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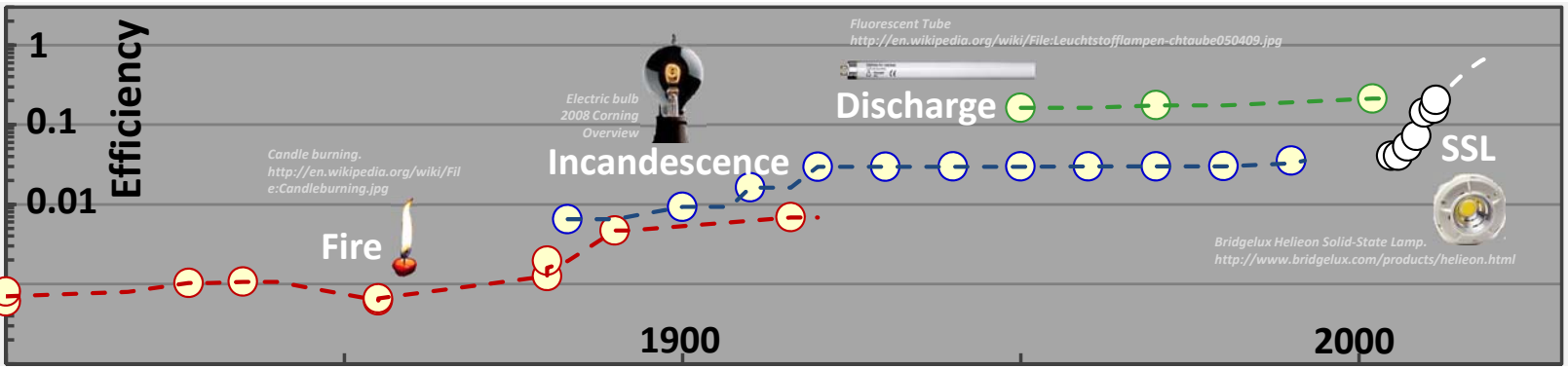

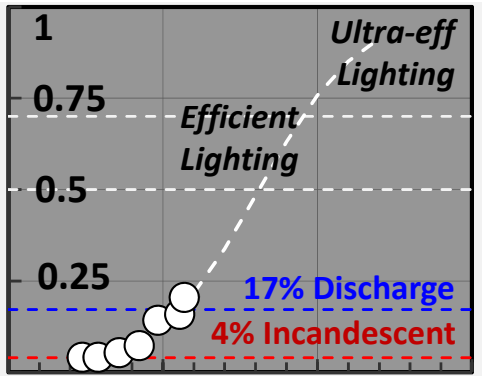

Perspectives on the Future of SSL: Characteristics, Economics, Approaches

Jeff Tsao

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Po-Chieh Hung, Harry Saunders, Dmitry Sizov, Jon Wierer
Mike Coltrin, Mary Crawford, Jerry Simmons
Steve Brueck , Wendy Davis, Sasha Neuman, Lauren Rohwer , Yoshi Ohno

