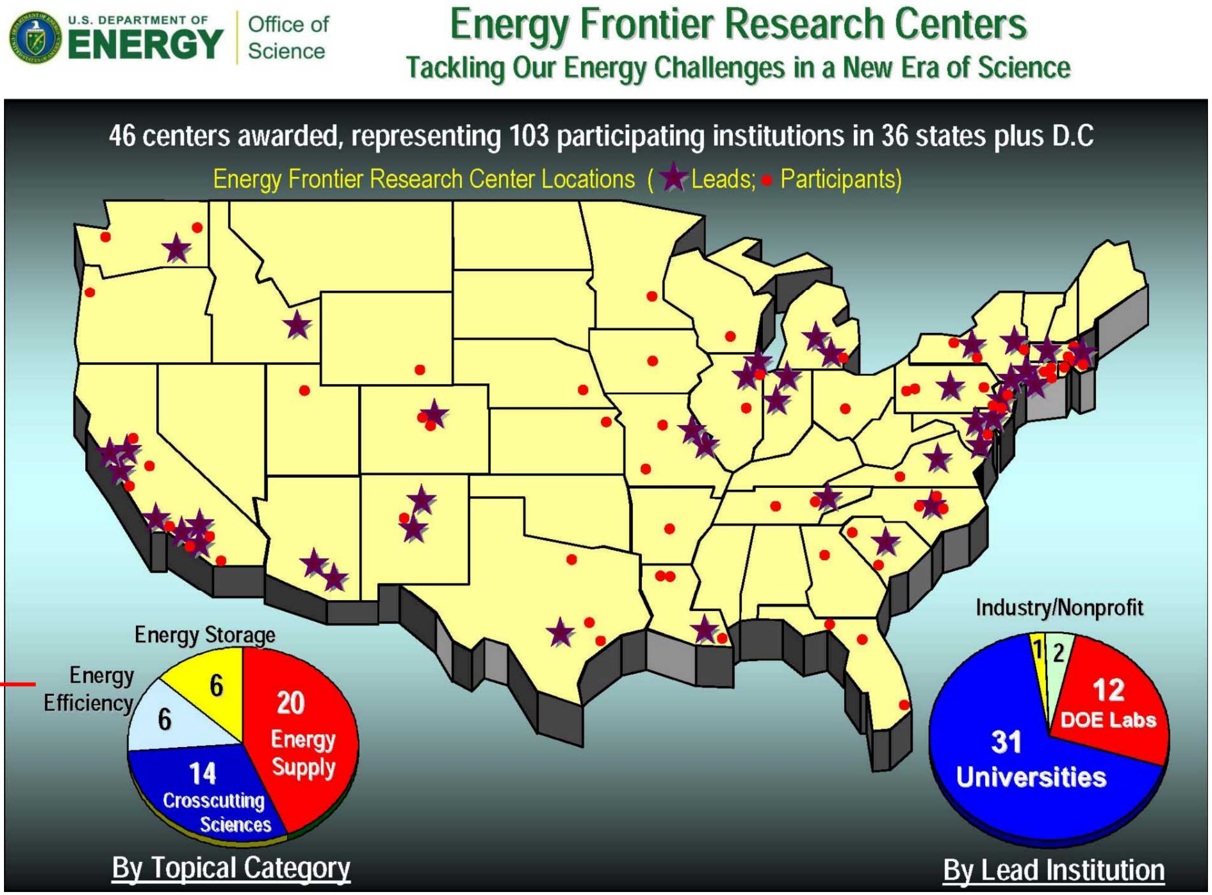
Jeff Tsao
Chief Scientist

SAND2012-0618P

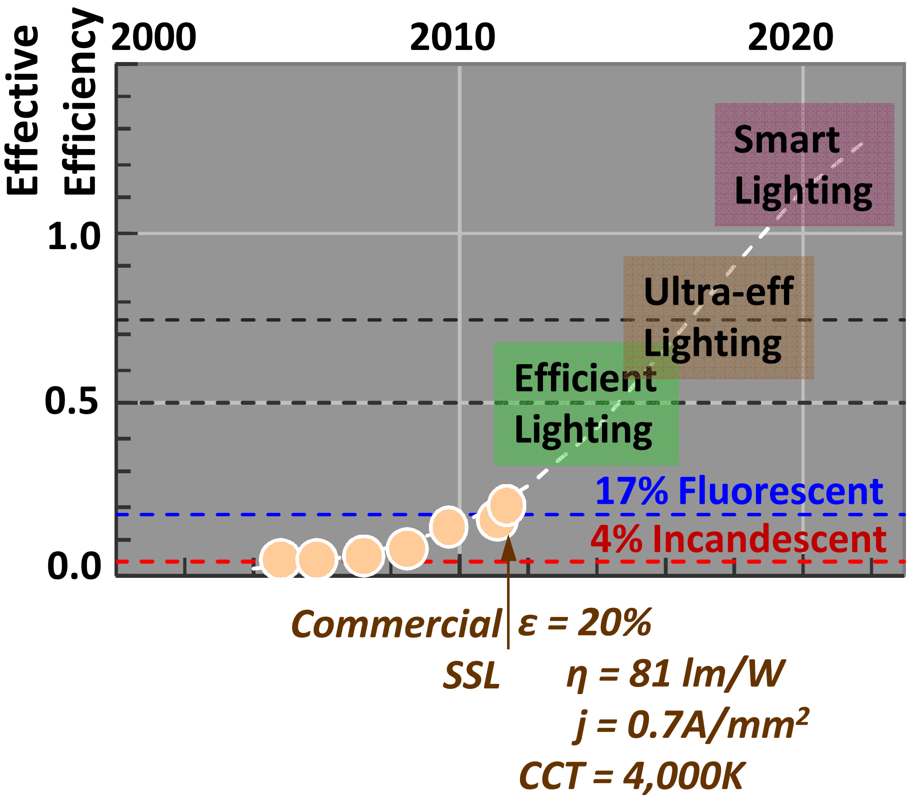
Sandia's Solid-State Lighting Science EFRC

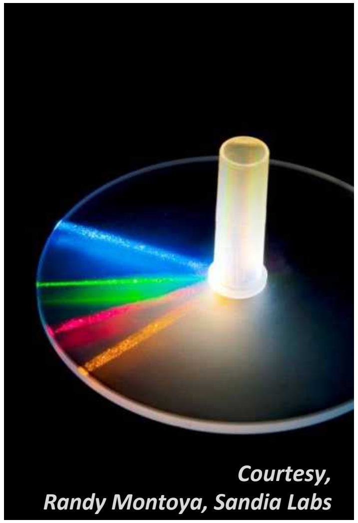


- We are one of 46 Department of Energy Office of Science EFRCs
- Our Budget: \$18M over 5 years beginning Aug 2009
- We are one of 6 EFRCs focused on efficiency, and the only one focused on SSL

Work at Sandia National Laboratories was supported by Sandia's Solid-State-Lighting Science Energy Frontier Research Center, funded by the U.S. Department of Energy, Office of Basic Energy Sciences. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Our Raison d'Etre





Building the scientific foundation that enables the most light for the least energy

