) upper body preening feathers.
http://en.wikipedia.org/wiki/File:Red_Lory_%28Eos_bornea%29-6.jpg



Gray wolf, canis lupus, courtesy of Chris Muiden.
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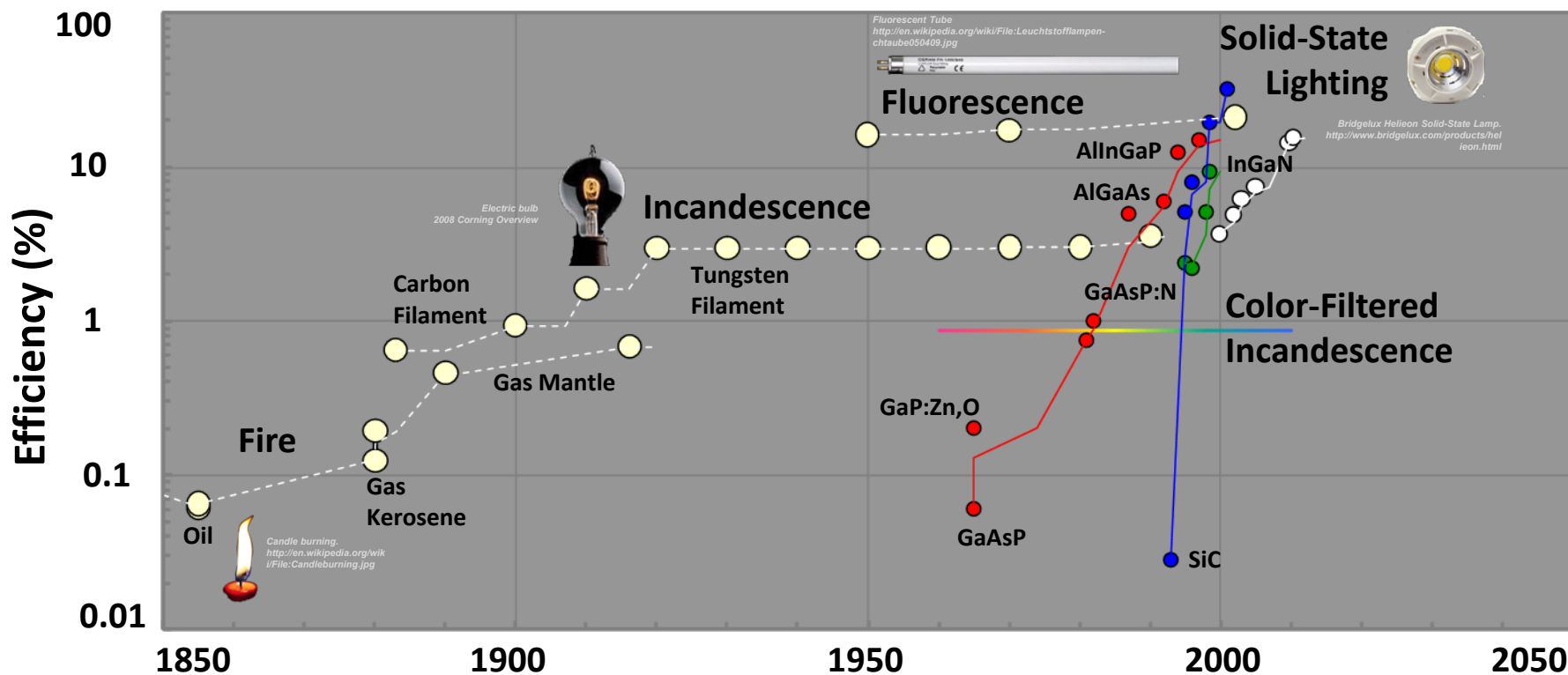
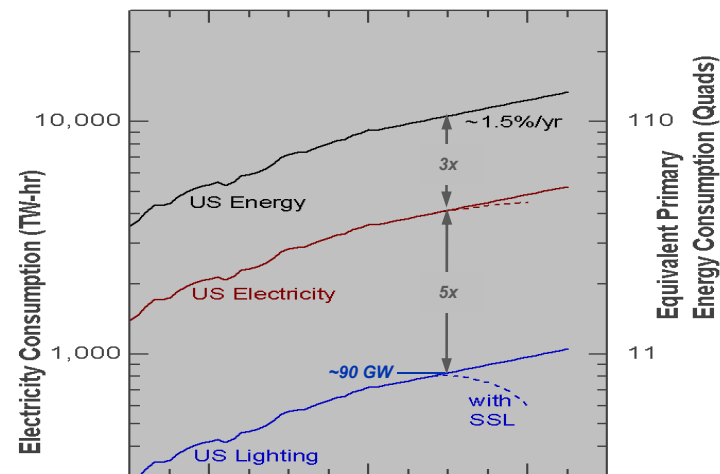


