



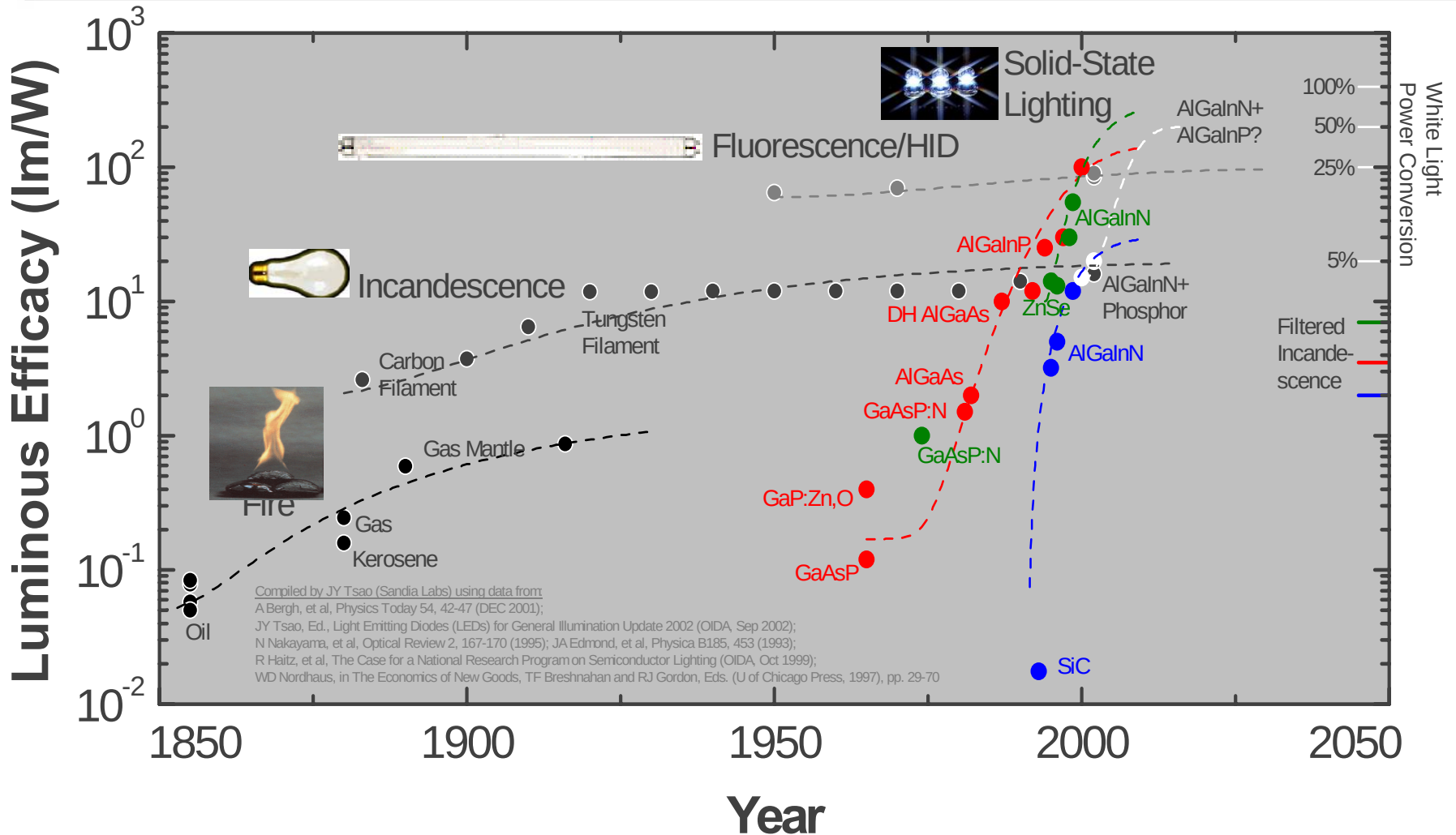
the Next Semiconductor Revolution: this Time it's Lighting!

Jeff Tsao

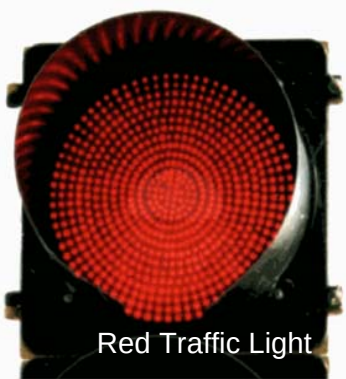
**Physical, Chemical and Nano Sciences Center
Sandia National Laboratories**

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Security Administration under Contract DE-AC04-94AL85000.

History of Lighting Technology



Applications for Colored LEDs



Red Traffic Light



NASDAQ Giant Video Display
Times Square NY (Jeff Tsao)



Programmable Lights Ben Franklin
Bridge, Philadelphia (Color Kinetics)



LED Flash
Camera
Phone
(Motorola
E815)