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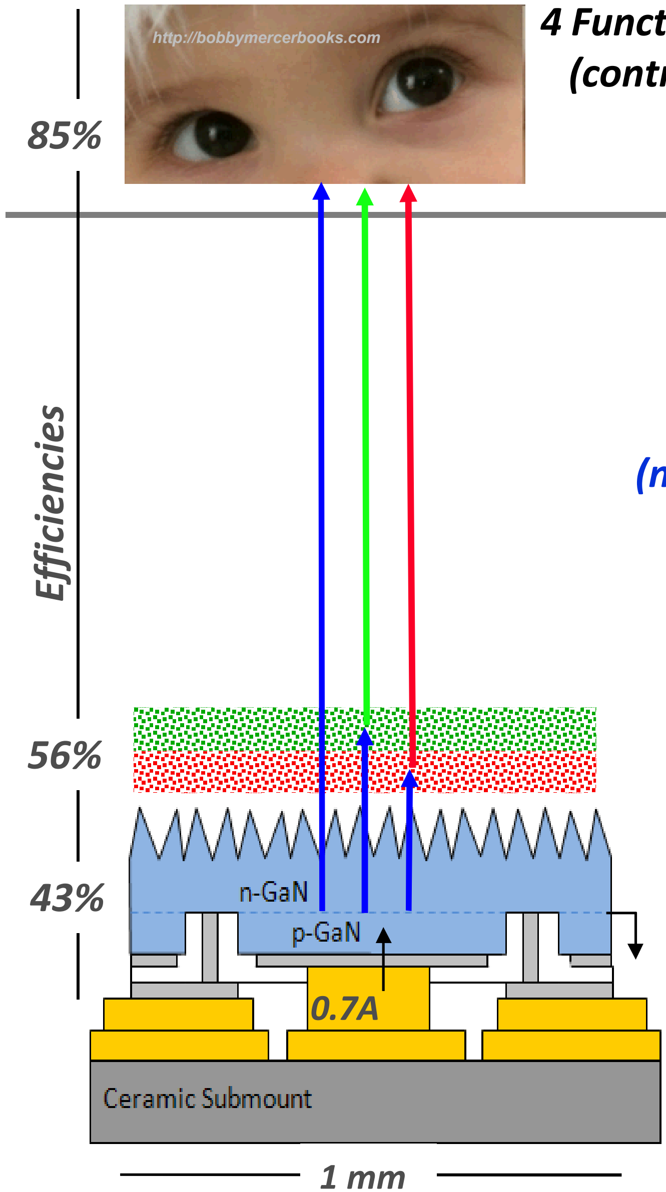
Why Only 20% Efficient?

Four SSL Technology Challenges

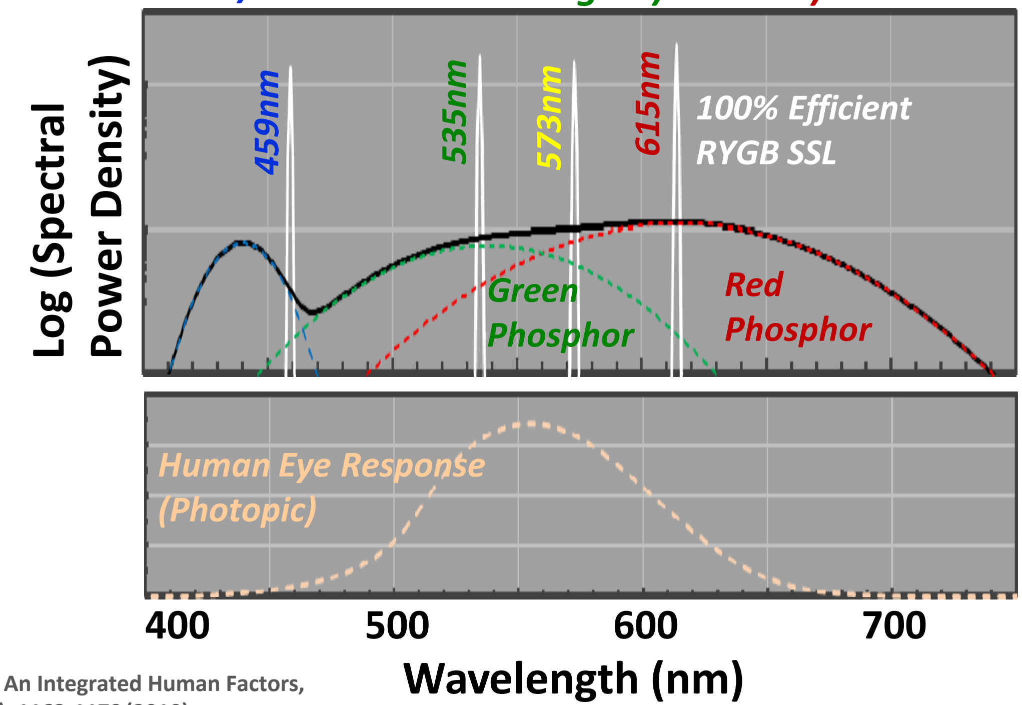
4 Functional Light (control of light in intensity, time, space, and chromaticity)



1 Droop (near-100% efficiency at all currents)

2 Green-Yellow Gap (near-100% efficiency at all wavelengths)

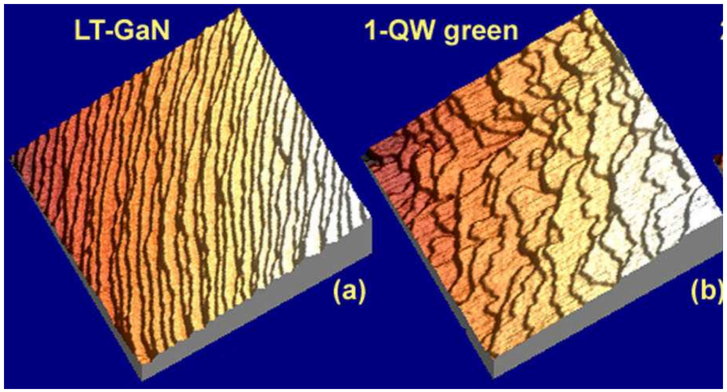
3 Narrow-linewidth phosphors (esp. red)



JY Tsao, ME Coltrin, MH Crawford, JA Simmons, Solid-State Lighting: An Integrated Human Factors, Technology and Economic Perspective, Proceedings of the IEEE 98 (7), 1162-1179 (2010).