Olive baboon in Kenya; courtesy of Ryan Harvey;
http://en.wikipedia.org/wiki/File:Male_Olive_Baboon_2.jpg

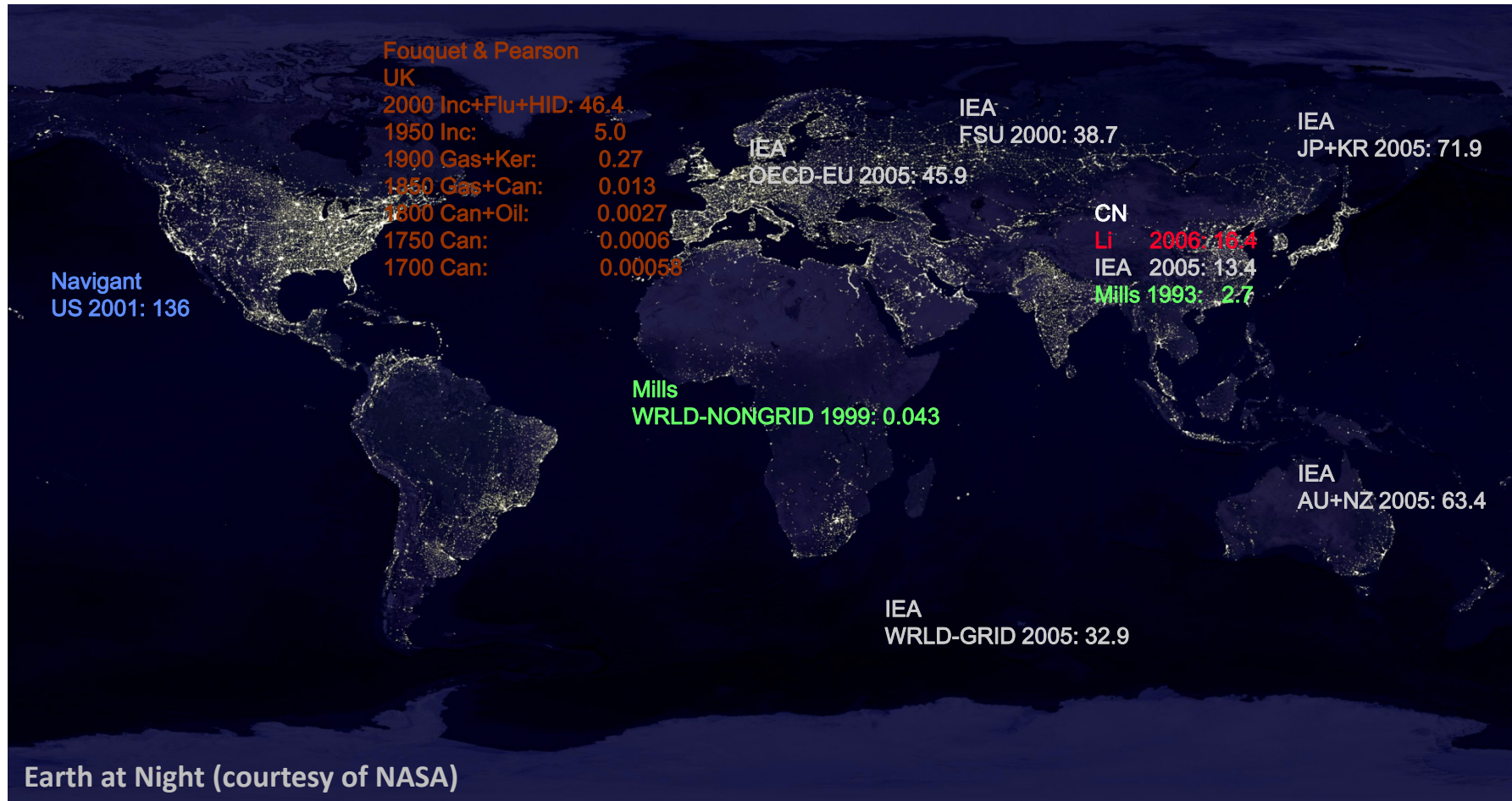


A baby wearing many items of winter clothing: headband, cap, fur-lined coat, shawl and sweater. Courtesy