June 26-29, 2012

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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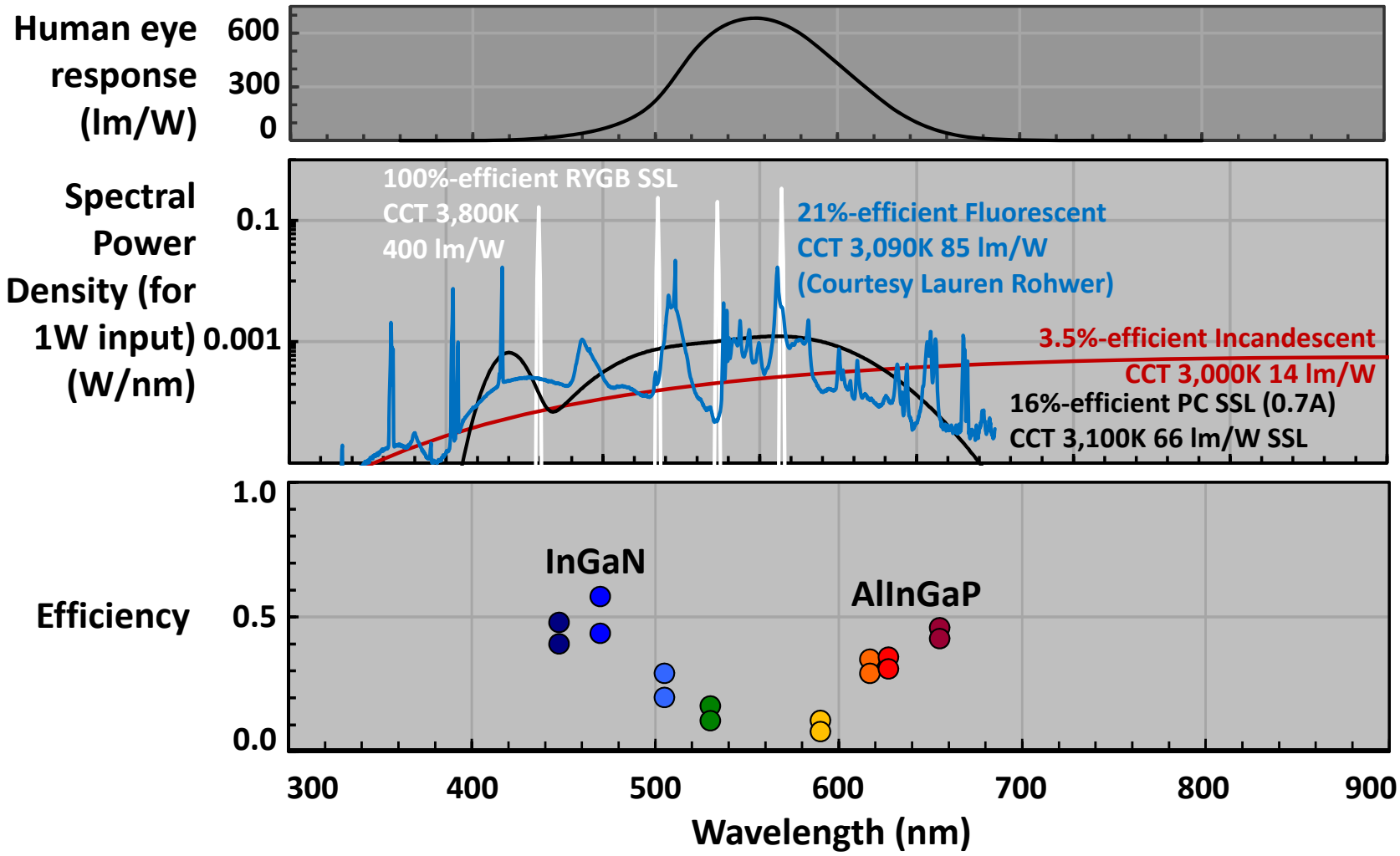
Toward ultra-high (>70%) efficiency