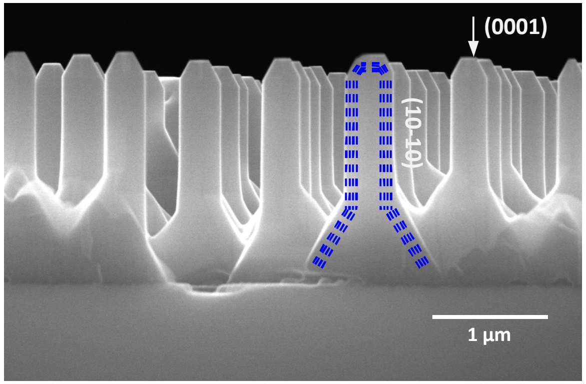
SSLS EFRC Research Challenges (2): Materials Architectures

2D AlInGaN "Planar" Films



InGaN planar films have lots of unanswered questions, but is mature enough for us to treat as an existing capability (not a Challenge)

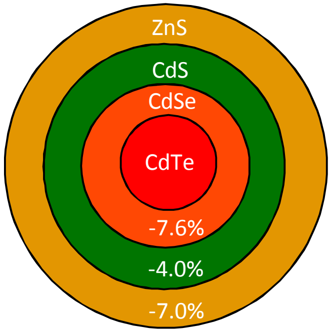
1D AlInGaN Nanowires



While investing in InGaN nanowires, a less explored platform with "breakthrough" potential (defect free, strain higher In content, ability to control crystal orientation, 2D coherent arrays)

George Wang

0D II-VI Quantum Dots



As well as in CdSe QDs for (possibly tunable) narrow-linewidth red wavelength downconversion

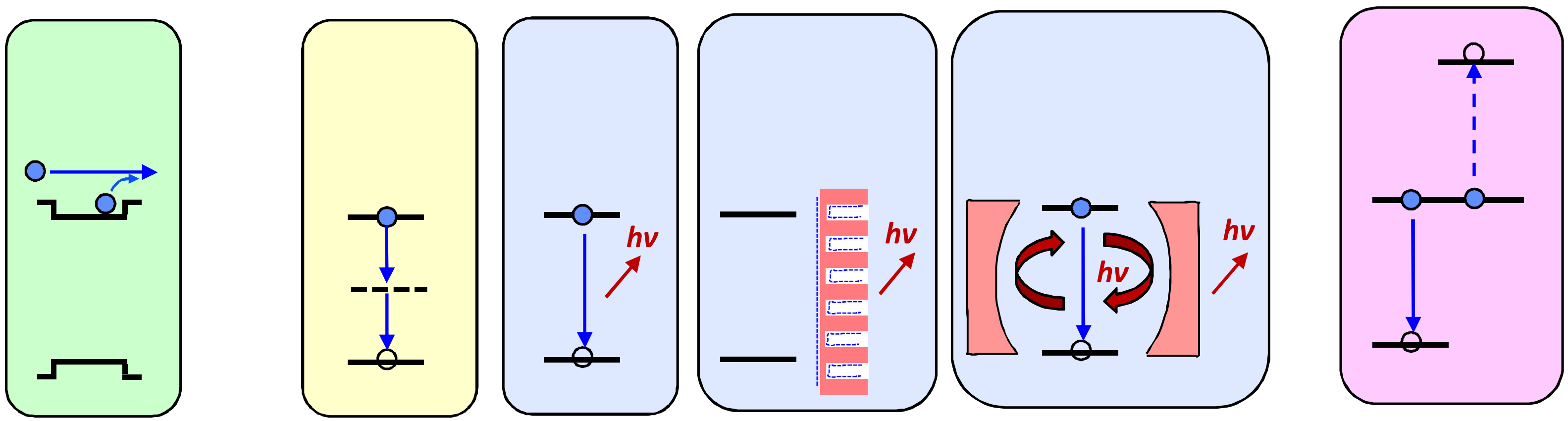
Jim Martin

SSLS EFRC Research Challenges (4): Light-Emission Physics

Wall-plug efficiency	Joule efficiency (ε_{Joule})	Injection efficiency	Internal quantum efficiency (ε_{IQE})	Extraction efficiency

$$\varepsilon = {}_{2.8V}\left(\frac{V_{ph}}{V_{ph}+IR}\right)_{0.6\Omega} \cdot \varepsilon_{inj} \cdot \frac{BN^2}{AN + BN^2 + CN^3 + \ldots} \cdot \varepsilon_{ext}$$

Mary Crawford



Carrier overshoot & escape

Shockley-Read-Hall (defect mediated)