of Andrew Vargas, Clovis, United States.
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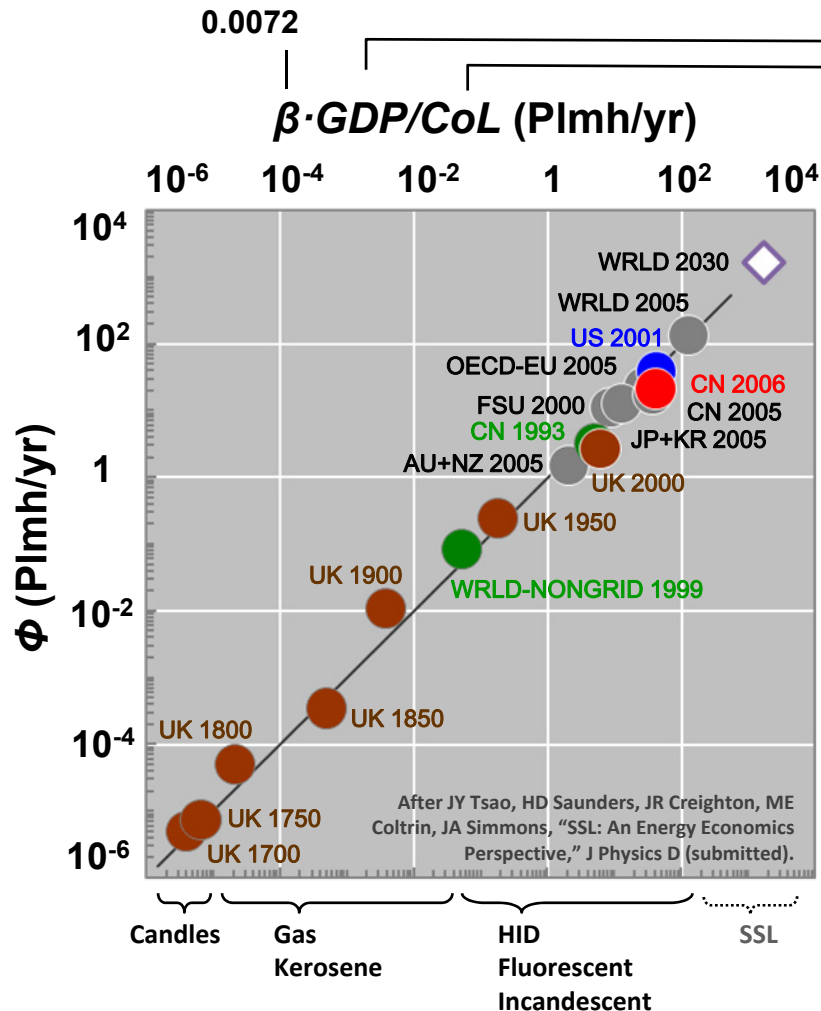
Lighting Efficiency and Energy Consumption



per capita Consumption of Light: ϕ , in Mlmh/(person-yr)