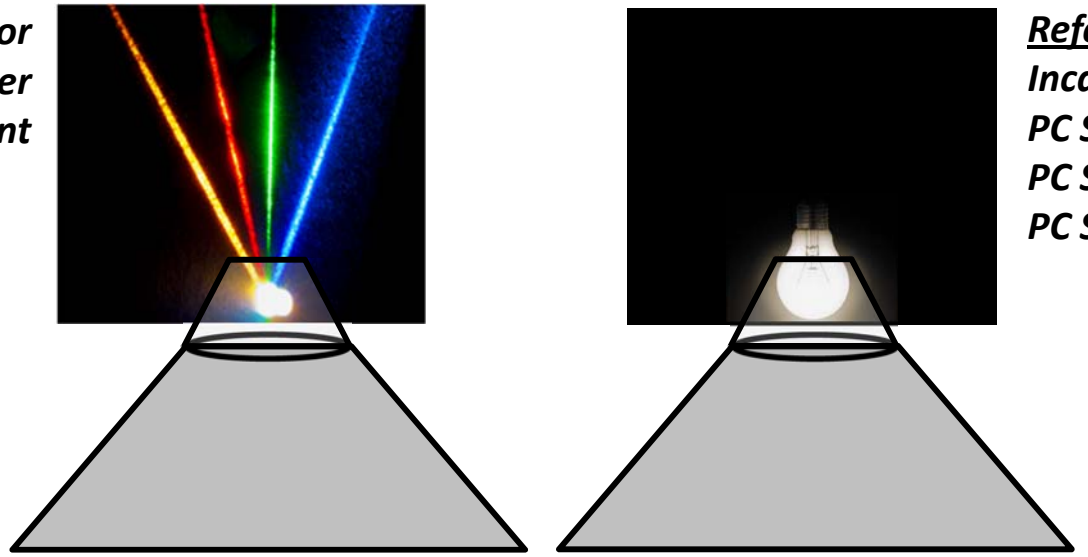


B
Spiky spectra

A
All EL (no Stokes loss)
0.2 = 0.8x0.25

The ultimate spiky source: a 4-color laser illuminant

4-Color Laser Illuminant

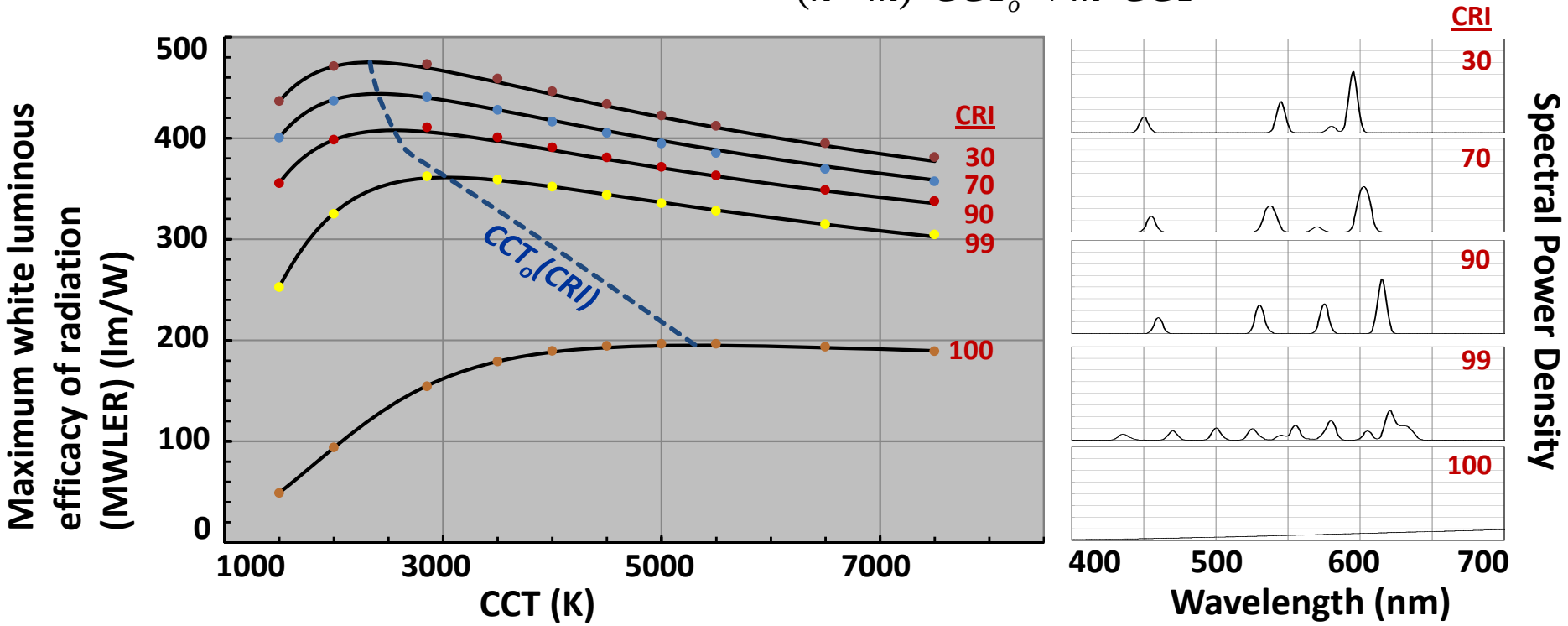


Reference sources
Incandescent (o)
PC SSL Warm (o)
PC SSL Neutral (-)
PC SSL Cool (-)

A. Neumann, J.J. Wierer, Jr., W. Davis, Y. Ohno, S.R.J. Brueck, and J.Y. Tsao, "Four-color laser white illuminant demonstrating high color-rendering quality," Optics Express **19**, A982-A990 (2011).