Spon-taneous Emission

Enhanced Spontaneous Emission

Beyond Spontaneous Emission

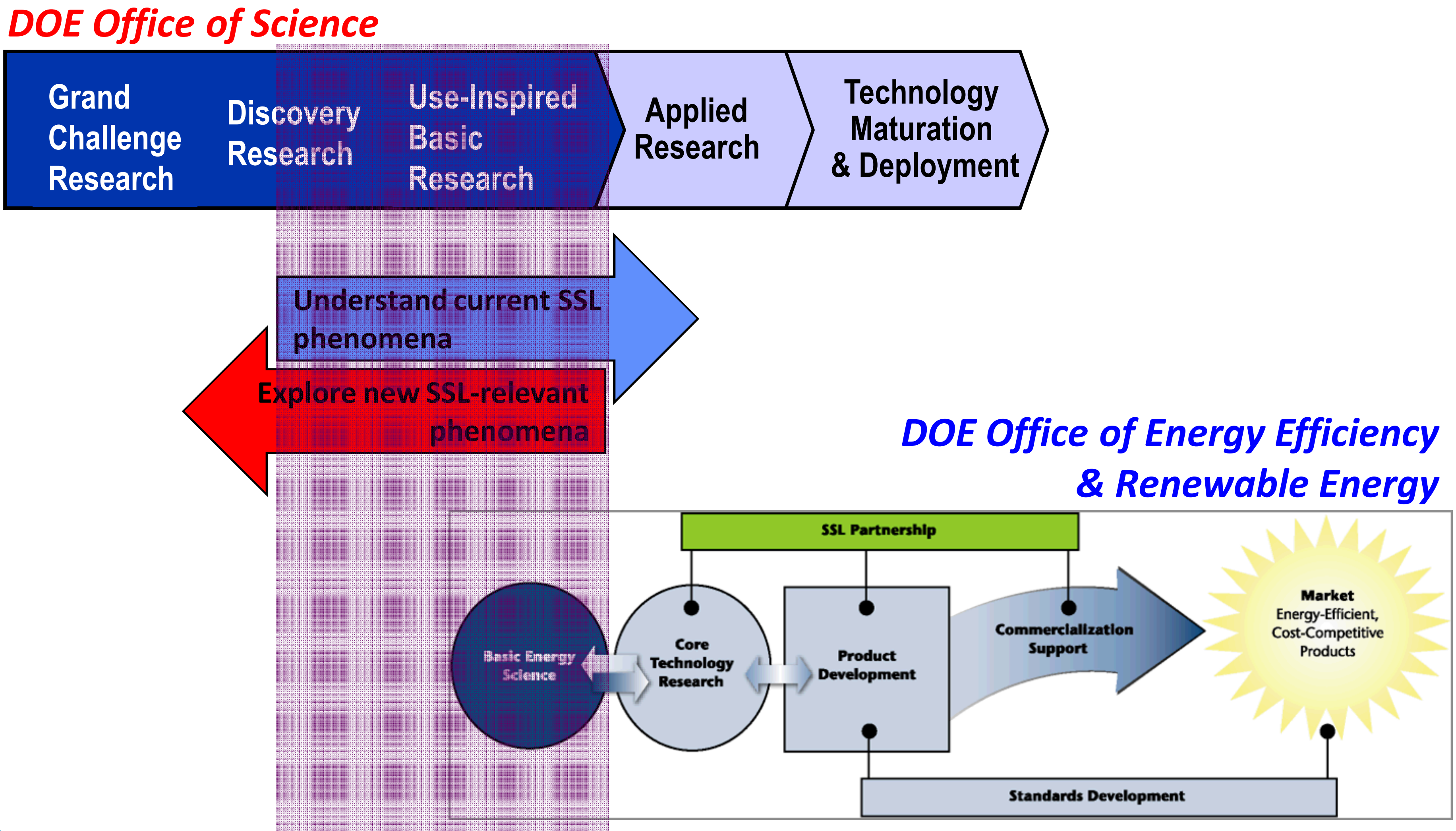
Auger

Andy Armstrong

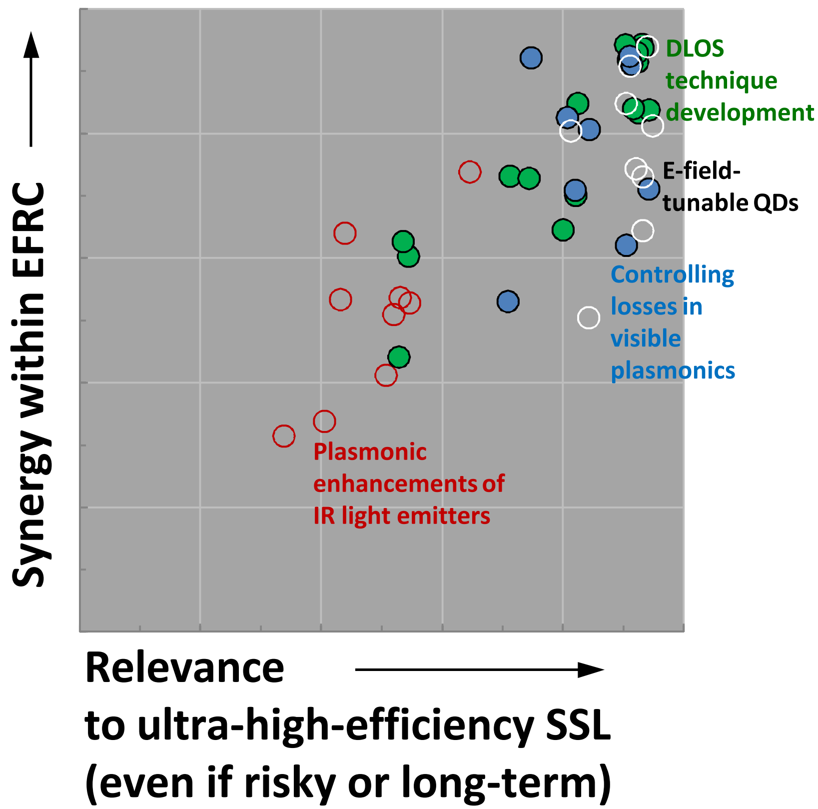
Igal Brener

Art Fischer

SSLS EFRC Guiding Principles:
1 Use-Inspired *Basic* Research



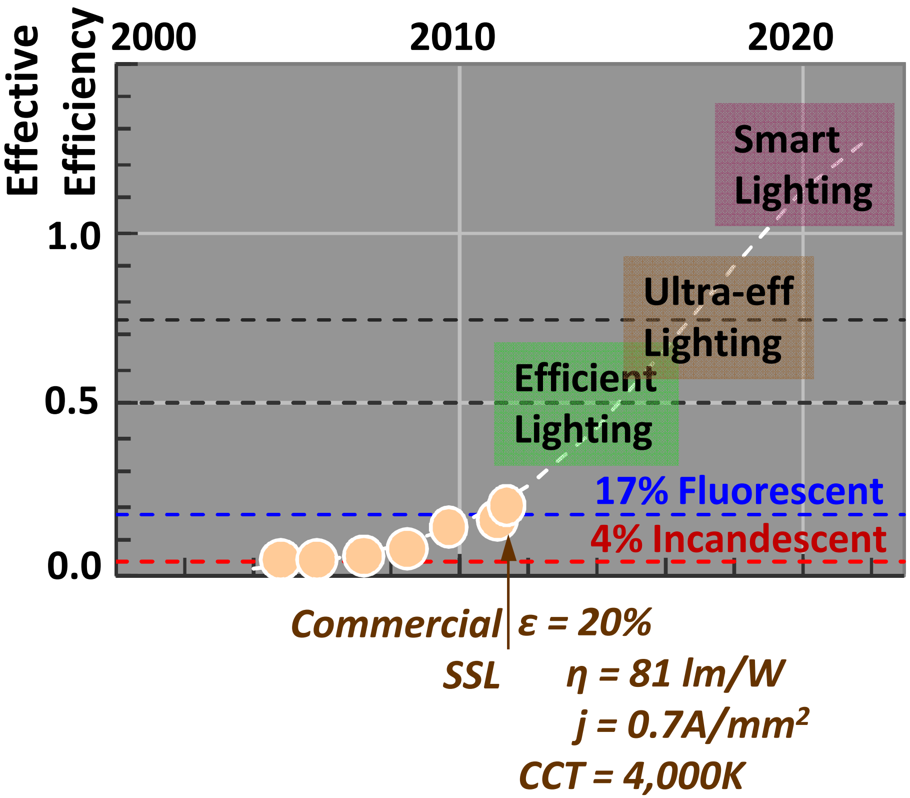
SSLS EFRC Guiding Principles:
2 SSL-Relevance and 3 Synergy

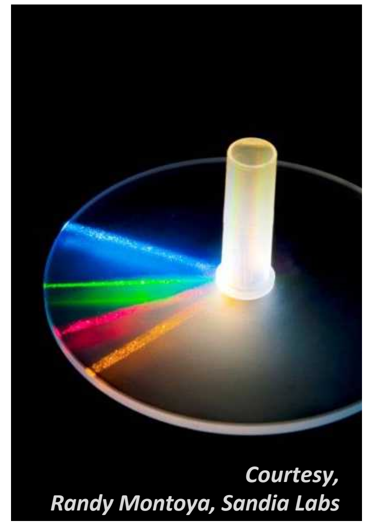


Intense mid-2nd year self and external scrutiny, with deliberate decisions made on ~18 projects within our 6 Challenge area

- Original (ongoing)
- Original (dropped)
- New (ongoing)
- New (wish)

