



A History Of Lighting Technologies

Flames to Filaments to Quantum Devices

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Overview

- Broad survey of historical evolution
- Qualities of light
- How incandescent, fluorescents, LED's work
- Energy efficiency, demand elasticity, and climate
- Lessons: technological feedbacks, efficiency vs quality of service, long-term unpredictability of energy service demands

Lighting Technologies

- 400,000 BCE controlled use of fire
- 70,000 BCE moss & animal fat lamps*
- 4500 BCE oil lamps
- 3000 BCE candles



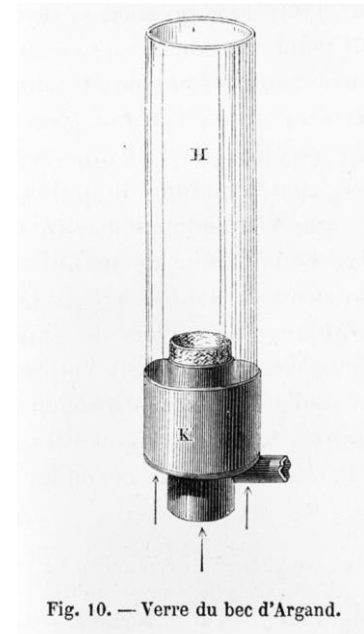
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- 1800 Gas lamps, Argand lamp
- 1800-1840 Demonstration of electric & incandescents



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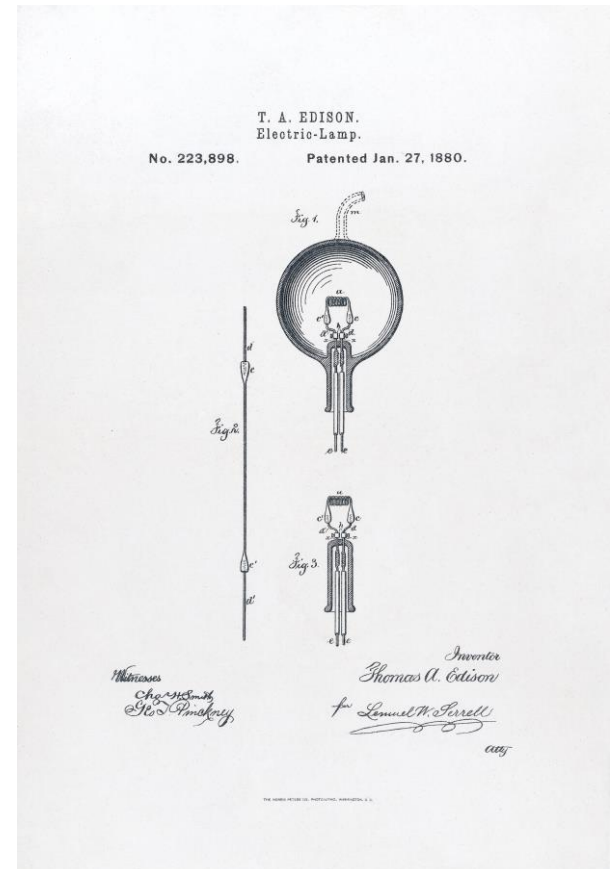
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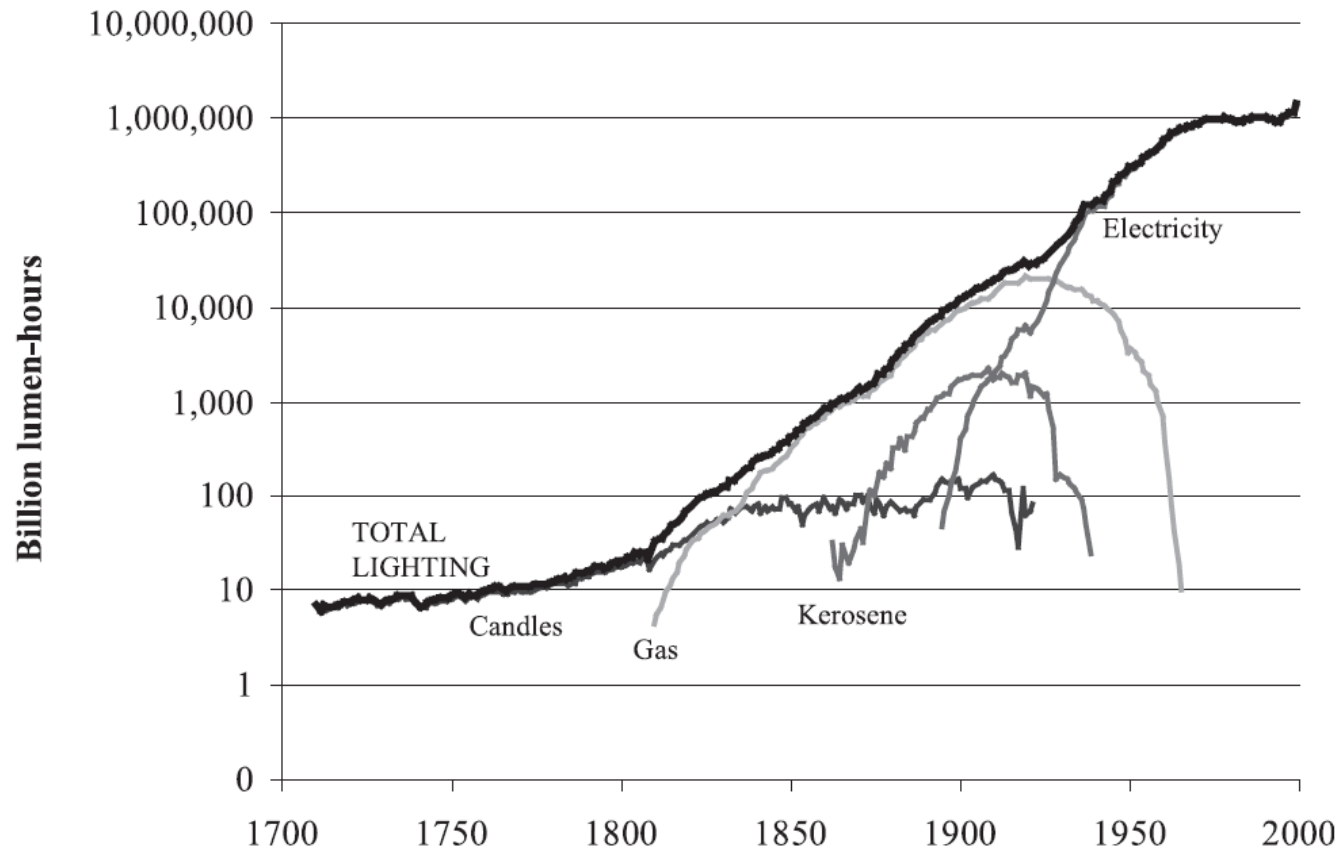
For the coal needed to power electric lights

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- 1800 Gas lamps, Argand lamp
- 1800-1840 Demonstration of electric & incandescents
- 1815 Miner's safety lamp
- 1867 First Fluorescent bulb
- 1879 Edison & Swan patent incandescent
- 1930's-90's big advances in fluorescents
- 1960's-current big advances in LED's



Lighting Consumption By Source



Source: authors' own estimates – see Section 2.2 and 2.3. Billion: 10^9 (i.e. one thousand million)