Even with spiky spectra, the 100%-efficiency LER depends on CCT & CRI

$$MAXLER_{MAXLER_o,CCT_o,n,m}(CCT) = \frac{MAXLER_o \cdot n \cdot CCT_o^{n-m} \cdot CCT^m}{(n-m)\cdot CCT_o^n + m \cdot CCT^n}$$

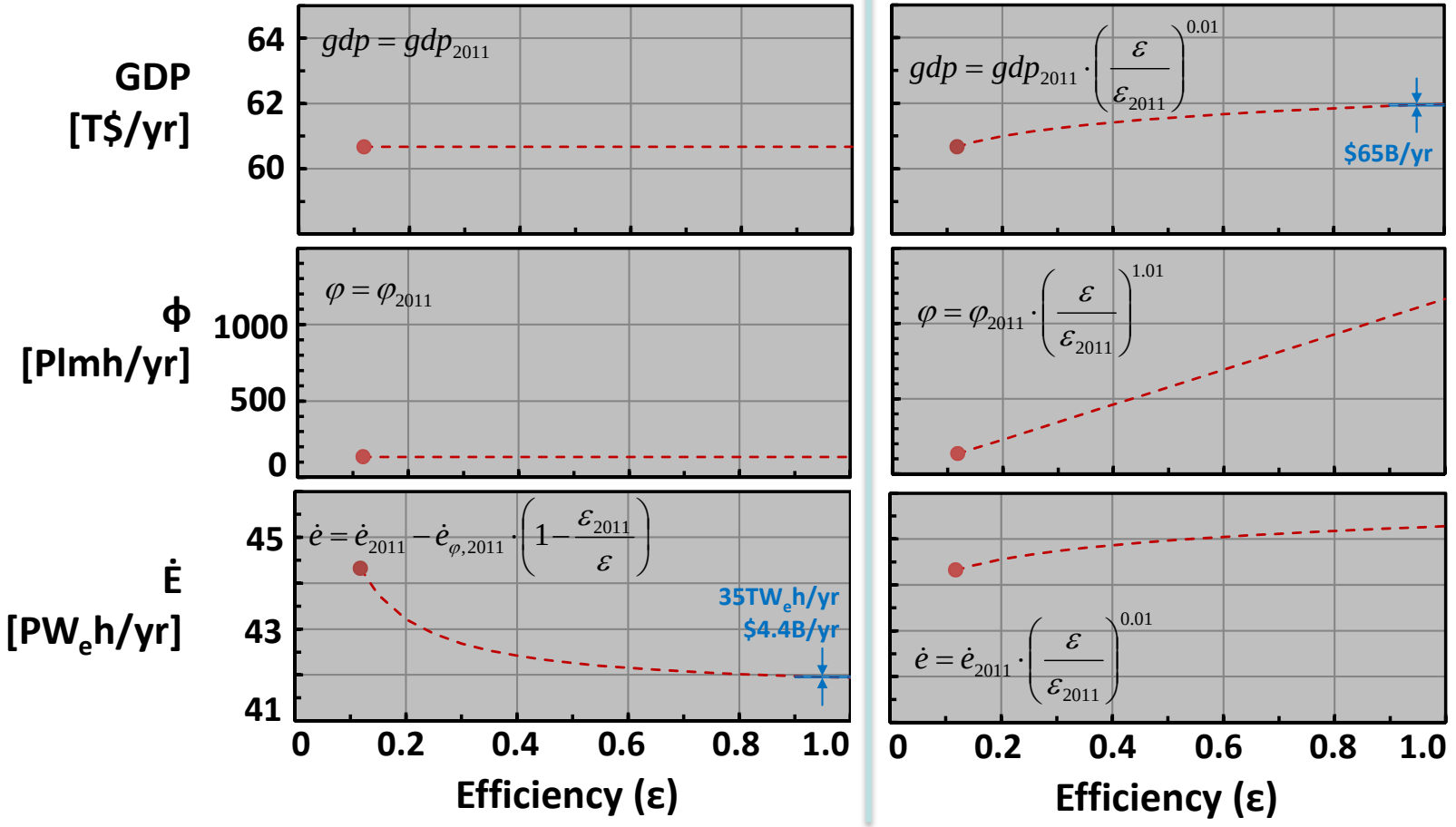


After P.C. Hung and J.Y. Tsao, "Maximum luminous efficacy of radiation versus color temperature and color rendering index: exact results and a useful semi-empirical expression," manuscript in preparation.

But…, is near-100% efficiency worth pursuing?