Solid-State Lighting Science EFRC: Technical Overview





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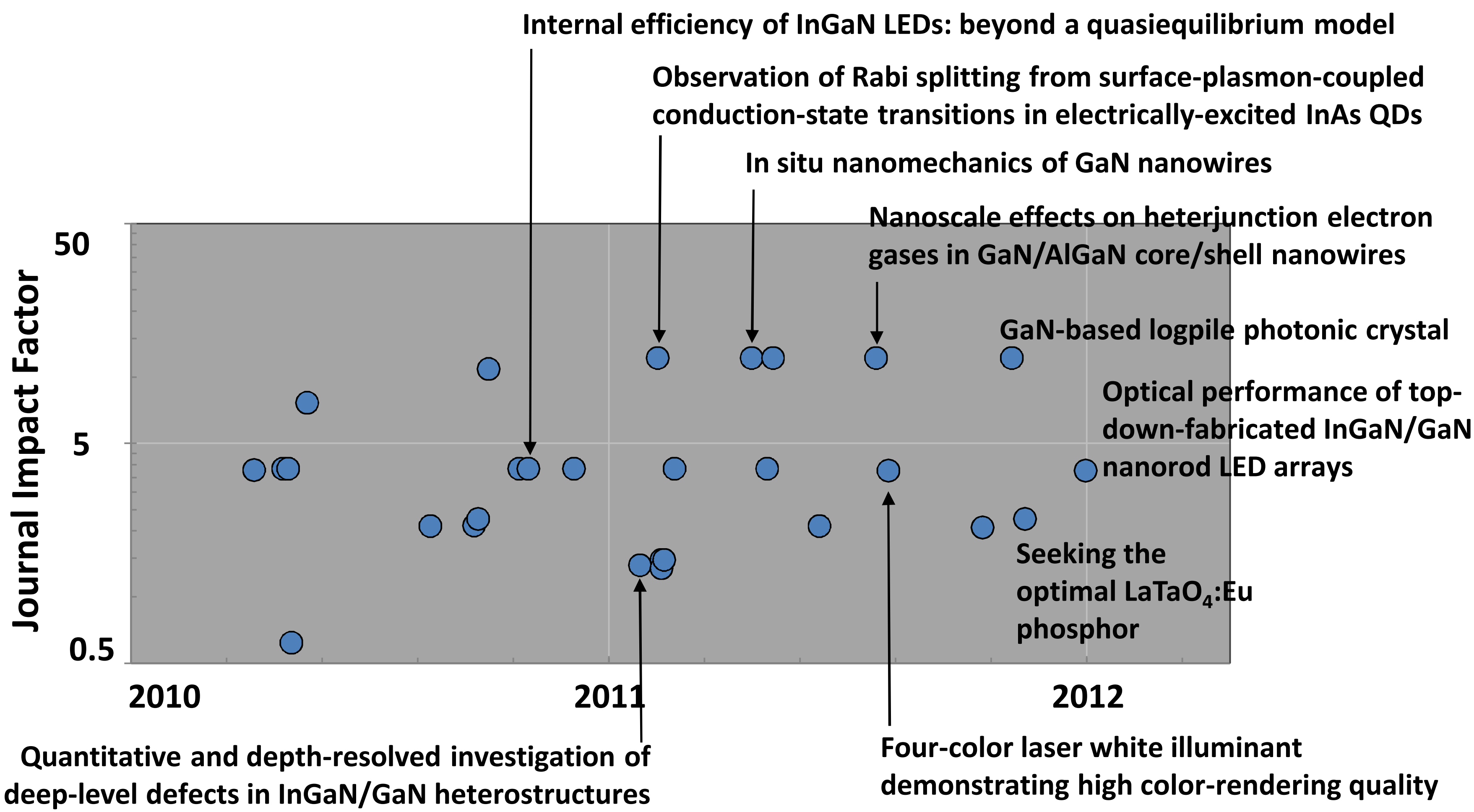
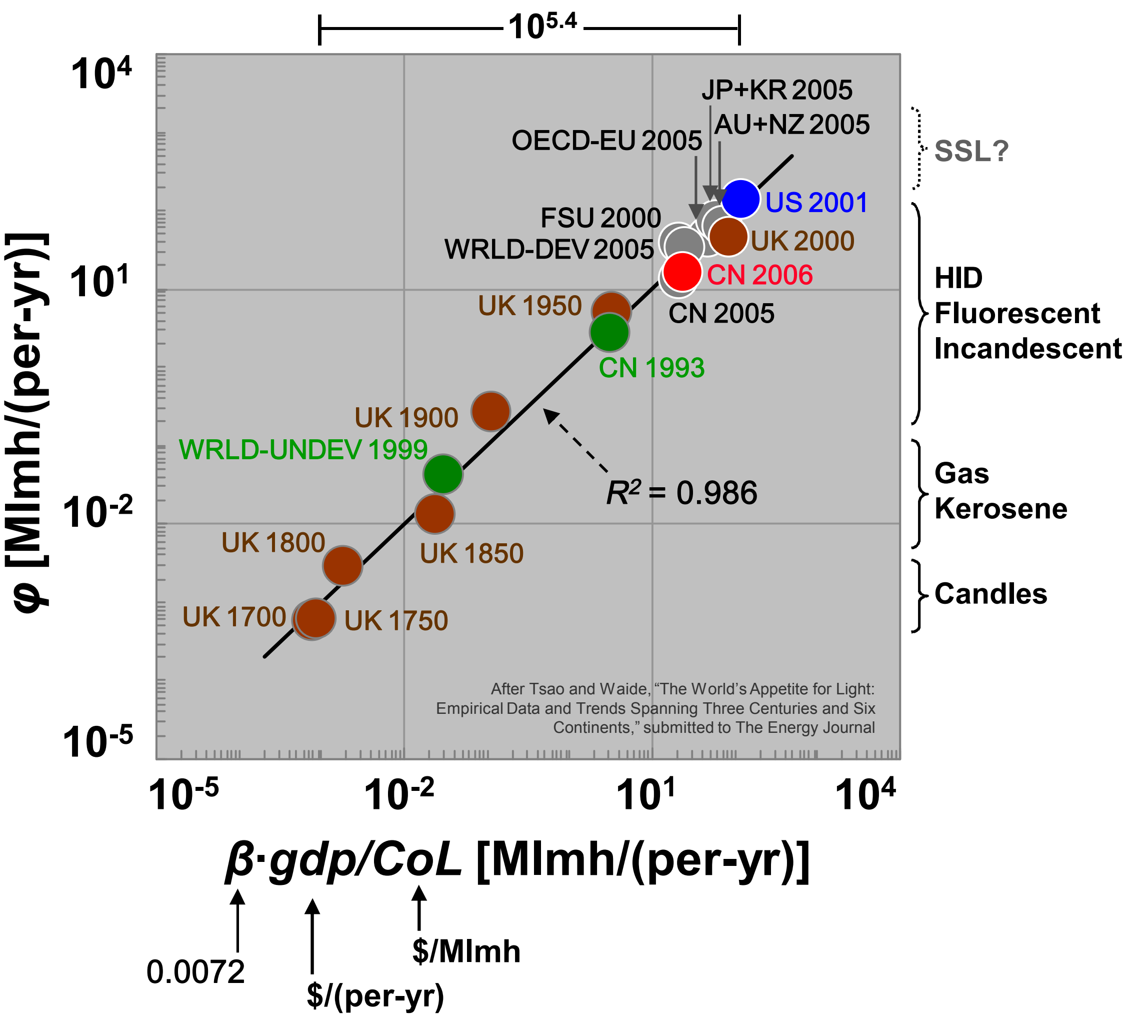
Back-Up

Publications



$\varphi = \beta \cdot (gdp/CoL)$



Implication 1:

World has spent, and spends, ~0.72% of GDP on artificial light

The world in 2005:

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

6.5% = 1 TW_c / 16 TW_c

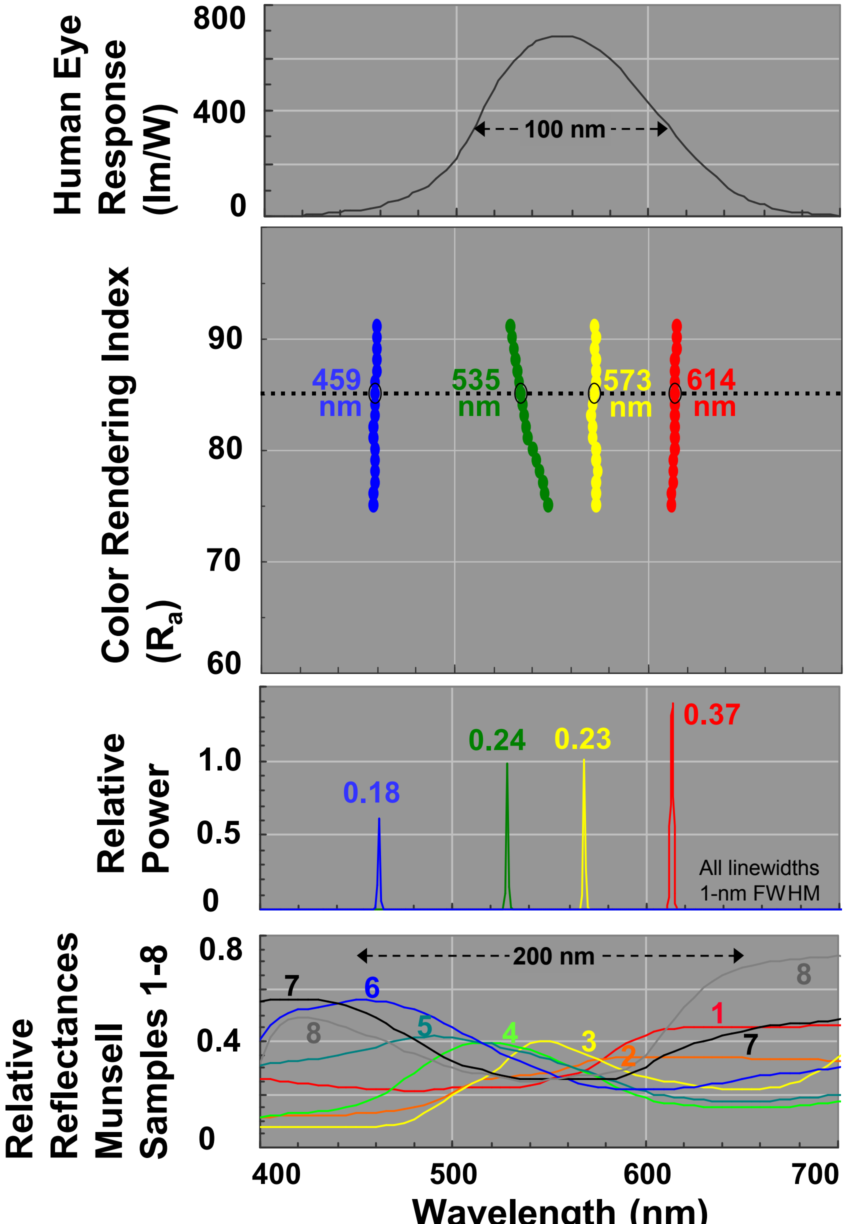
Implication 2:

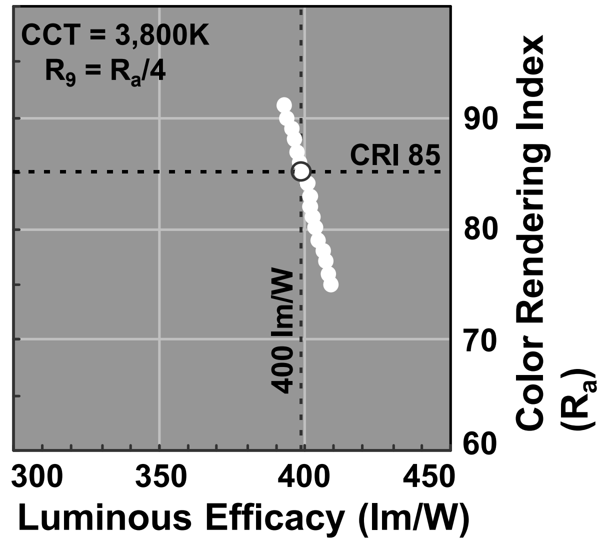
Price and income elasticity of consumption of light is ~unity

Rebound is likely driven by human productivity:

If light is cheaper, we consume more so that we will be more productive (we're not just treading water)