Lighting Quality

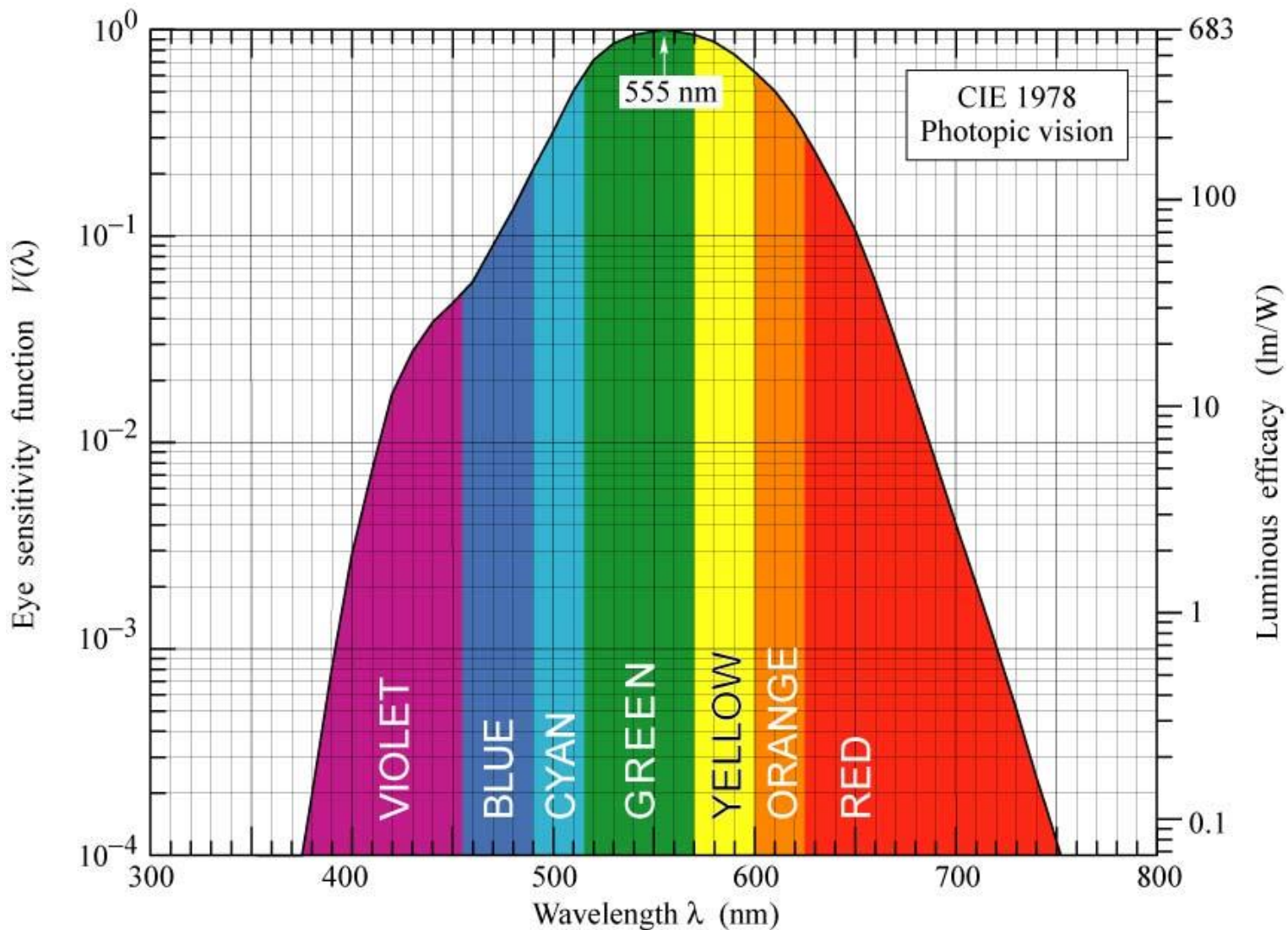


Fig. 16.7. Eye sensitivity function, $V(\lambda)$, (left ordinate) and luminous efficacy, measured in lumens per Watt of optical power (right ordinate). $V(\lambda)$ is greatest at 555 nm. Also given is a polynomial approximation for $V(\lambda)$ (after 1978 CIE data).

Lumens

- So when we measure the light output of sources we shouldn't just measure Watts of output
- $\text{Lumen} = \text{Watts} * \text{luminosity function}$
- Lighting “efficiency” vs “efficacy”

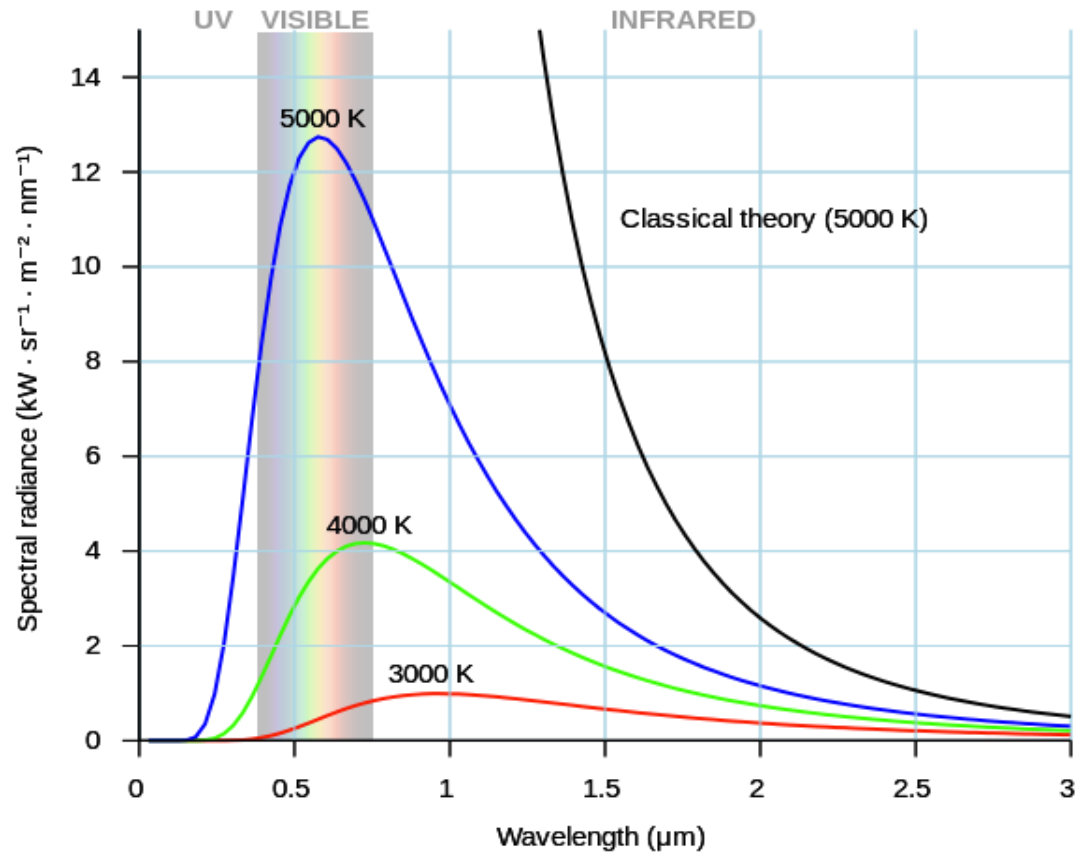
Lighting Quality

- Monochromatic lights makes it hard to see
- Biological impacts of different wavelengths

Specific Lighting Technologies and Their Properties

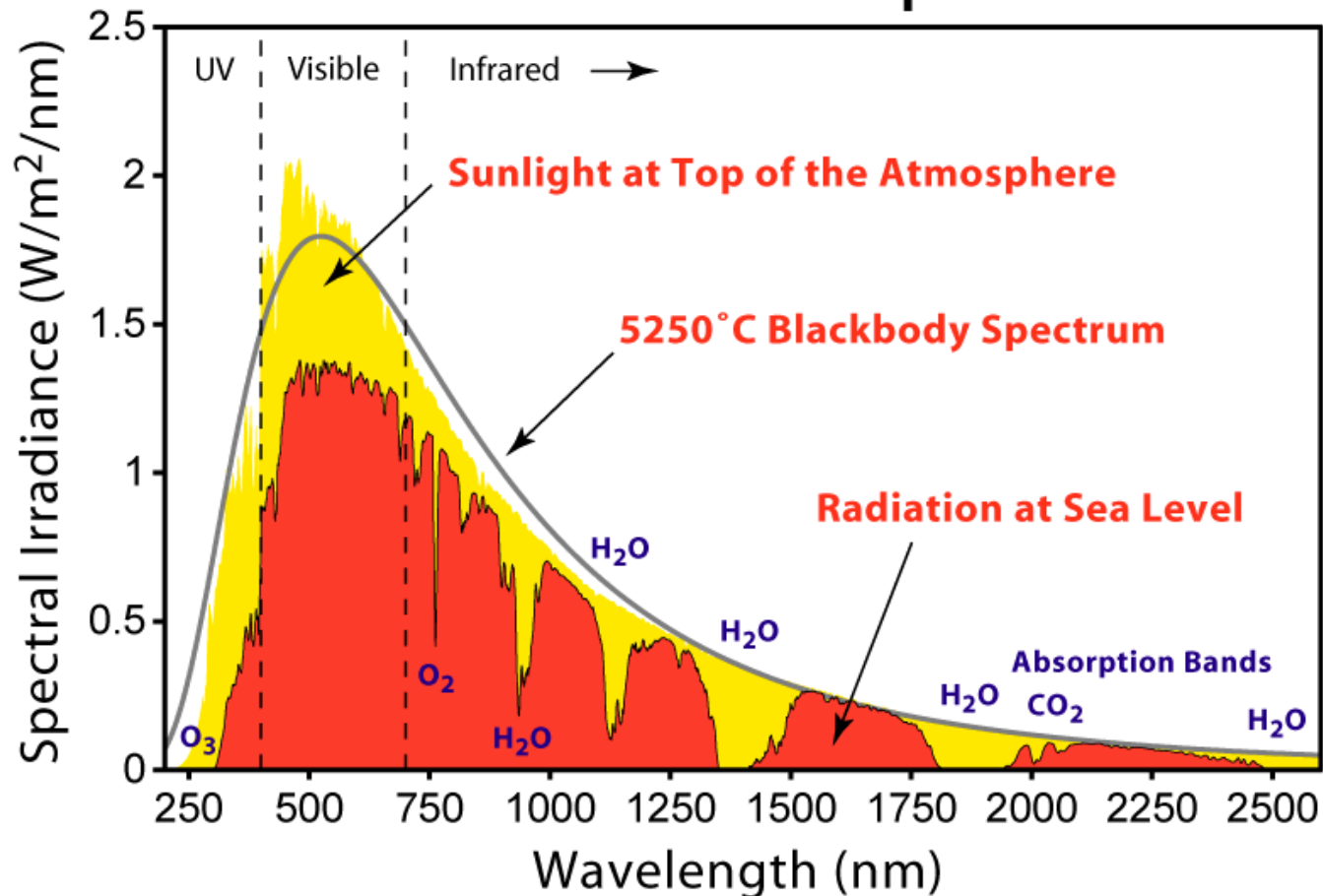
Black Body Radiation:

the first 401,900 years

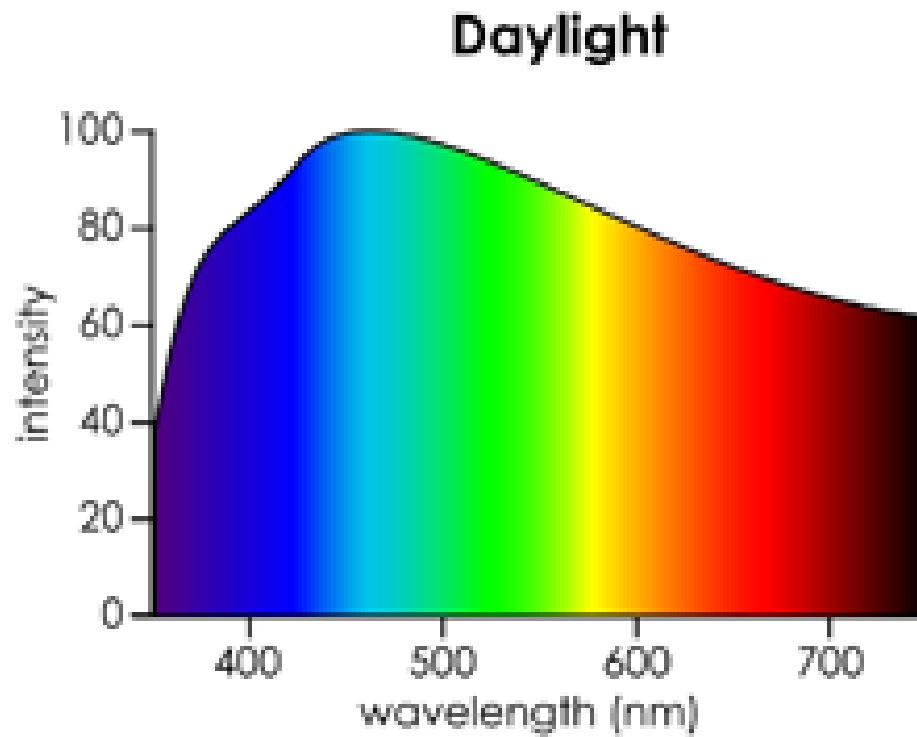


Qualities of Light

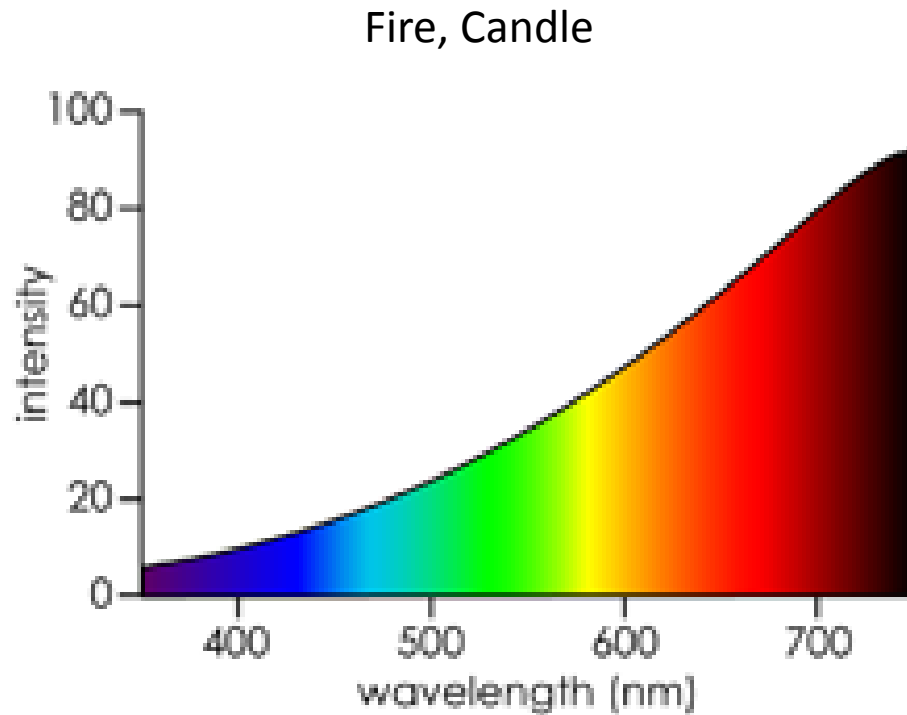
Solar Radiation Spectrum



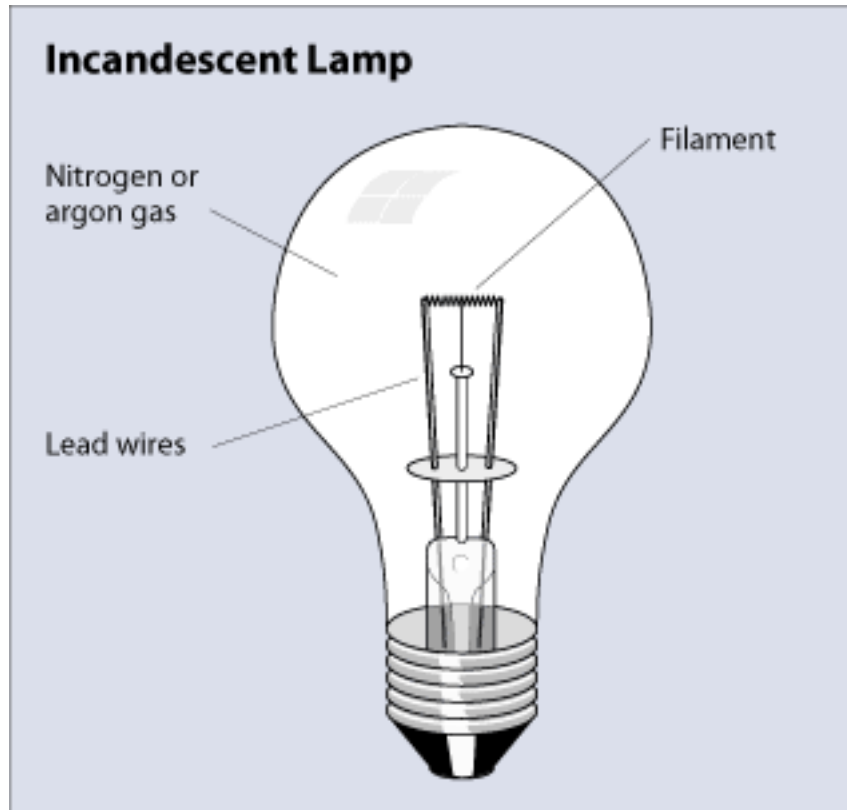
The Visible Spectrum



Early Human Lighting

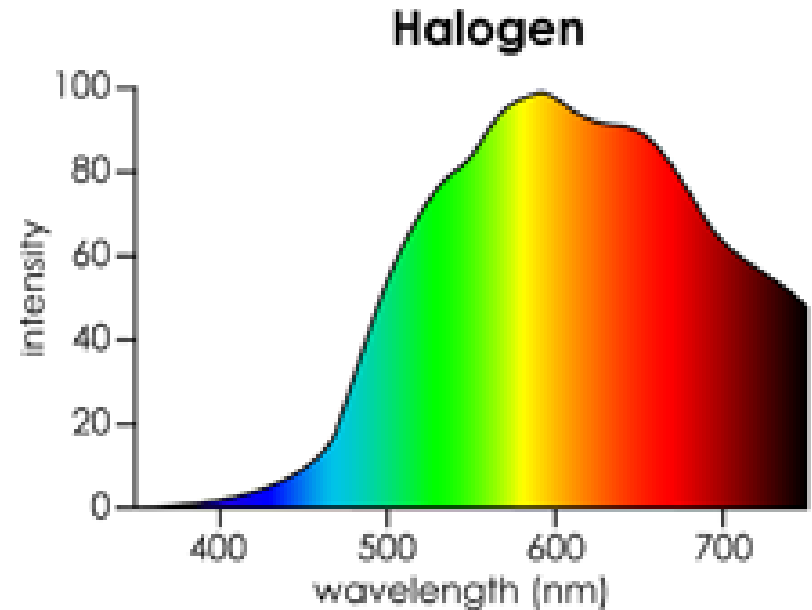
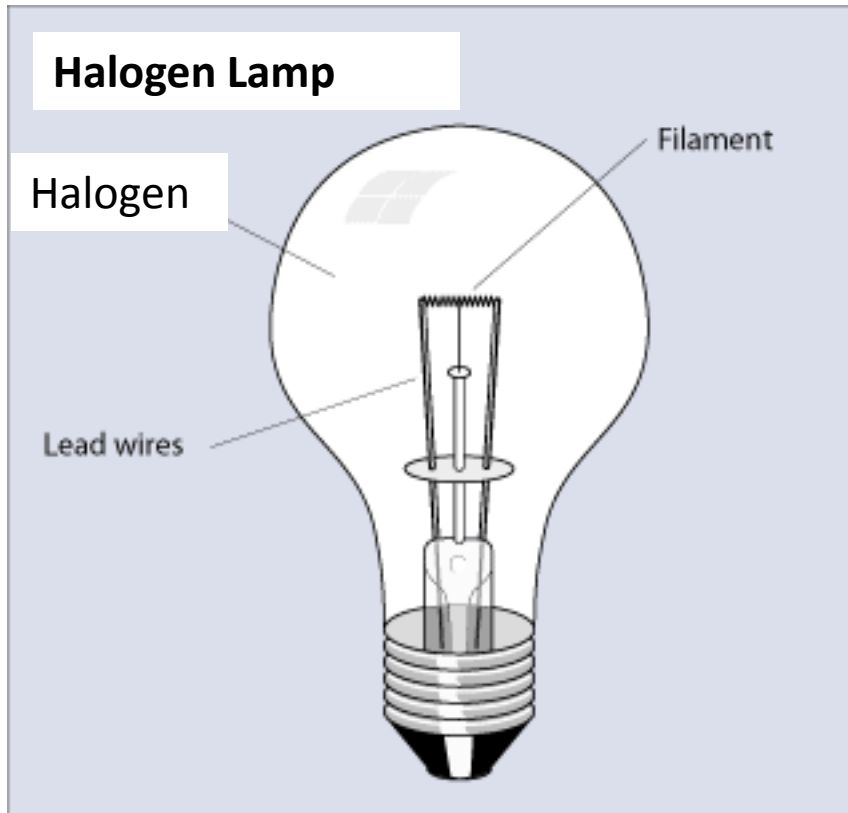


Incandescent



- Early ones used carbonized cotton and bamboo filaments, around 2000K, only 2-3 lm/W