Historical and projected consumption of light



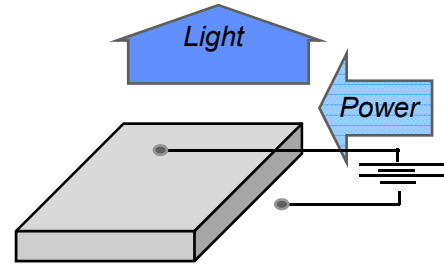
Nation or Nations	Year	$\beta \cdot \text{GDP/CoL (Plmh/yr)}$			$\text{GDP} = N \cdot \text{gdp}$		Φ	ϕ
		Cost of Light $\frac{\$}{\text{Mlmh}}$	Cost of Energy $\frac{\$}{\text{MWh}}$	Luminous Efficacy $\frac{\text{lm}}{\text{W}}$	Gross Domestic Product $\frac{\text{G\$}}{\text{yr}}$	Population Gper	per capita gross domestic product $\frac{\$}{\text{per-yr}}$	per capita consumption of light $\frac{\text{Plmh}}{\text{yr}}$
WrlD	2030	0.6	119	268.0	139,091	8.3	16,704	1,688.00
WrlD	2005	3.3	119	47.5	60,670	6.4	9,445	129.52
US	2001	2.0	76	49.7	12,039	0.3	42,237	41.99
WrlD Non-Grid	1999	600.2	183	0.3	4,404	2.0	2,202	0.05

Chip area needed to light the world



<http://tan-moneyonline.com/wp-content/uploads/2008/03/earthatnight-asia1.jpg>

$$\Phi_{Demand} \cong \frac{\overset{0.0072}{\beta} \cdot GDP}{\underset{\text{Cost of energy}}{CoE} / \underset{\text{Luminous efficacy}}{\eta}} = \overset{\text{Input power density}}{p} \cdot \underset{\text{Area}}{A} \cdot \overset{\text{Luminous efficacy}}{\eta} \cdot \underset{\text{Duty cycle}}{D} = \Phi_{Supply}$$



Area

$$A = \frac{\overset{\sim 1.3 \text{ km}^2}{\underset{240 \text{ football fields}}{\beta}} \cdot GDP}{\underset{119 \text{ \$/MWh}}{CoE} \cdot \overset{137 \text{ T\$/yr}}{p} \cdot \underset{300 \text{ W/cm}^2}{D}^{1/4}}$$

Area Turnover

$$\frac{dA}{dt} = \frac{\overset{\sim 0.15 \text{ km}^2/\text{yr}}{\underset{28 \text{ football fields/yr}}{A}} / \overset{\text{Yield}}{Y}}{\underset{\text{Life}}{\tau} / \underset{25 \text{ khr}}{D}^{1/4}}$$

The other electronics “killer apps”

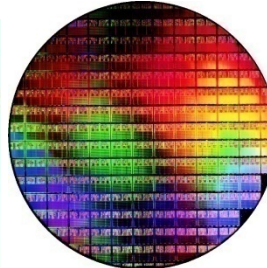
Sharp QuadPixel RGBY LED-backlit LCD Display.
http://www.macworld.com/article/145541/2010/01/sharp_quadpixel.html



http://en.wikipedia.org/wiki/File:Solar_cell.png



http://blog.elisehuard.be/wp-content/uploads/2007/12/wafer_200mm_90nm_1024k_dc.jpg



<http://tan-moneyonline.com/wp-content/uploads/2008/03/earth-atnight-asia1.jpg>



<http://www.itechnews.net/wp-content/uploads/2009/07/Nokia-3720-Classic-the-most-rugged-mobile-phone.jpg>



Market	Liquid crystal displays (2009)	Solar cells (2009)	Si electronics (2009)	GaN solid-state lighting (2030)	GaAs electronics (2009)
Approximate area turnover (km ² /year)	230	64	4.4	0.15	0.026
# football fields / year	43,000 (2.5 x Corning)	11,800 (Manhattan)	800 (2 x Monaco)	28 (Vatican City / 4)	5

Estimate from Steven S. Rosenblum, Corning, Inc

Assuming 9.6 GW_p (<http://www.displaybank.com/en/g/info/sread.php?id=5730>) at 15% efficiency

Estimate from Gartner (http://www.fabtech.org/news/_a/gartner_revises_silicon_wafer_demand_forecast/)