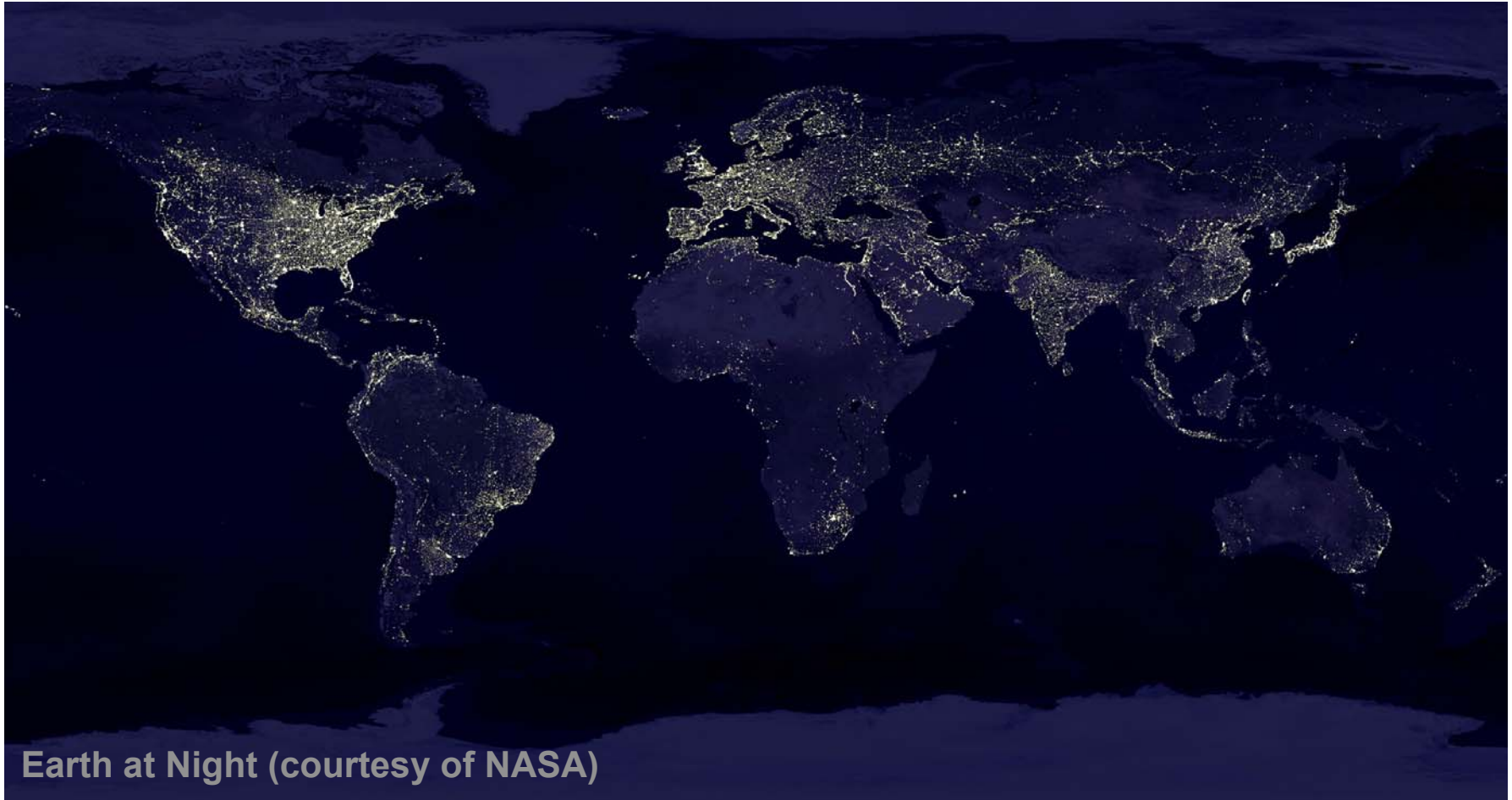
Rear Combination Lamp
(LumiLeds)



LED Backlit LCD Display
(Sony Qualia)