- Eventually settled on tungsten, can operate at 2700K, 15 lm/W
- Primarily limited by evaporation of tungsten

Halogen Bulbs

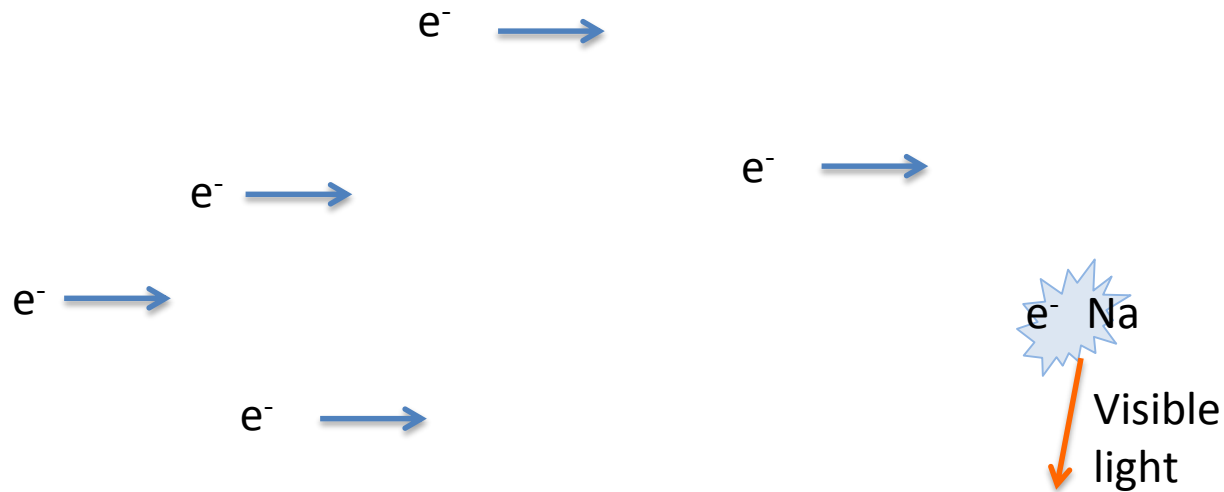


- Use gases in bulb to reduce evaporation
- Operate up to 3300K, get up to 20-25 lm/W
- Can't go a whole lot further with black body lighting at this point, hard to make stable filaments