Estimate from A Anwar, Strategy Analytics

Anatomy of State-of-Art Commercial SSL

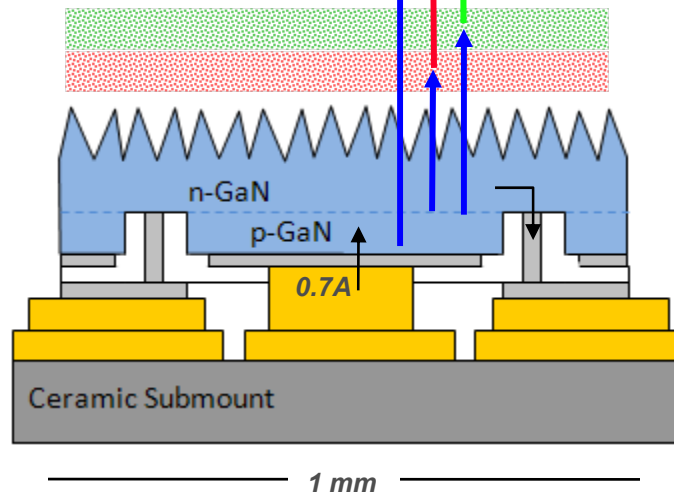
ε = 16%
 η = 66 lm/W
 CRI = 85
 CCT = 3,100K



Spectral 78%

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

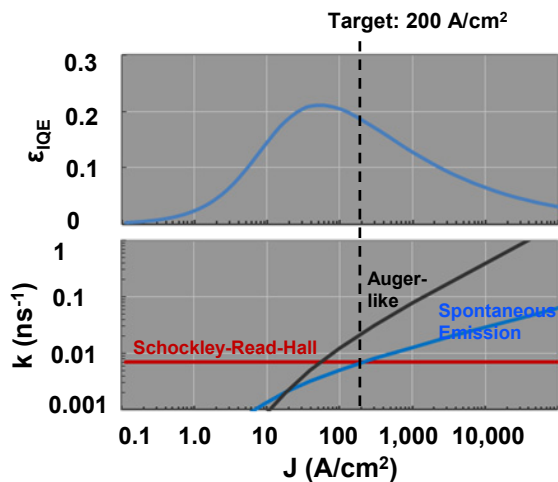
Blue LED 38%
 Joule 90%
 IQE at low power 75%
 Droop at high power 70%
 Light extraction 80%



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

Two Grand Challenges for Efficiency

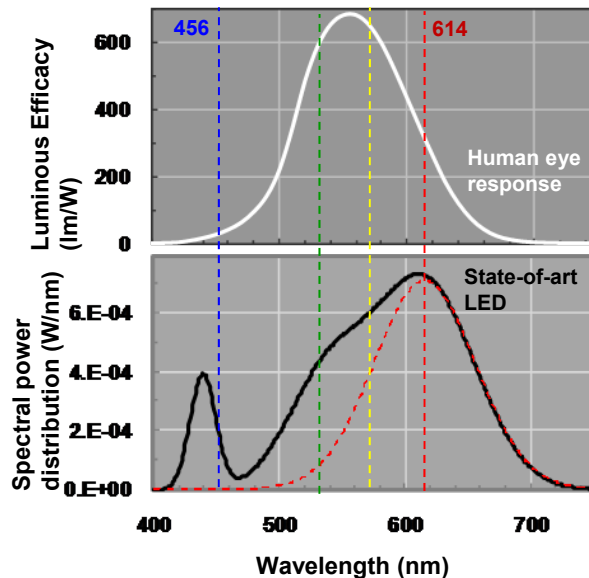
①a Eliminate blue LED droop



$$\epsilon = \left(\frac{V_{ph}}{V} \right) \cdot \epsilon_{INJ} \cdot \frac{Bn^2}{An + Bn^2 + Cn^3} \cdot \epsilon_{EXT}$$

Shockley-Read-Hall
Spontaneous Emission
Auger-like

①b Fill in the shallow-red EL gap



One for Functionality

② Bring luminaire functionality to the chip



<http://www.irradianthq.com>



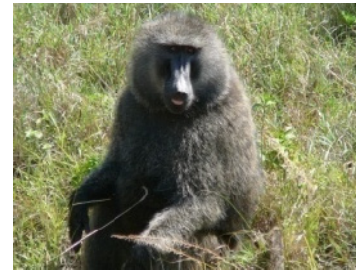
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IEA (Paul Waide), Decision Processes Inc (Harry Saunders), Philips Lumileds (George Craford)

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