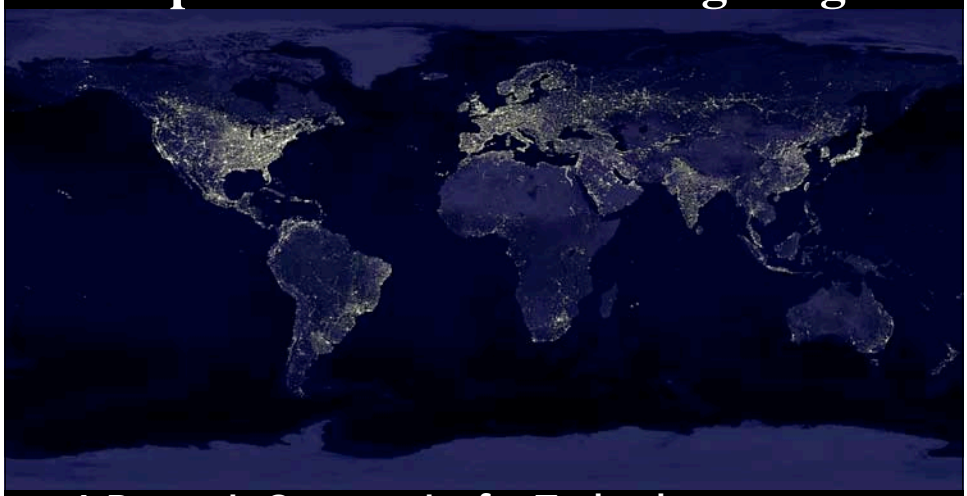
The Specter of Fuel-Based Lighting…



… A Dramatic Opportunity for Technology Leapfrogging in the Developing World

Evan Mills, Ph.D.
Lawrence Berkeley National Laboratory

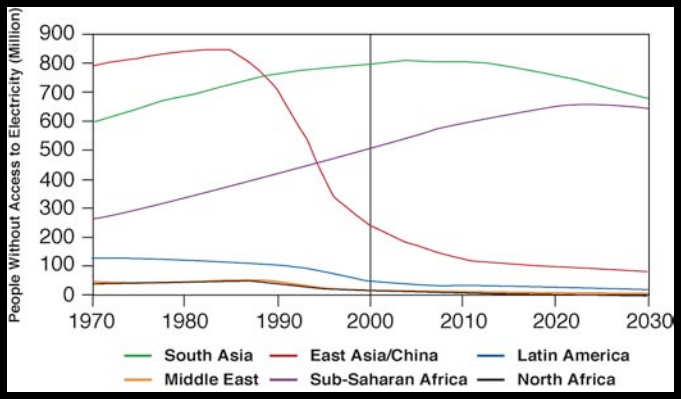
"We will make electricity so cheap that only the rich will burn candles"

- Thomas Edison

As of 2000: in the developing world, 14% of urban households and 49% of rural households have no electricity