Beyond the Black Body: Sodium & Neon Lights

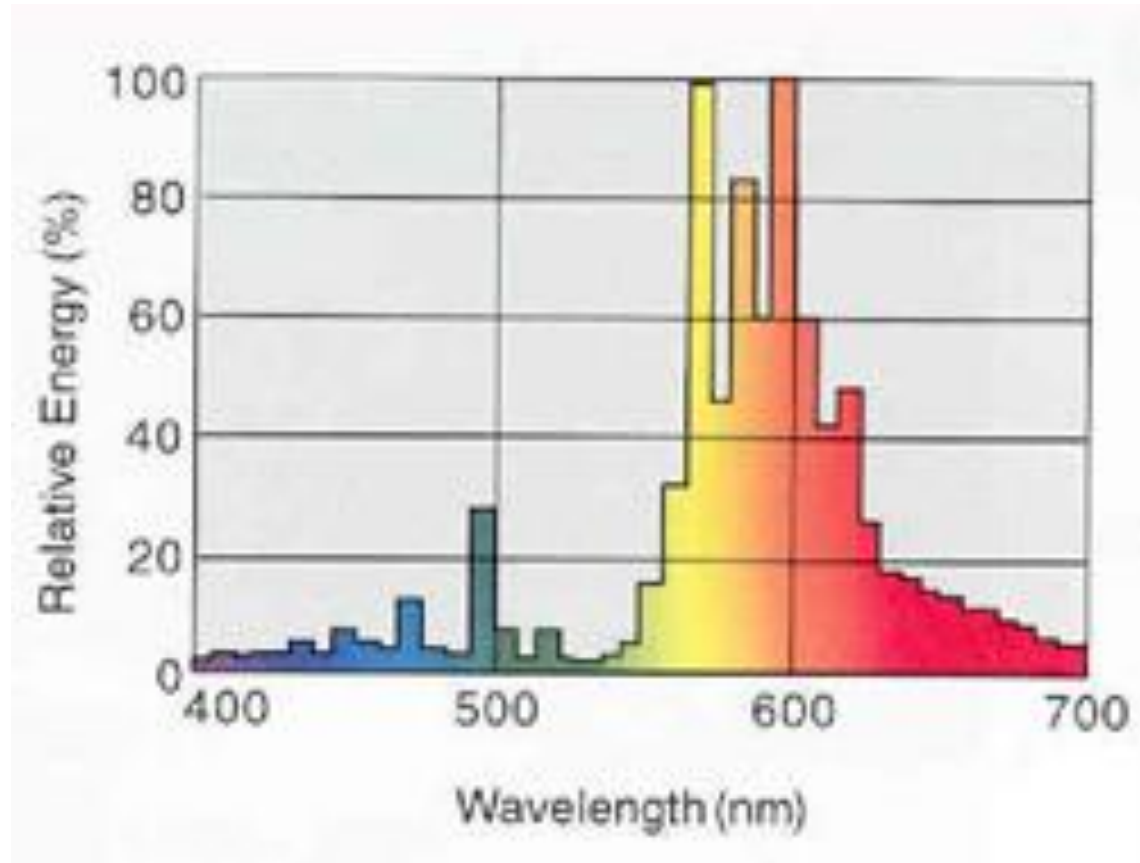


Sodium, neon lights



- 150 lm/W!
- ugly monochromatic light

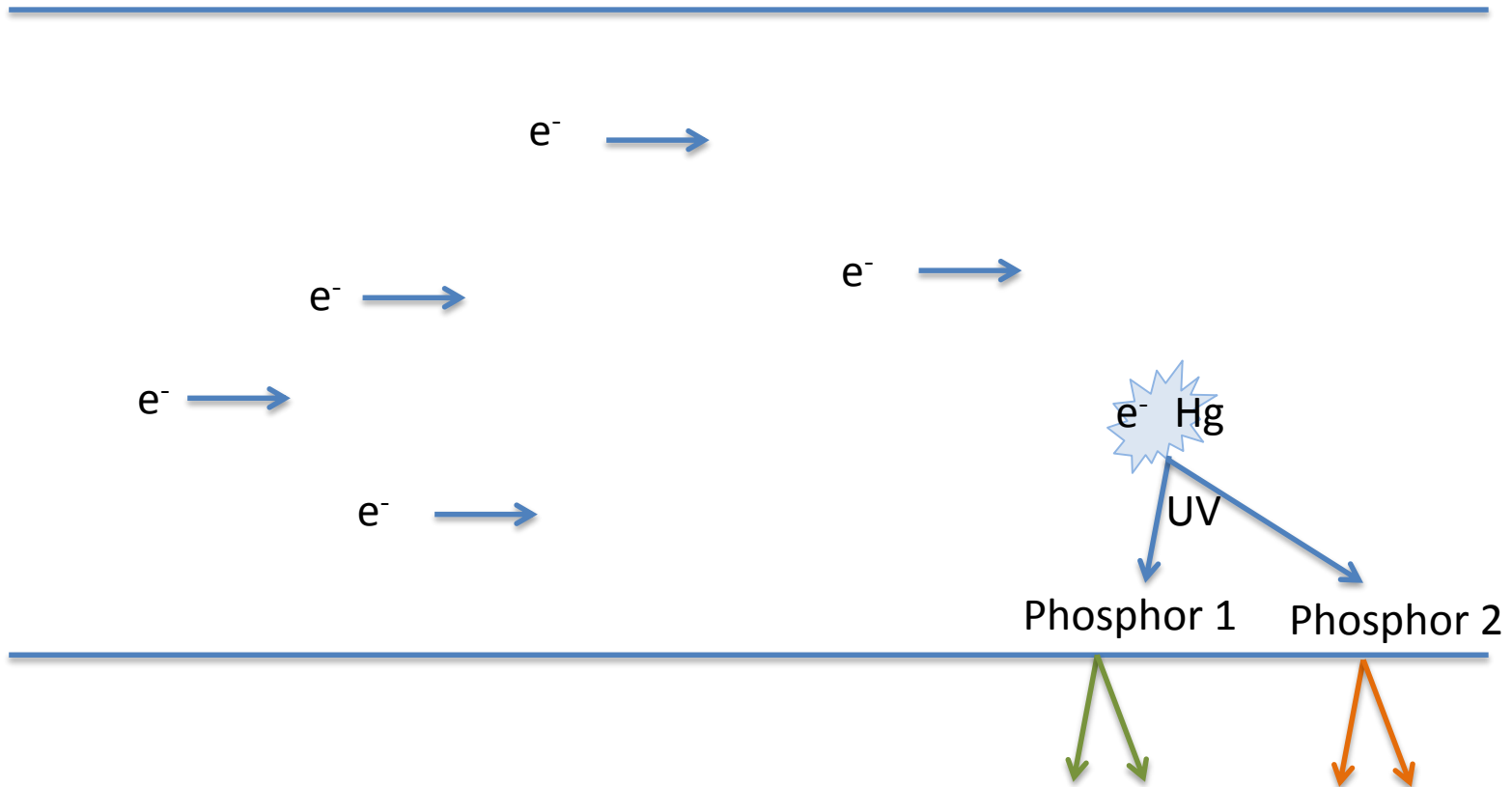
Sodium, neon lights



CFL's



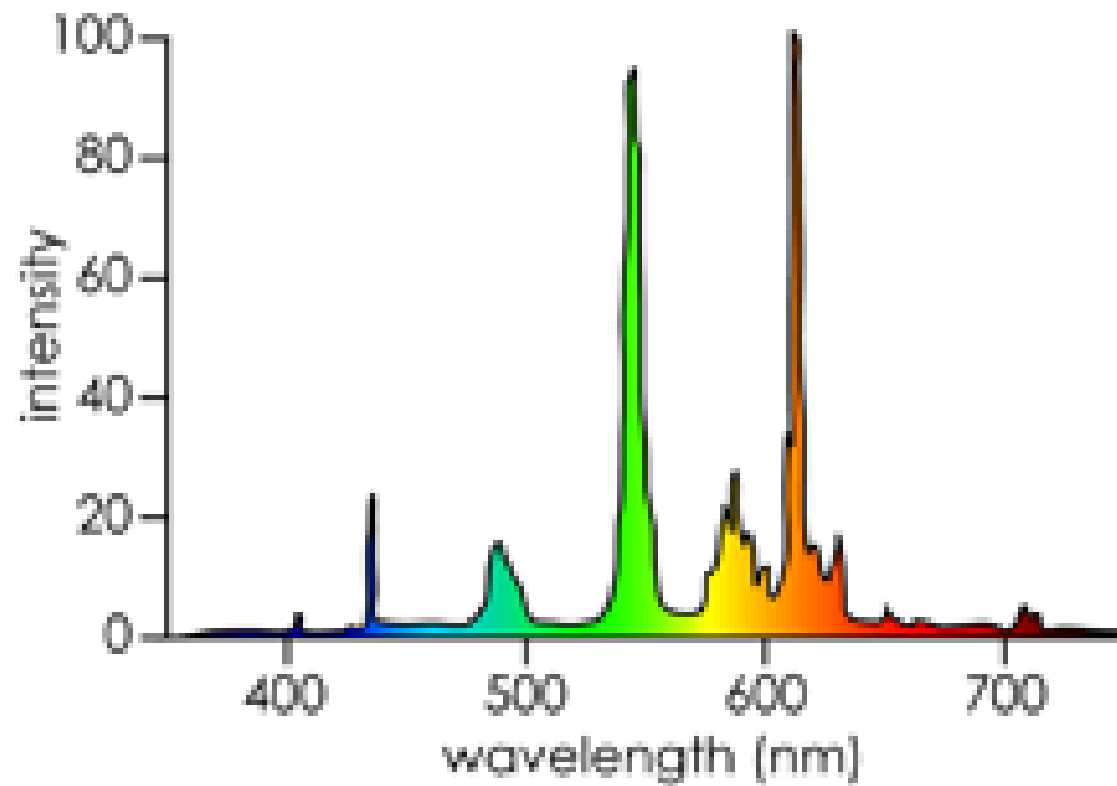
CFL's



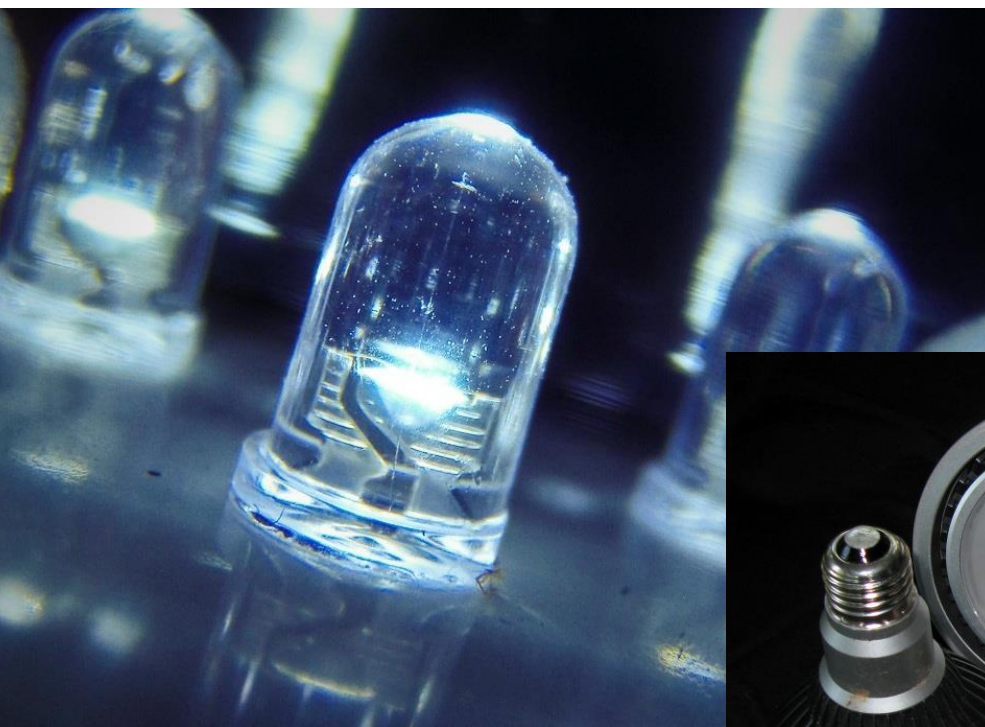
- 100 lm/W, much less than sodium
- a bit for better light quality (still not *good*)
- Tradeoffs – “efficient” isn’t always better