Characteristics of “100%-Efficient” Lighting

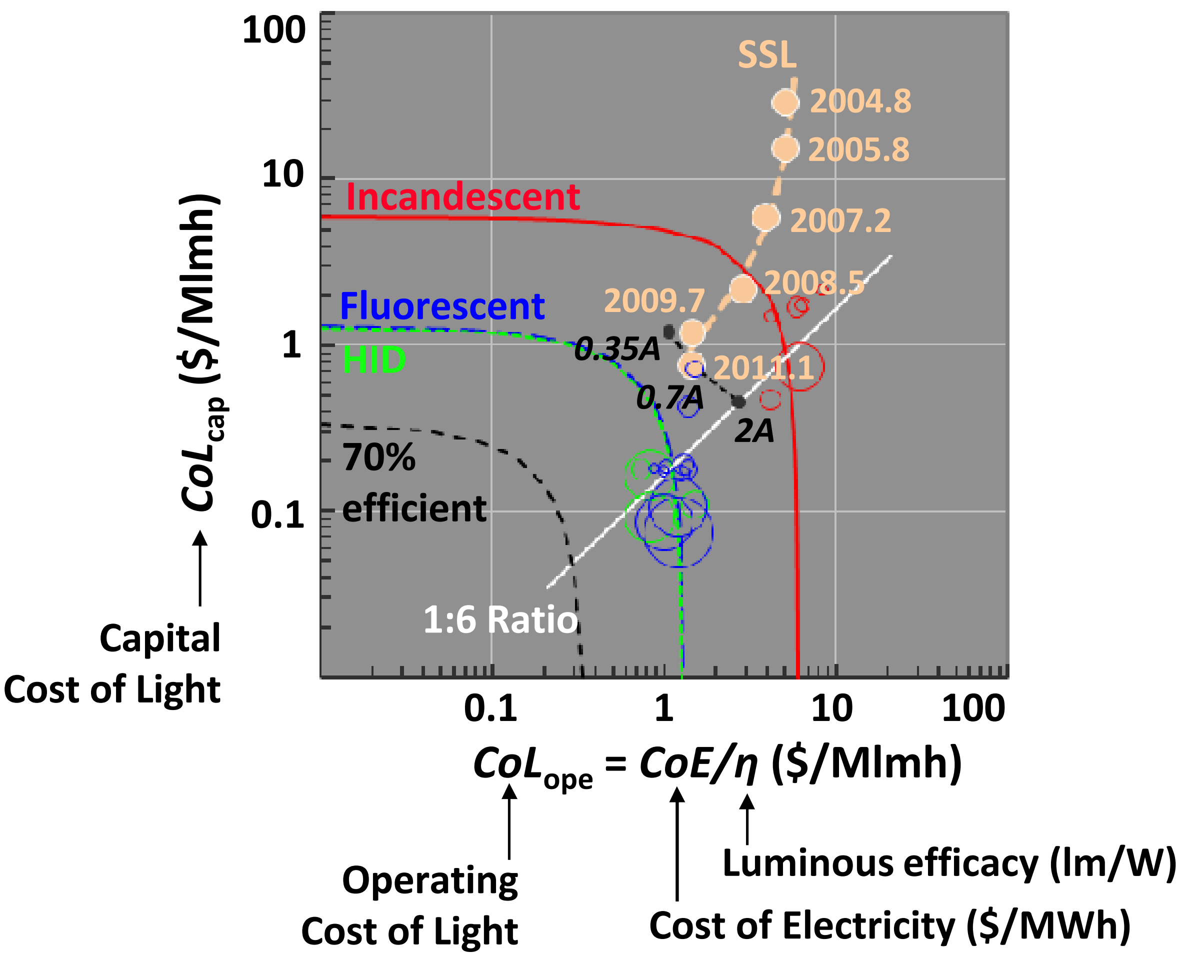




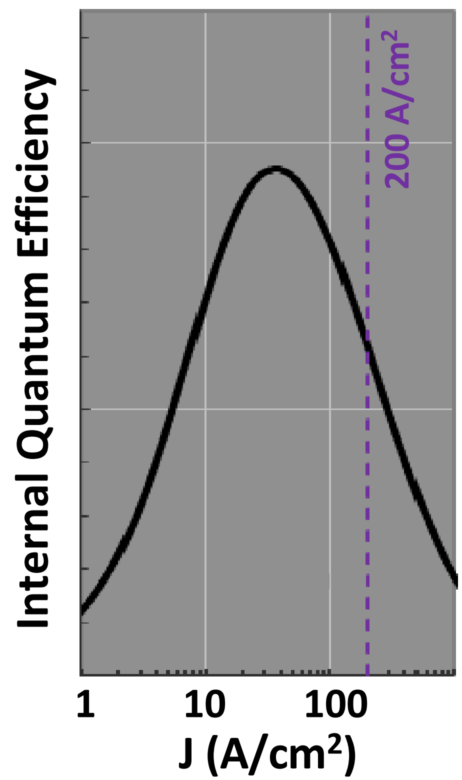
J.M. Phillips, et al, “Challenges to Ultra-Efficient SSL”, Laser & Photonics Reviews (2007). Calculations based on white LED simulator 5-3 (Y. Ohno, NIST).

1 Efficiency droop

High current density is the preferred route to lower capital cost of light

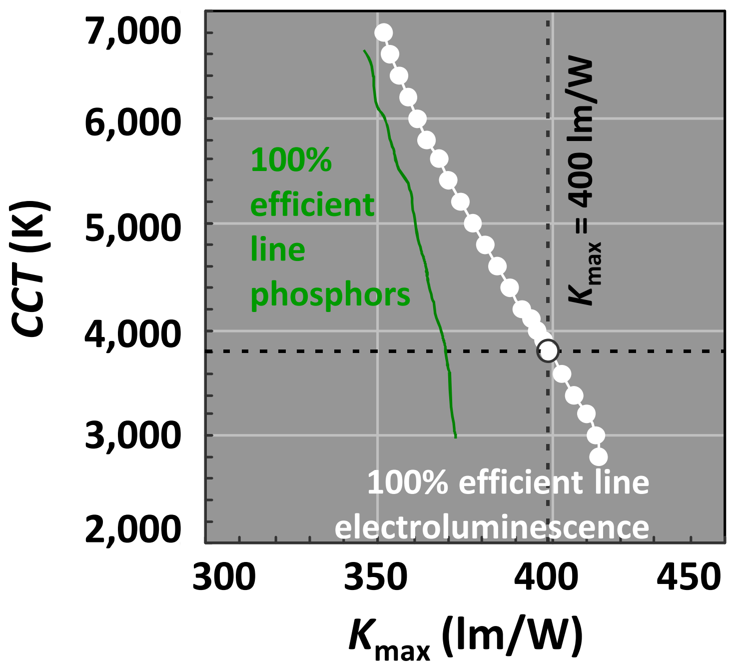


if not for efficiency droop

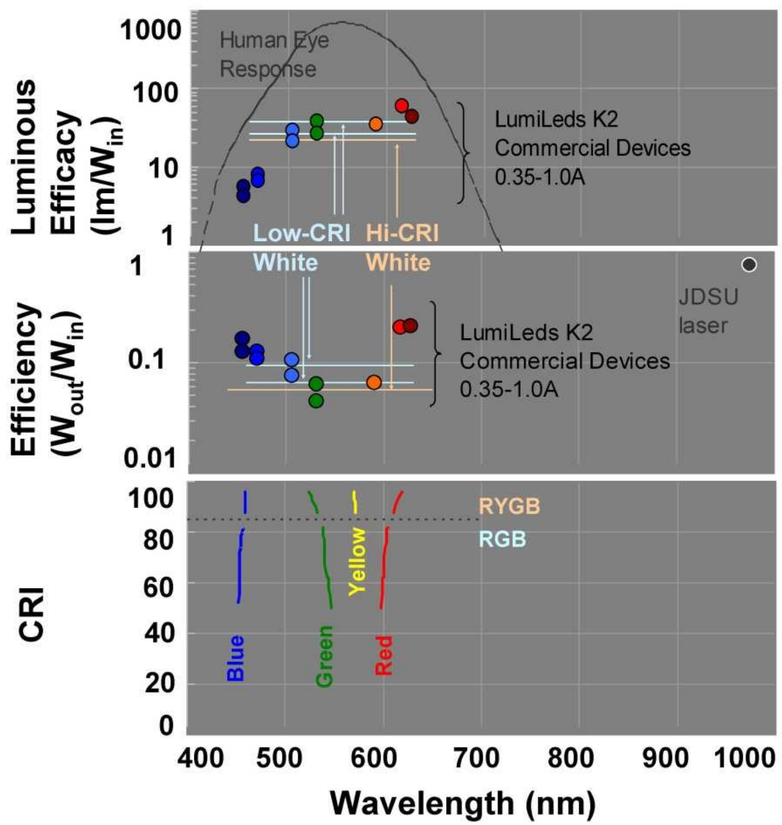


2 Green-Yellow-Orange Electroluminescence Gap

We would like to do away with phosphors, and their inherent Stokes deficit



But the GYO color range cannot yet be bridged by electroluminescent semiconductors