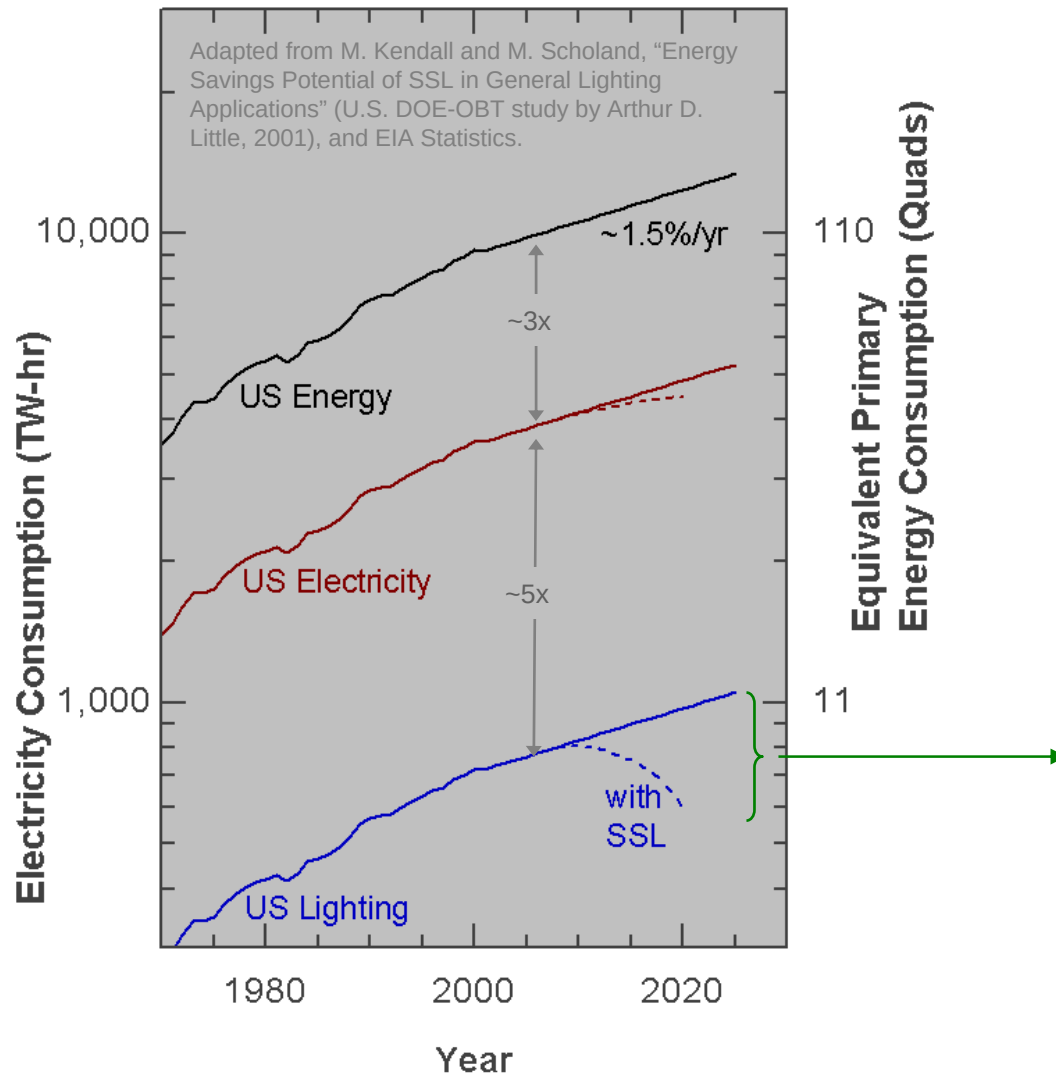


Lighting the Earth



Projected Energy and Carbon Savings

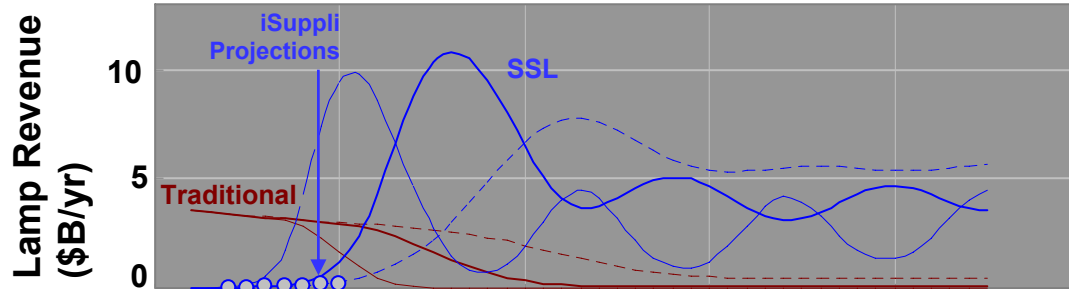
Adapted from M. Kendall and M. Scholand, "Energy Savings Potential of SSL in General Lighting Applications" (U.S. DOE-OBT study by Arthur D. Little, 2001), and EIA Statistics.



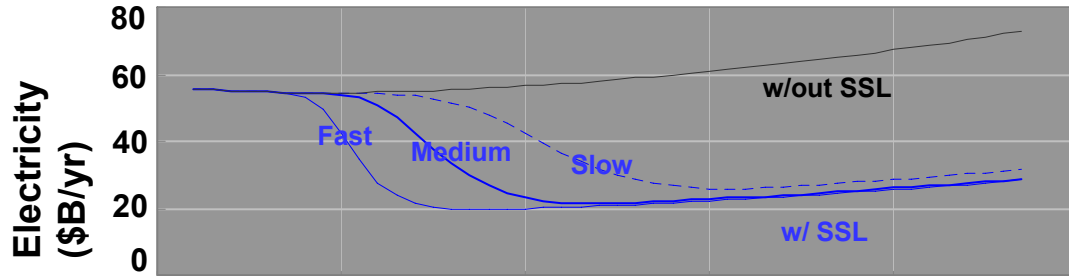
<u>Projected Year</u> <u>2025 Savings</u>	<u>US</u>	<u>World</u>
Electricity used (TWh/yr)	620	~2,000
\$ spent on Electricity (\$B/yr)	42	~150
Electricity generating capacity (GW)	70	~250
Carbon emissions (MtC/yr)	100	~350
% of Kyoto protocol	7.5	

Projected Industry Revenue (U.S.)