CFL's

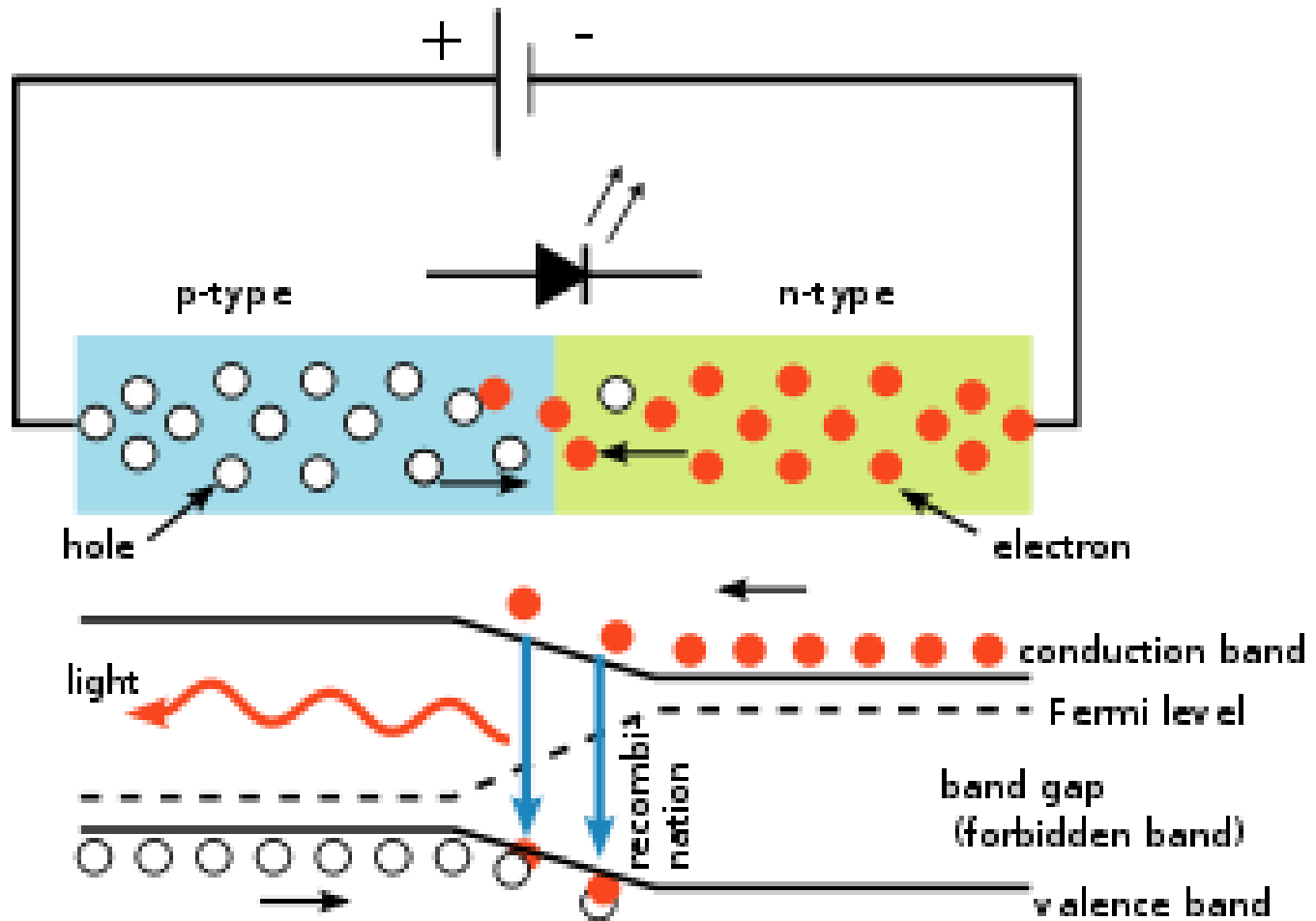
Fluorescent



LED's

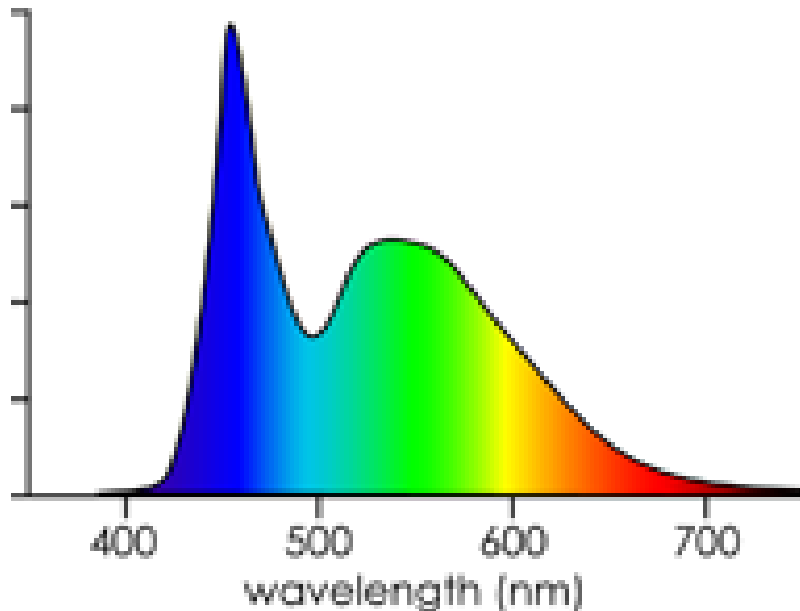


LED's

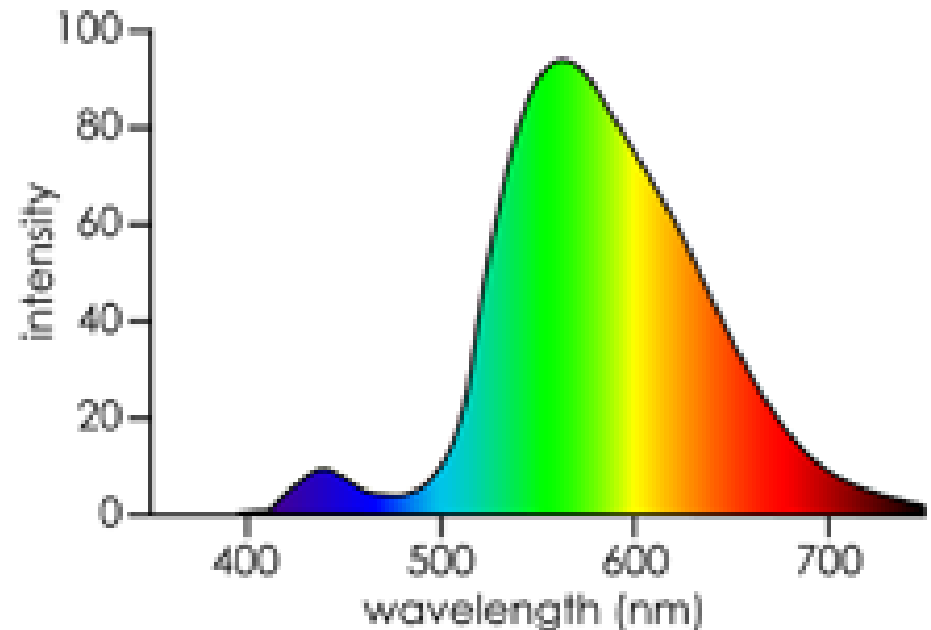


Modern LED's

Cool White LED

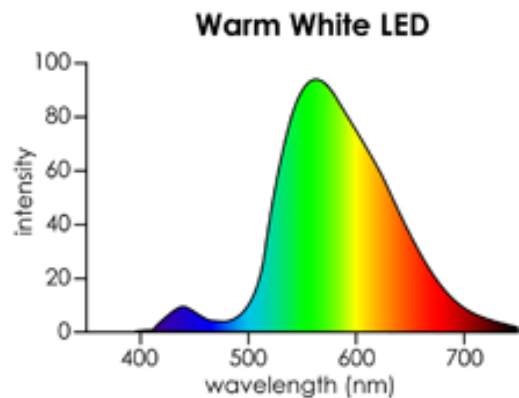
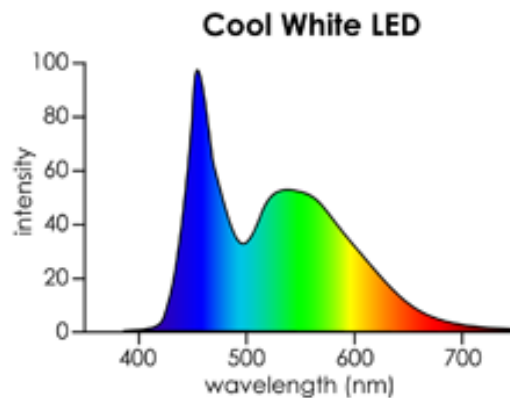
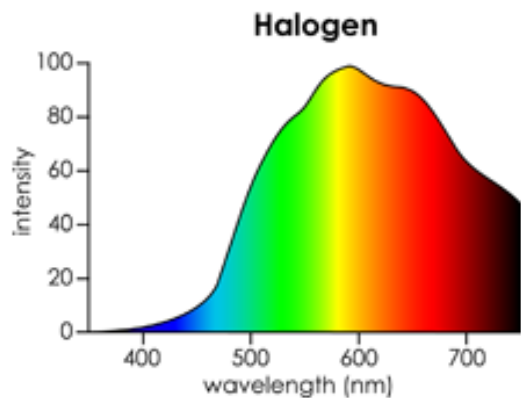
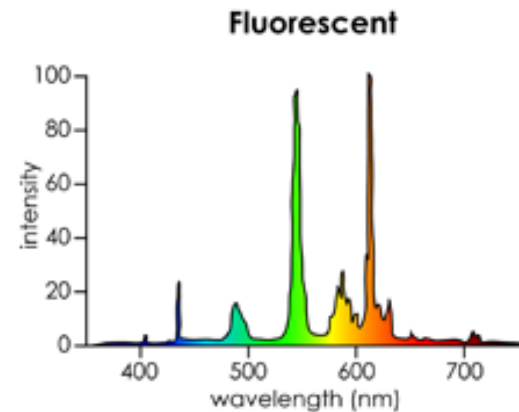
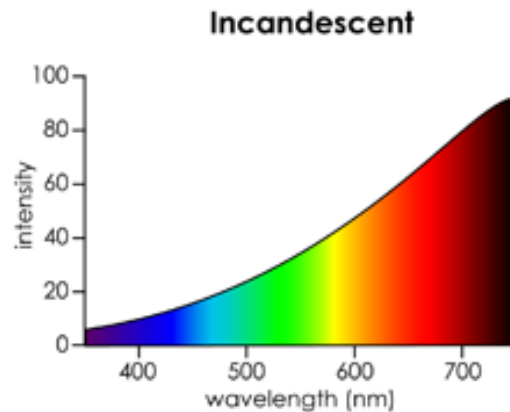
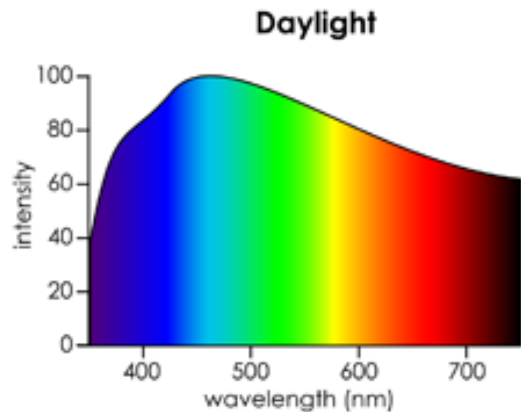