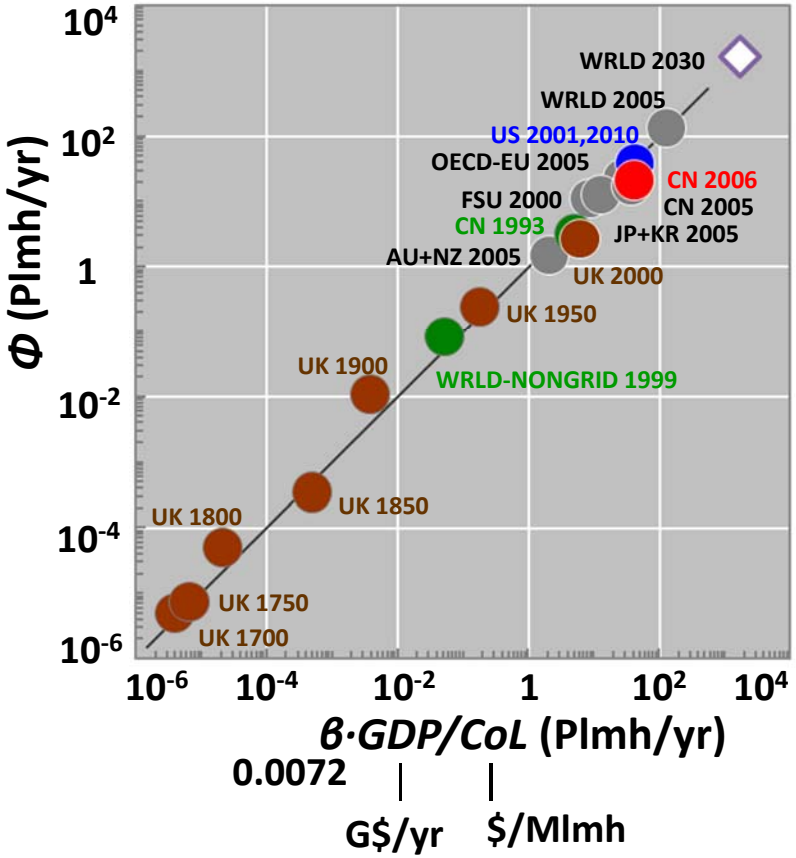
Light *isn't* an economic factor of production, and consumption is saturated

Light *is* an economic factor of production, and consumption isn't saturated

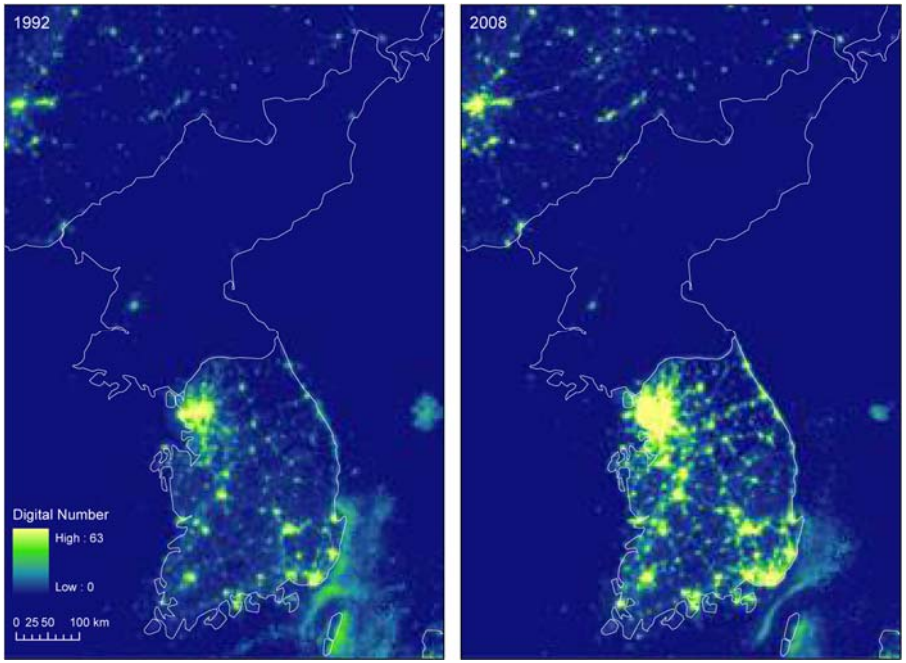


J.Y. Tsao, H.D. Saunders, J.R. Creighton, M.E. Coltrin and J.A. Simmons, "Solid-state lighting: an energy-economics peerspective," J. Physics D **43**, 354001 (2010).

A qualified yes: more light = more productivity



J.Y. Tsao and P. Waide, "The World's Appetite for Light: Empirical Data and Trends Spanning Three Centuries and Six Continents," LEUKOS **6**, 259-281 (2010).