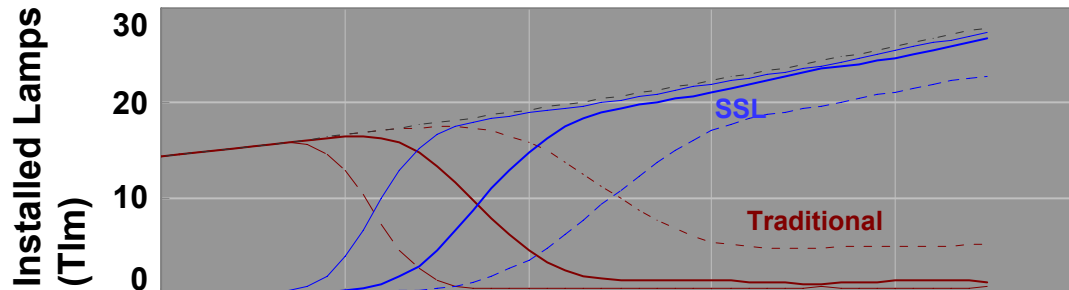
Impact on Industry Revenue



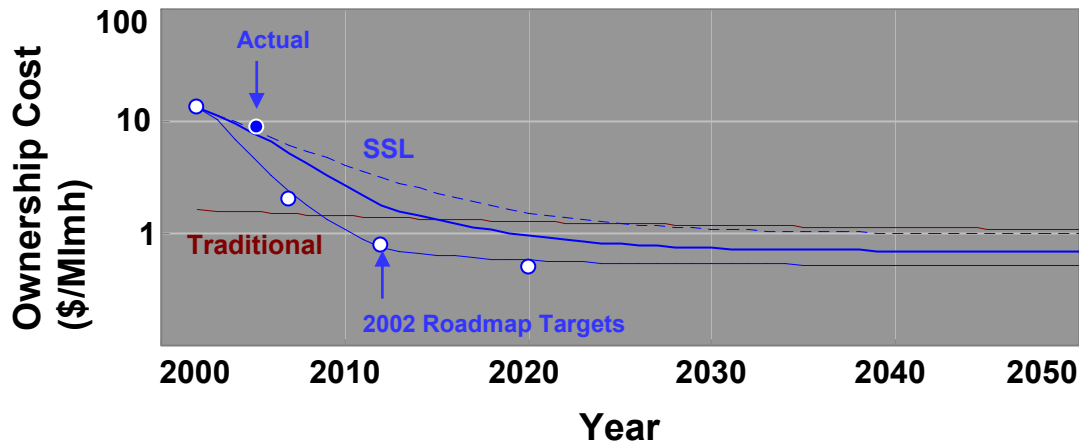
Impact on Energy Consumption



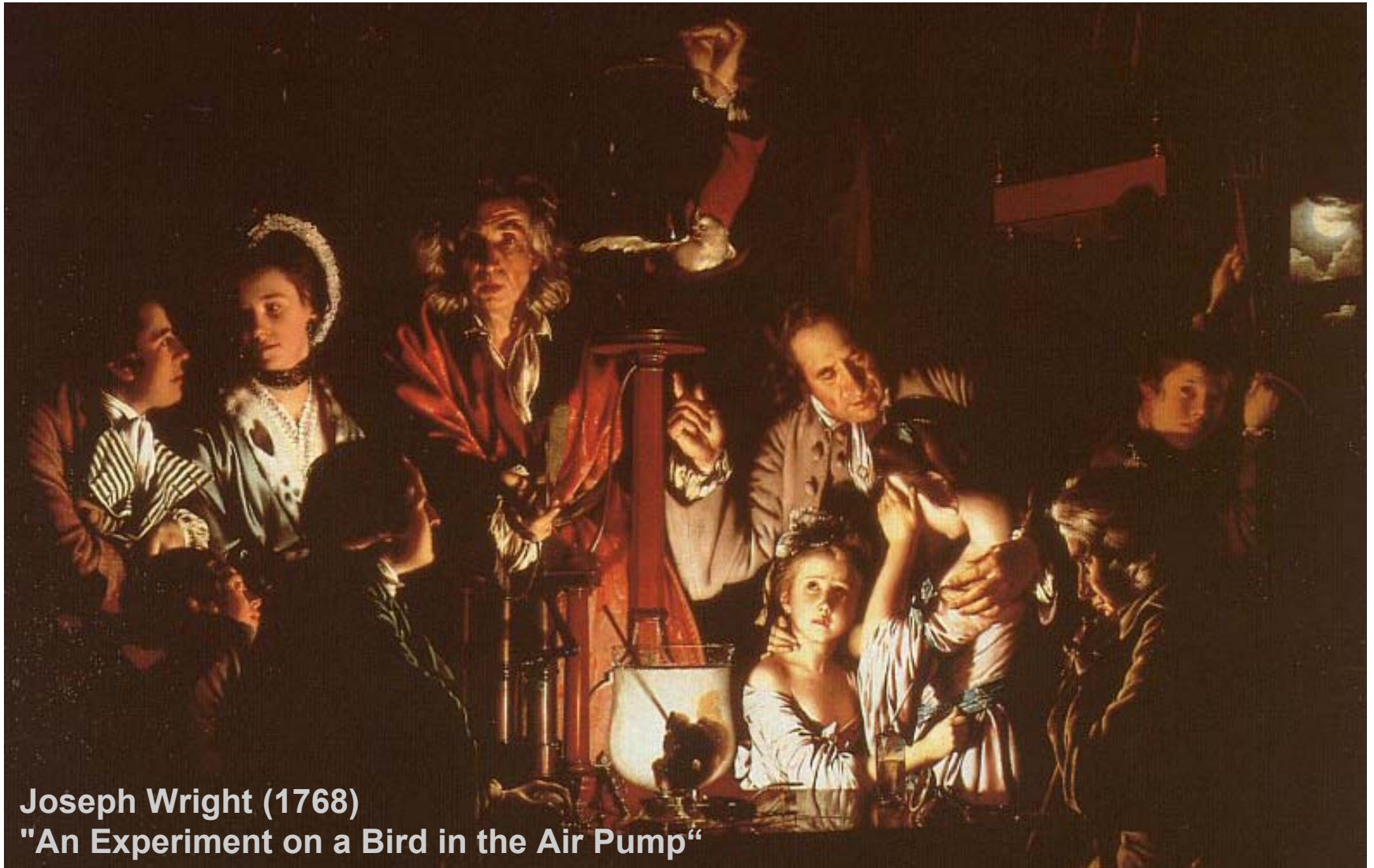
Technology Diffusion (Market Penetration)