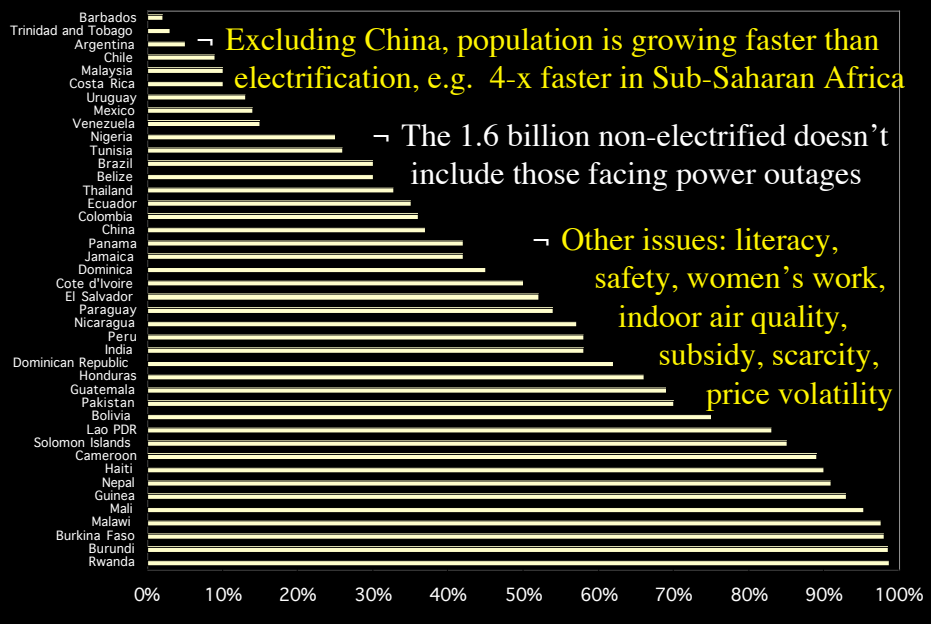
Photo: Evan Mills ©

World Non-electrified Population Projected to Decline from 1.6 billion in 2000 to 1.4 billion in 2030 (0.4%-y)



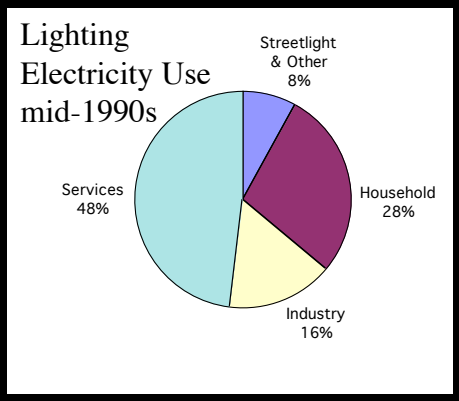
Source: International Energy Agency

Non-Electrified Population: mid-1990s



- Excluding China, population is growing faster than electrification, e.g. 4-x faster in Sub-Saharan Africa
- The 1.6 billion non-electrified doesn't include those facing power outages
- Other issues: literacy, safety, women's work, indoor air quality, subsidy, scarcity, price volatility

Global Lighting Energy: 178 Countries



- Cost: $185 Billion/year electricity $25 billion fuel
- Power Plants: ~2000 (200 MW each)
- $C0_2$ Emissions: ~2Bt/year
- Direct Fuel: 1.3 Mboe/day (Brazil, Algeria, Libya, or Indonesia)
- Savings: $75-$115B/year (> Canada, France, or Germany TWh)

Conservatisms: most estimates go back to mid-1990s; excludes HVAC-interactions; T&D losses at 10%; electricity price $0.1/kWh; savings potential excludes daylighting

Butter Lamps - Yunnan, China

Photos: Evan Mills ©

Distributing Kerosene: Huangshan, China

Photo: Evan Mills ©

Market - Cambodia

Photo: Evan Mills ©

Barber Shop - (electrified) Assam, India

Photo: Evan Mills ©

Textile Seller - Assam, India

Photo: Evan Mills ©

“High-End” Tourist Hotel - Bhutan

Photo: Evan Mills ©

Merchant - Assam, India

Photo: Evan Mills ©

Schools - Yunnan, China

Photos: Evan Mills ©

Electrification: At What Cost?