3 Fat linewidth shallow-red phosphor

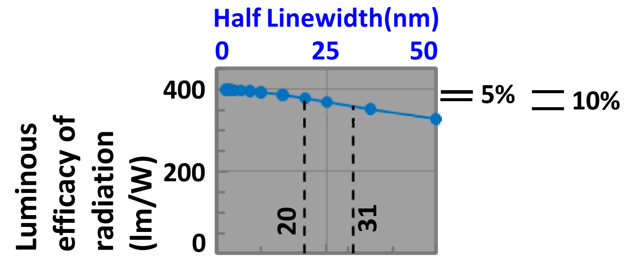
~1/2 of white is red

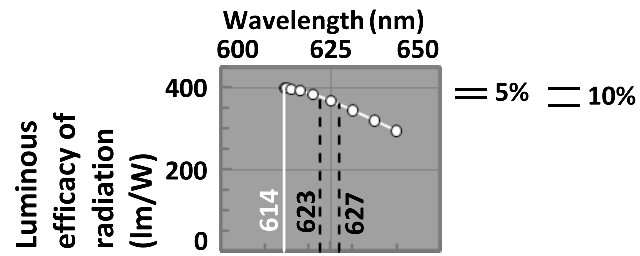
Stokes loss from blue to red is ~1/4

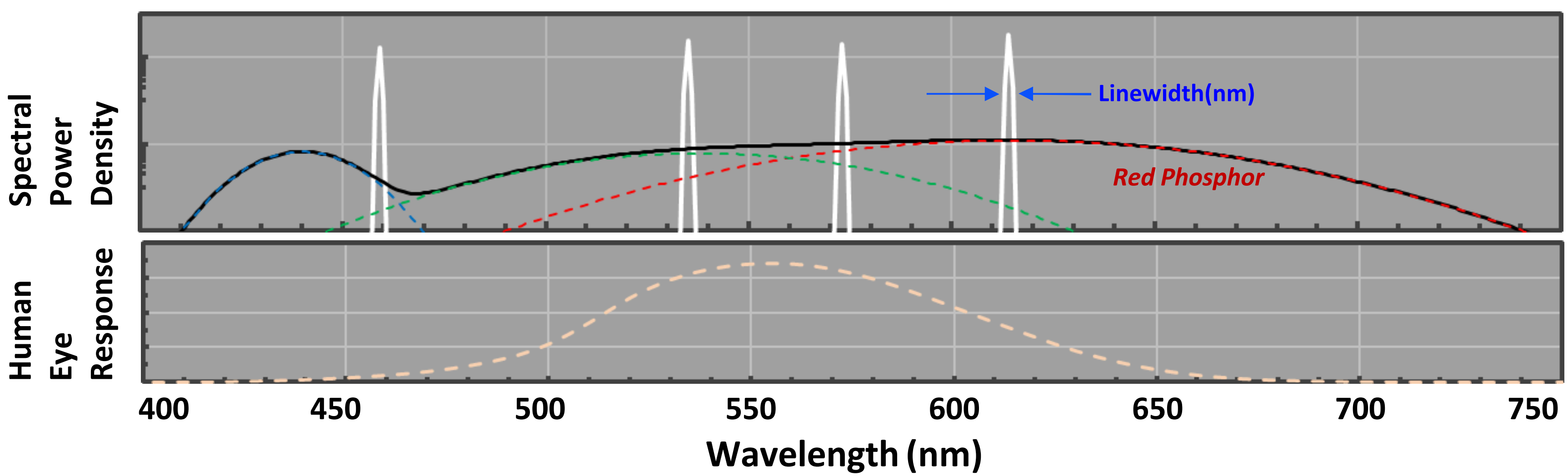
Red phosphors suffer from:

(a) Stokes inefficiency (1/2)*(1/4) = 12%

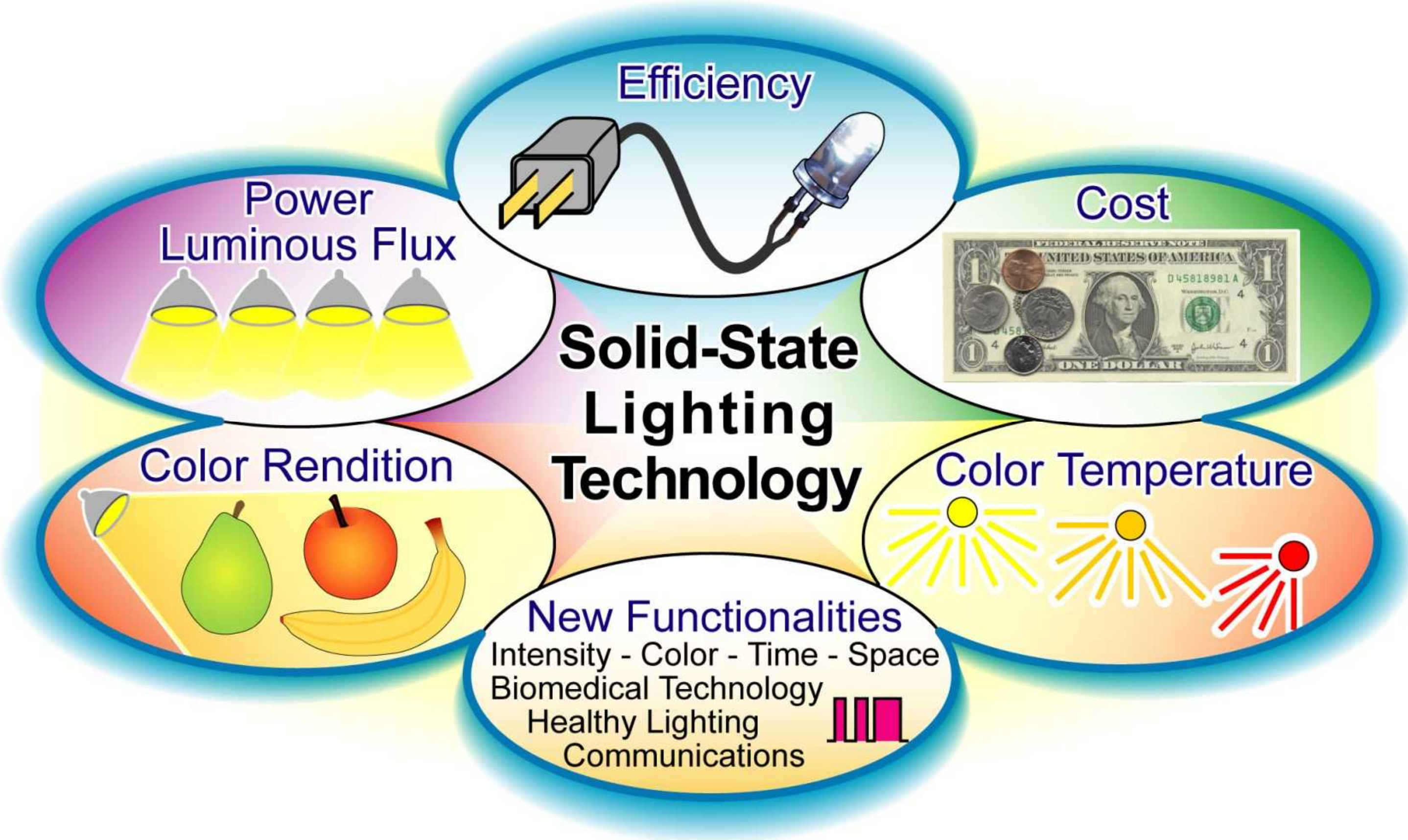
(b) Spectral inefficiency = 20%







4 Dumb Light



Efficiency
Power
Luminous Flux
Cost
Solid-State
Lighting
Technology
Color Rendition
Color Temperature
New Functionalities
Intensity - Color - Time - Space
Biomedical Technology
Healthy Lighting
Communications