Warm White LED

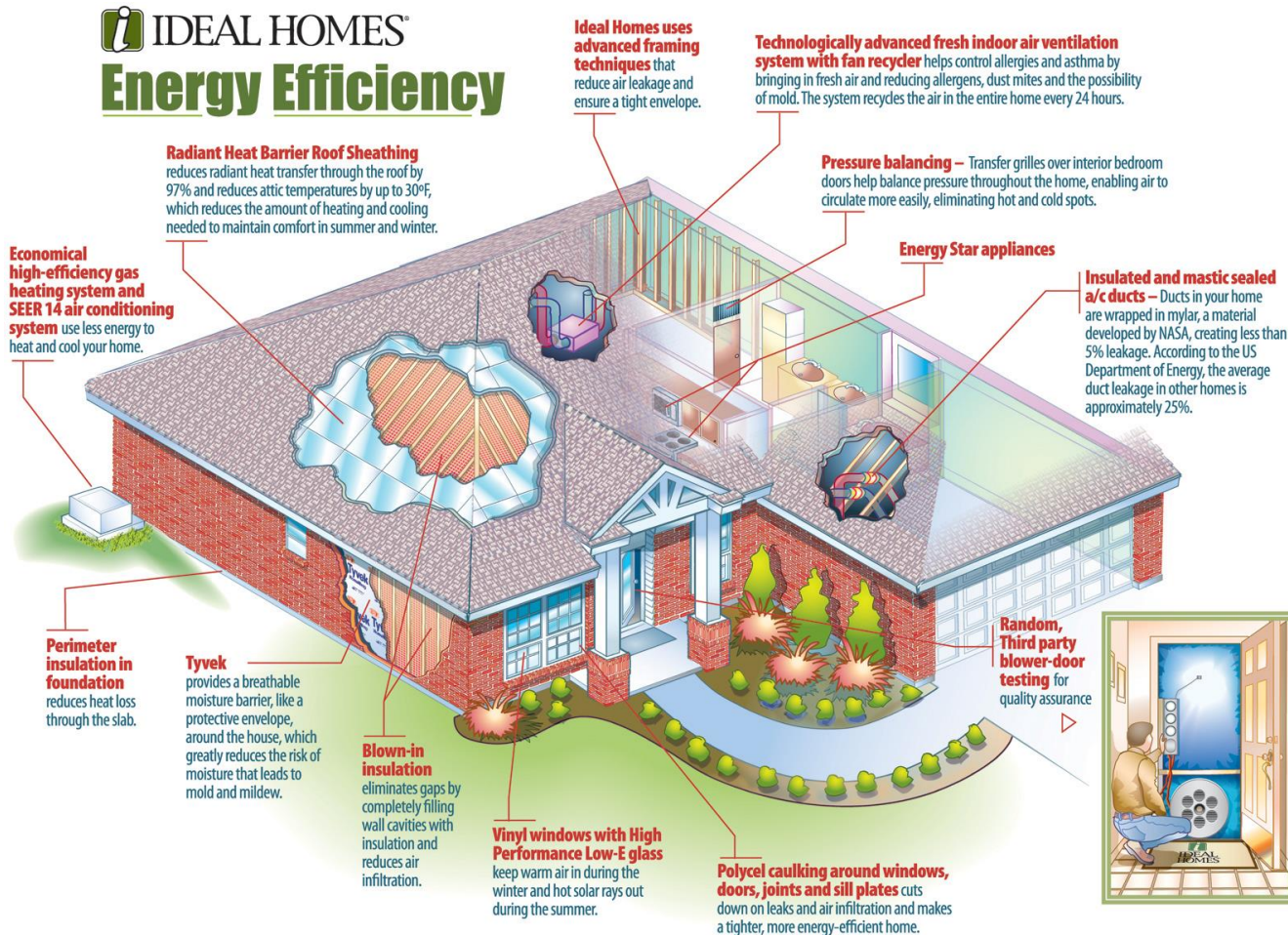


- All LED's before 1995 were quite warm
- Finally made cold ones, could use same phosphor trick as fluorescents
- Up to 300 lm/W!