Technology Evolution

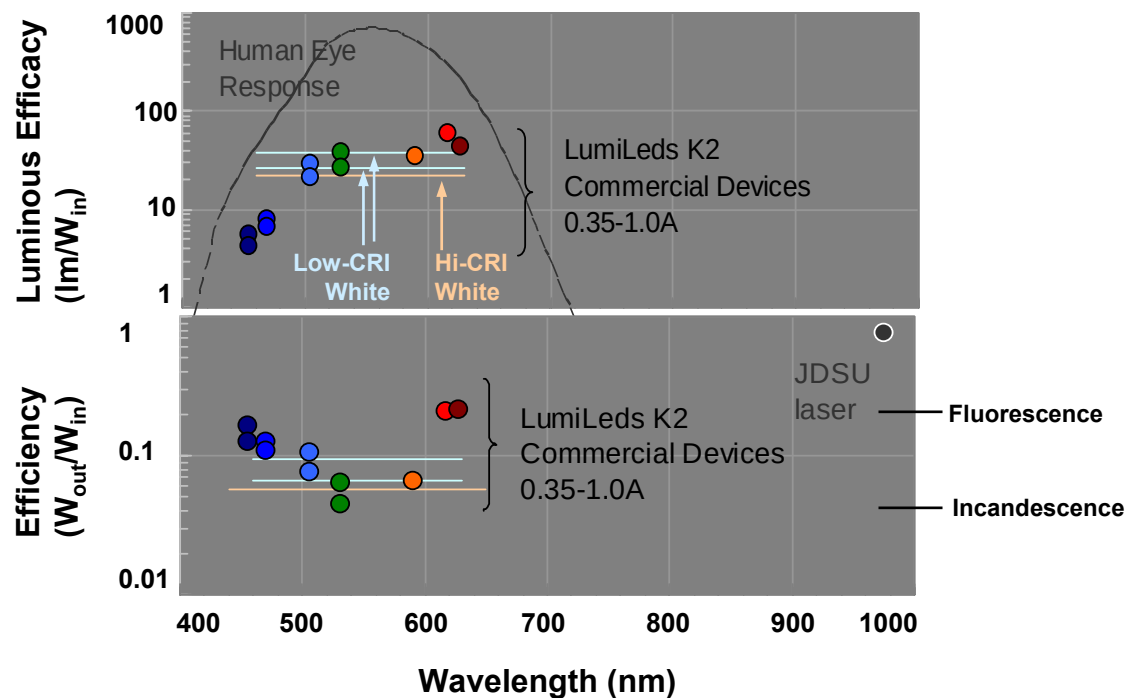


Human Visual Experience

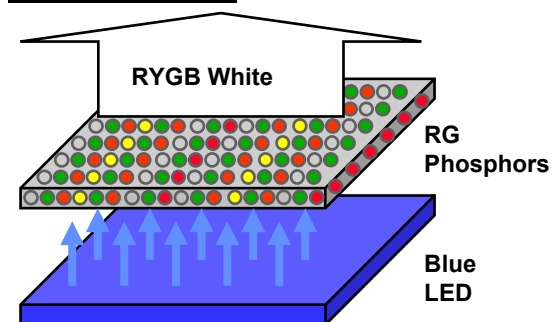


Joseph Wright (1768)
"An Experiment on a Bird in the Air Pump"