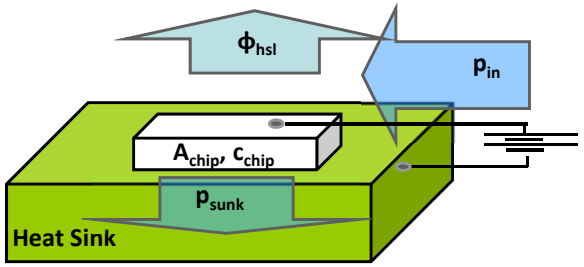


1992 2008

Korean Peninsula

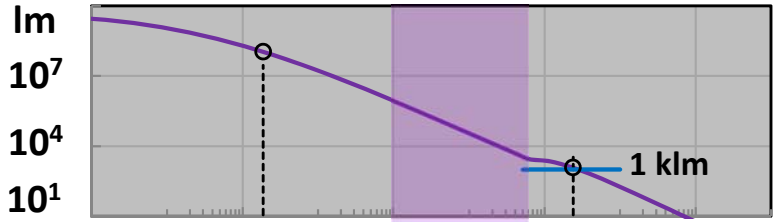
J.V. Henderson, A. Storeygard, and D.N. Weil, "Measuring Economic Growth from Outer Space," Amer. Economic review **102**, 994-1028 (2012).

Two competing approaches: low and high power densities



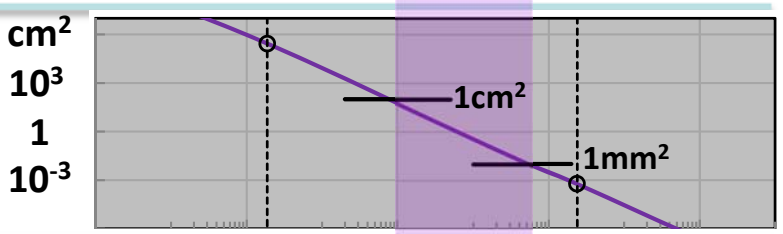
4 Heat-sink-limited white light flux

$$\Phi_{hsl} = \frac{MWLER \cdot \varepsilon_B \varepsilon_{PP}}{\left(P_{in}/A_{chip}\right)} \cdot \left[\frac{2\kappa_T \sqrt{4/\pi} \cdot \Delta T_{\max}}{(1-\varepsilon_B \varepsilon_{PP}) \cdot}\right]^2$$



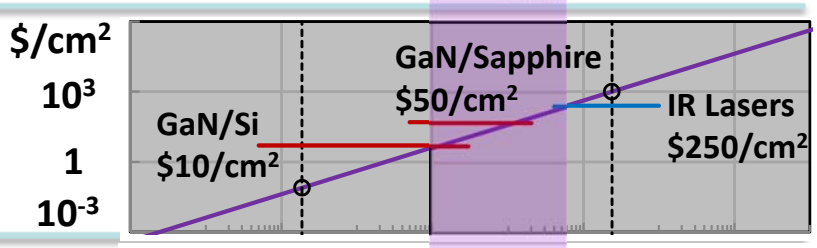
3 Heat-sink-limited chip area

$$A_{hsl} = \left[\frac{2\kappa_T \sqrt{4/\pi} \cdot \Delta T_{\max}}{(1-\varepsilon_B \varepsilon_{PP}) \cdot \left(P_{in}/A_{chip}\right)}\right]^2$$



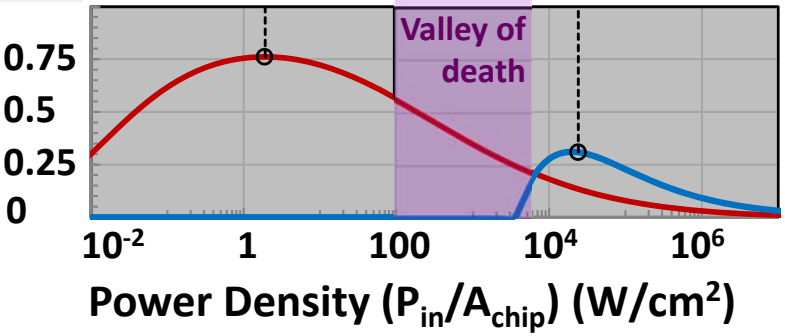
2 Chip areal cost necessary for $CoL_{cap} < CoL_{ope}/6$

$$c_{chip} = \frac{L \cdot CoE}{6\alpha} \cdot \left(P_{in}/A_{chip}\right)$$



1 Efficiency, and its valley of death

$$\varepsilon_B\,(Blue\ Emitter\ Efficiency)$$



After J.J. Wierer, et al, "Blue Lasers for Solid-State Lighting: Potential and Challenges," manuscript in preparation.