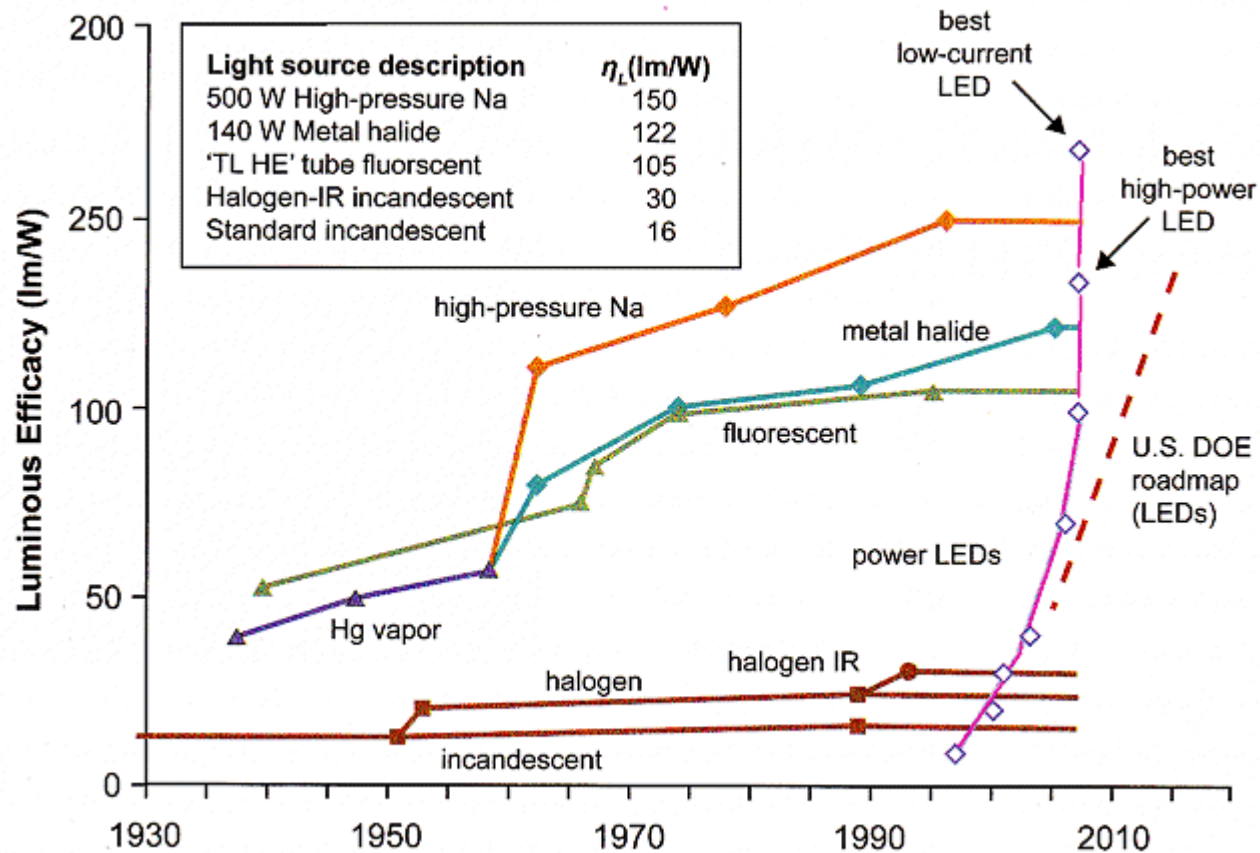
Modern Lighting Options



Energy Efficiency/Efficacy and Energy Use



Efficacy of Lighting

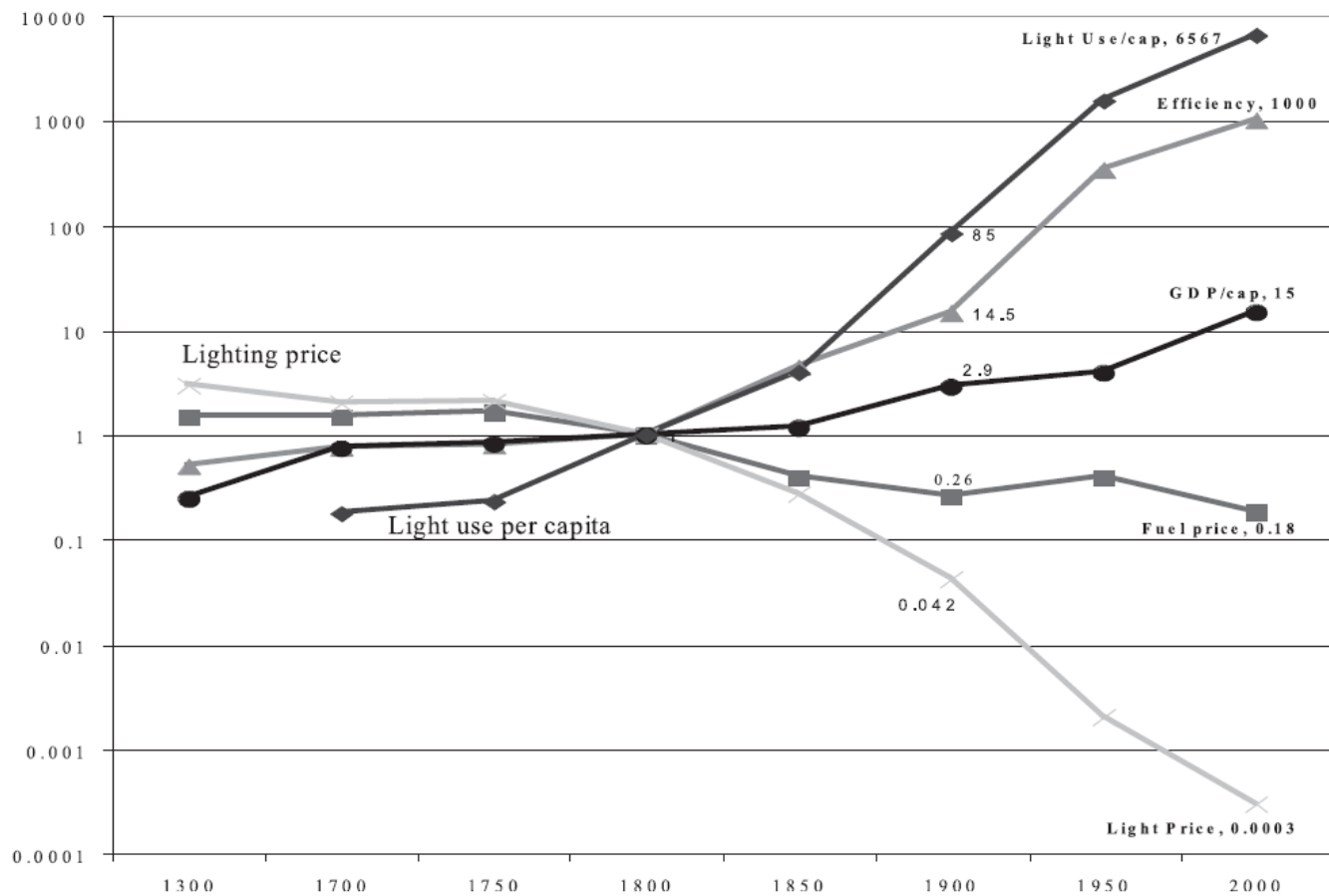


Light-emitting diodes versus conventional light sources. © 2007, IEEE

So Lighting Energy Demand Has Gone Down Right?

The Rebound Effect

**Figure 14. Indices of Key Lighting Variables in the United Kingdom
(Log Scale, 1800=1), 1300-2000**



Lighting history: price, technology

Figure 4. The Price of Lighting from Tallow Candles and Whale Oil in the United Kingdom (per million lumen-hours), 1300-1900

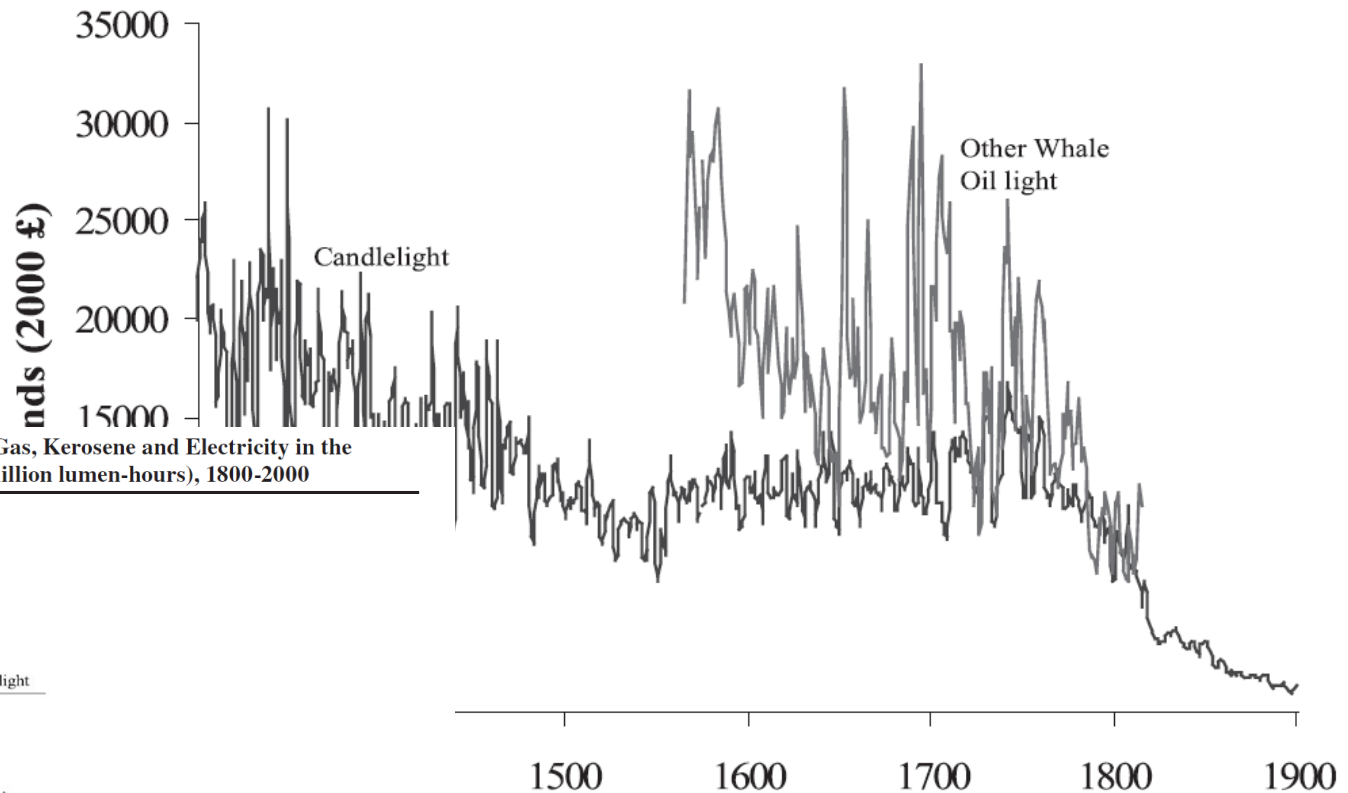
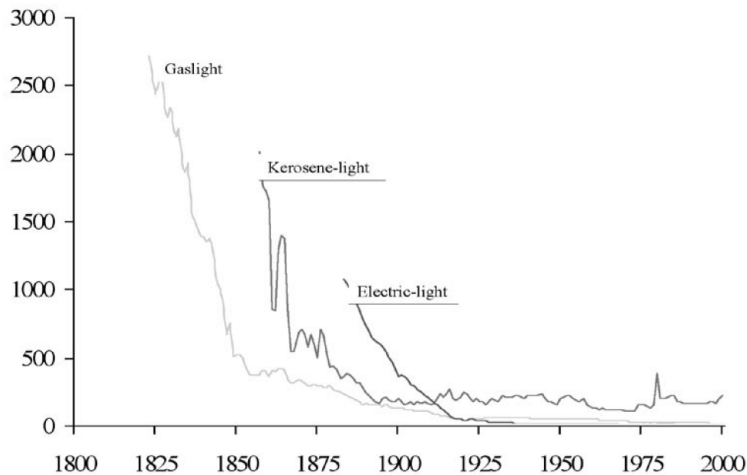


Figure 6. Price of Lighting from Gas, Kerosene and Electricity in the United Kingdom (per million lumen-hours), 1800-2000



Where Will Lighting Energy Demand Go In the Future?

- Will it plateau? Even Decrease?
- When do energy services become saturated?
- Can we envision crazy new uses for lighting?
- What does this mean for the role of energy efficiency in mitigating climate change?