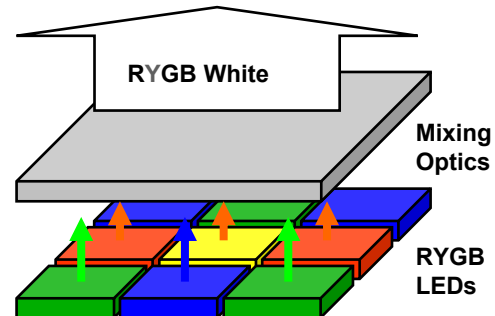
SSL Approaches and Challenges



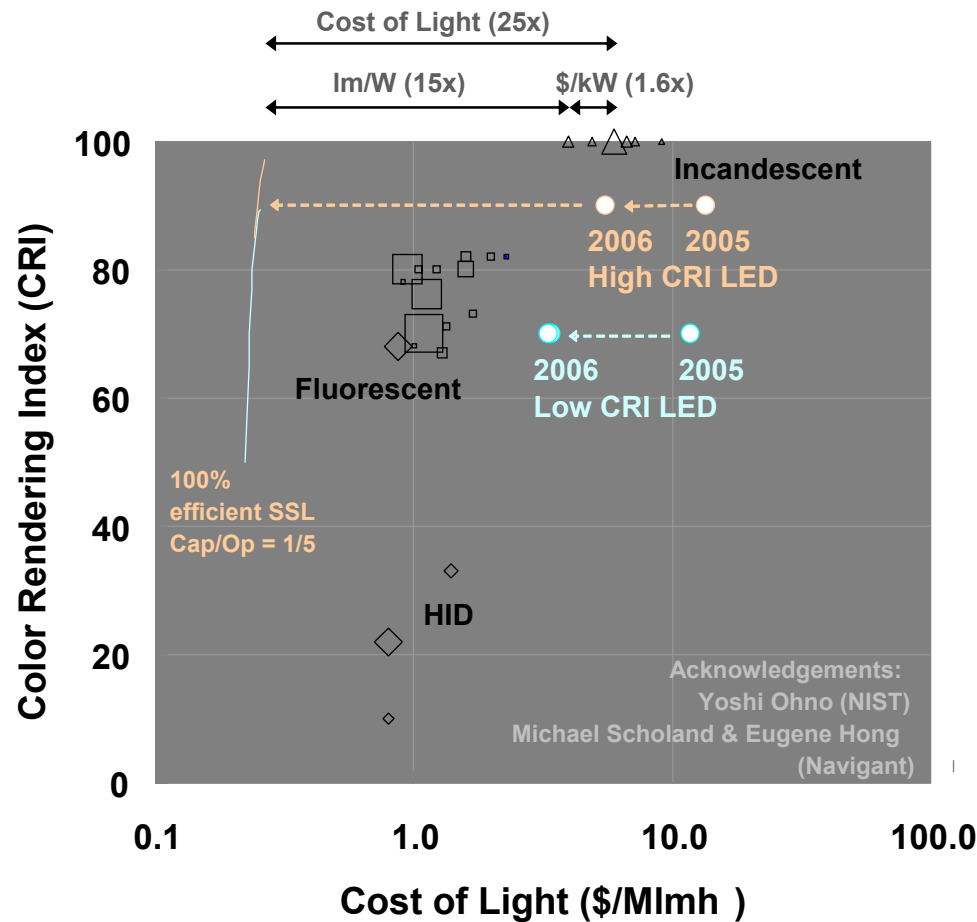
Phosphor Down-Conversion



Color Mixing

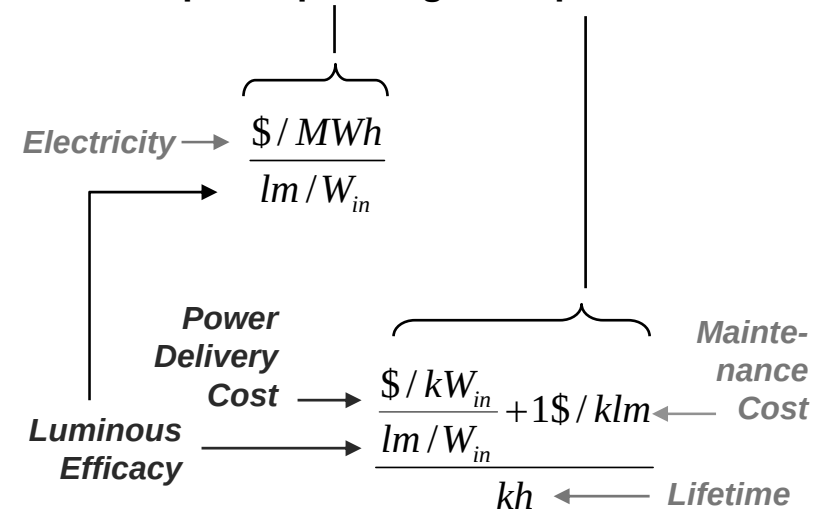


SSL Evolution

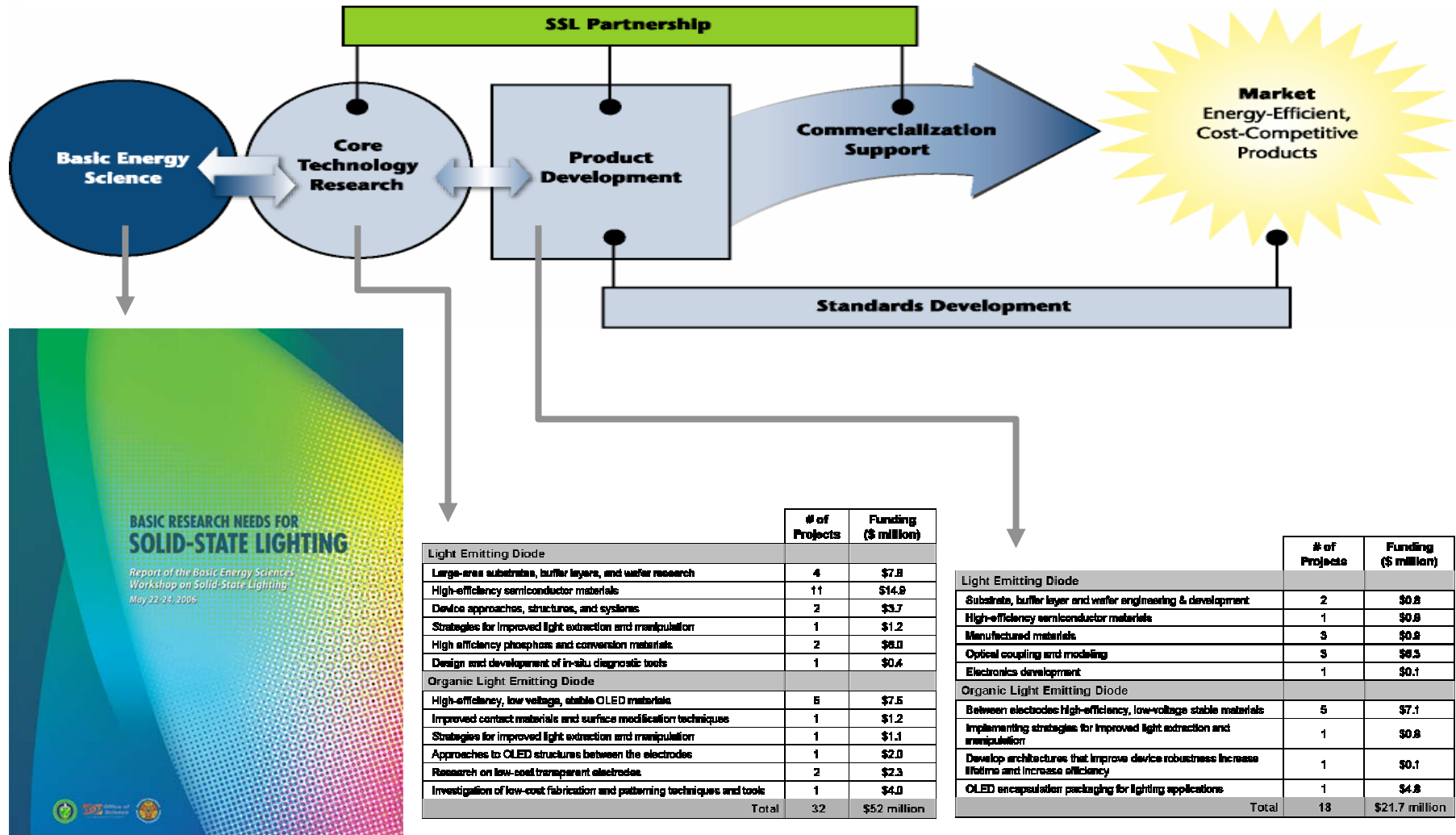


Costs:

Ownership = Operating + Capital

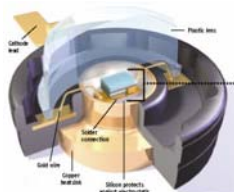
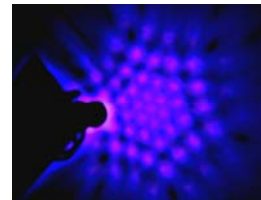
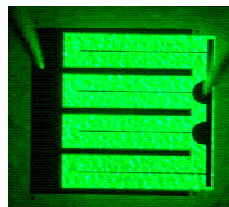
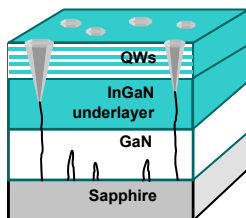
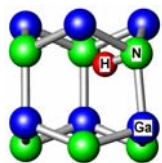
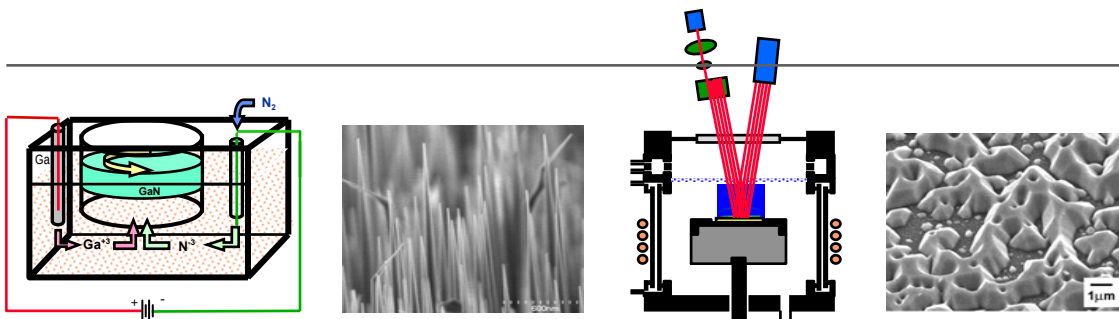


DOE Programs as of mid-2006



Sandia's SSL projects span a wide range of S&T

<http://lighting.sandia.gov/>



0 General

Economics
Roadmapping

1 Substrates, Buffers and Epitaxy

1.1 Substrates
1.2 Buffers
1.3 Epitaxy Tools
1.4 Epitaxy Processes

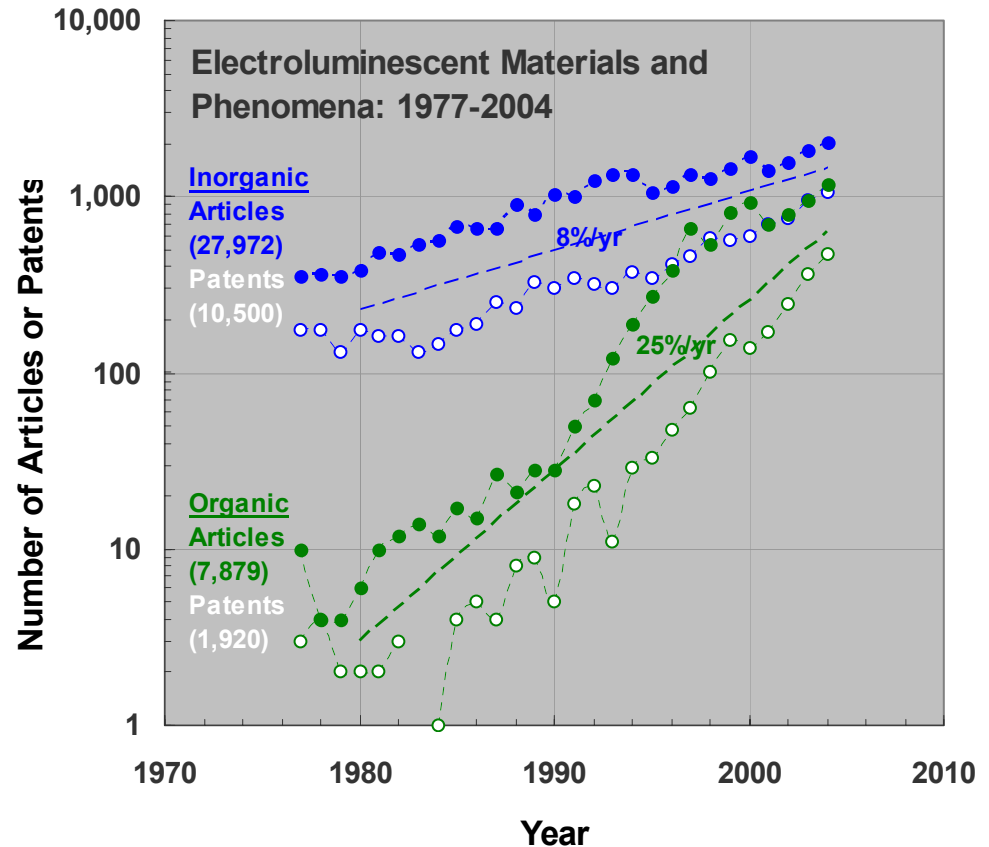
2 Physics, Processing and Devices

2.1 Semiconductor Physics
2.2 Device Processing
2.3 LEDs and Integrated LEDs
2.4 Directional Emitters

3 Lamps, Luminaires and Systems

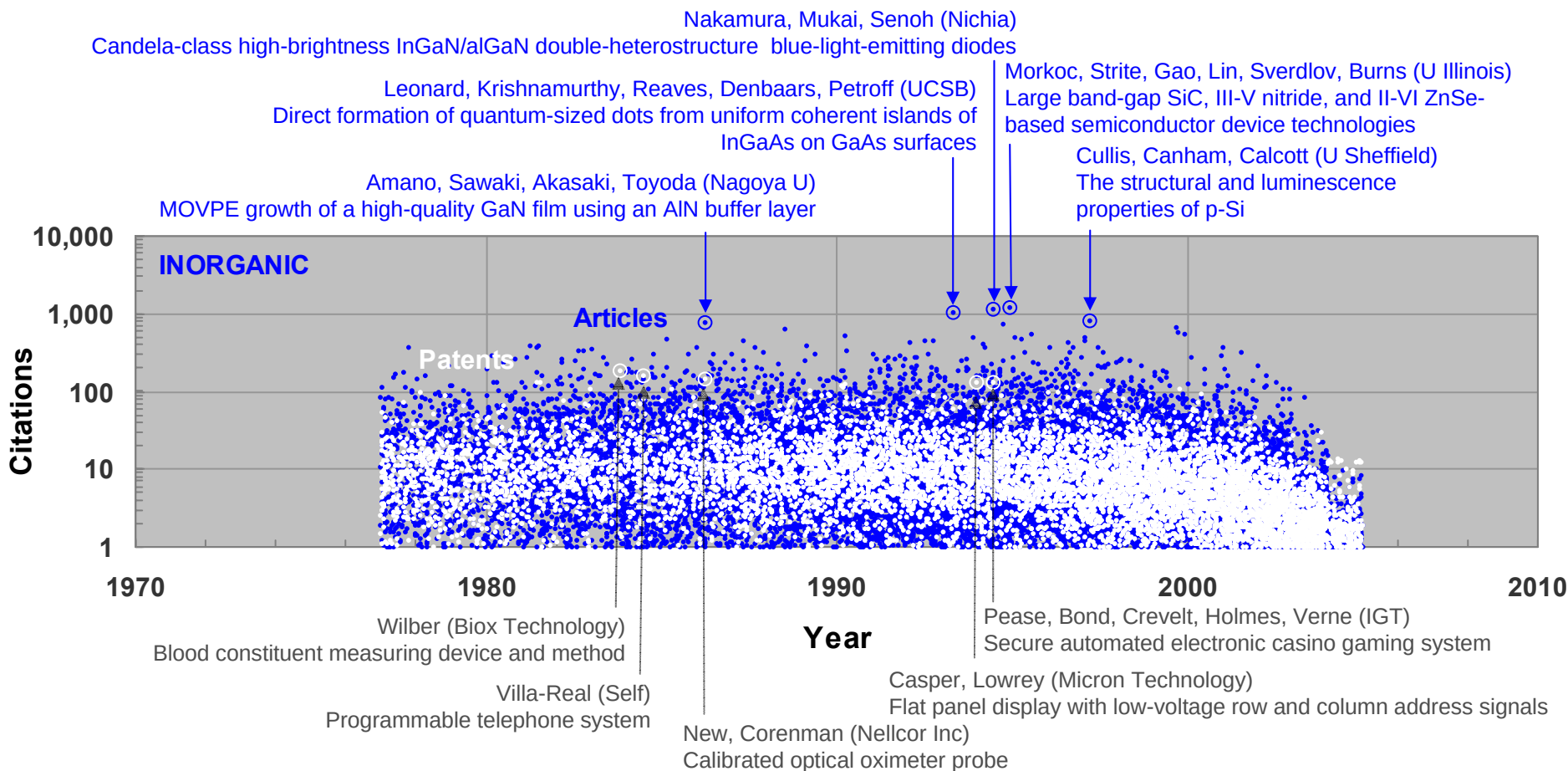
3.1 Phosphors and Encapsulants
3.2 Lamps and Electronics
3.3 Luminaires
3.4 Lighting Systems

International SSL Knowledge Base is Growing Rapidly

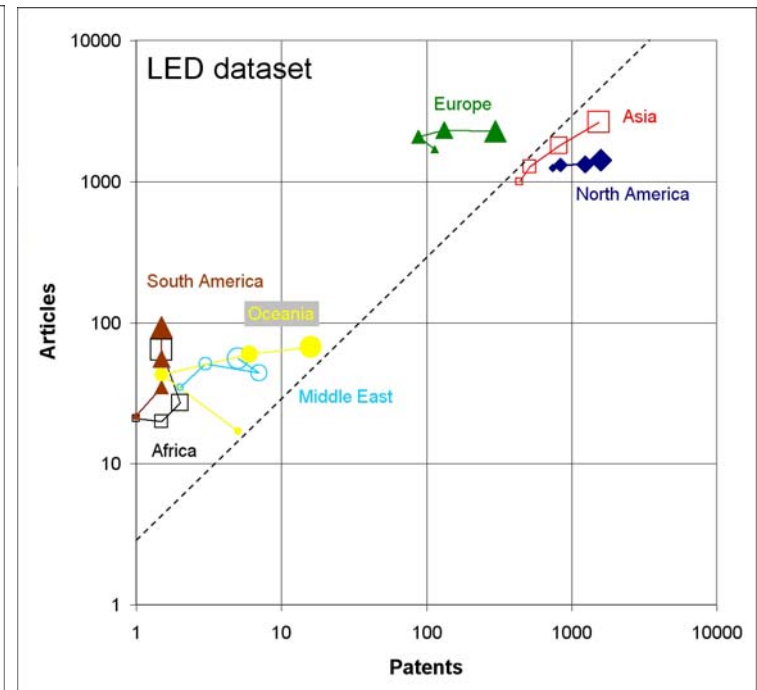
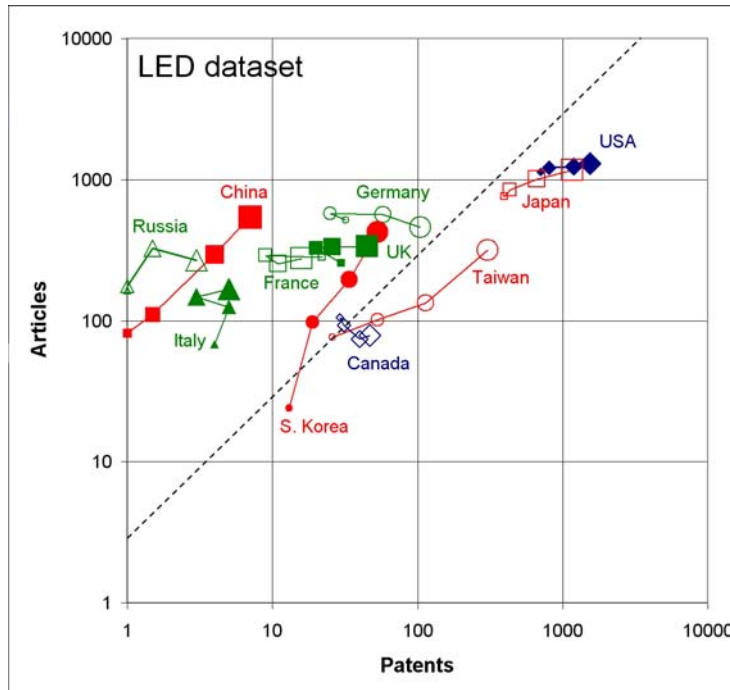




Inorganic SSL Knowledge Base: Citation Chronology



Inorganic SSL Knowledge Base: Distribution by Nation and Continent





Energy
Consumption Rate
Population

Impact of SSL on Energy Intensity

per capita
GDP

Energy
Intensity

=

Energy consumption rate
required to sustain a given GDP

$$\dot{E} = N \cdot (GDP / N) \cdot (\dot{E} / GDP)$$



As technology (T) evolves,
energy intensity ($\dot{E}/GDP$)
can evolve in two ways

$$\frac{\partial(\dot{E} / GDP)}{(\dot{E} / GDP) \partial T} = \frac{\partial \dot{E}}{\dot{E} \partial T} \bigg|_{GDP} - \frac{\partial GDP}{GDP \partial T} \bigg|_{\dot{E}}$$

1 Decrease in energy consumption rate
(easy to imagine, though may be near-zero
if there is a “rebound” effect)

2 Increase in GDP (difficult to
imagine, but may be as large or
larger)