Photos: Evan Mills ©

Rural Electrification

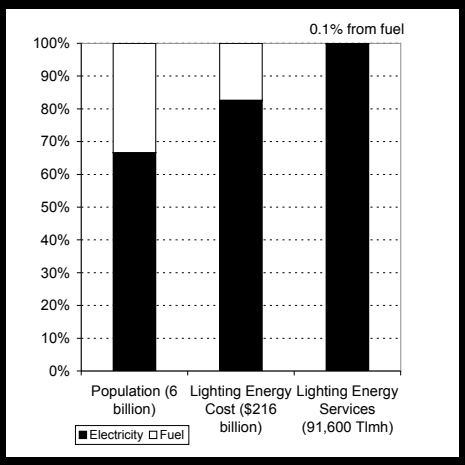
Photos: Evan Mills ©

Urban "Electrification" - Tibet

Photos: Evan Mills ©

Lighting Equity

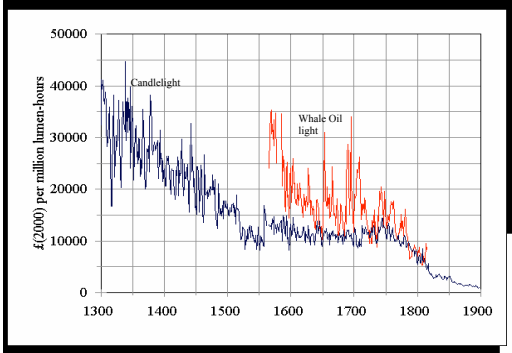
Although one in three people obtain light with kerosene and other fuels, representing about 20% of global lighting costs, they receive only 0.1% of the resulting lighting energy services

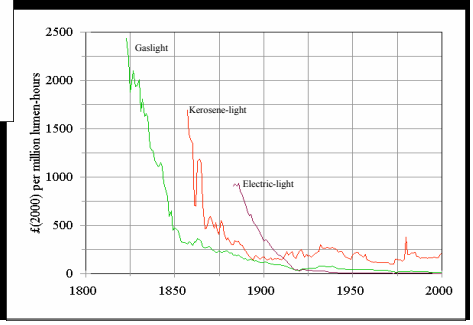


An un-electrified household consumes as many lumens over an entire year as a single 100W incandescent bulb produces in 10 hours

LBNL Analysis

Steady March of Lighting Efficiency

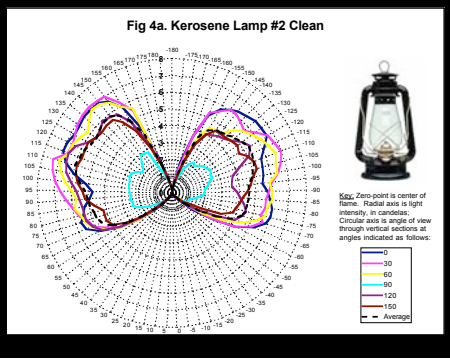


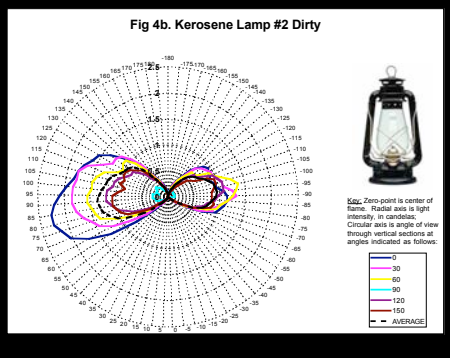


Lighting Output and Performance of Fuel Lanterns is Poor

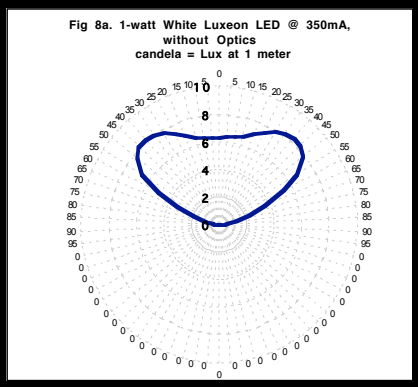
Photometric tests show cross-sectional views of lighting intensity and distribution

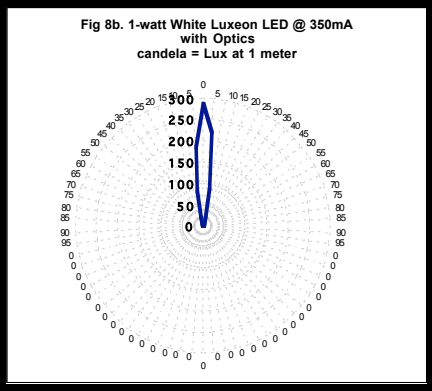
LBNL Goniophotometer





LEDS Provide Superior Illumination to Flame-Based Lanterns

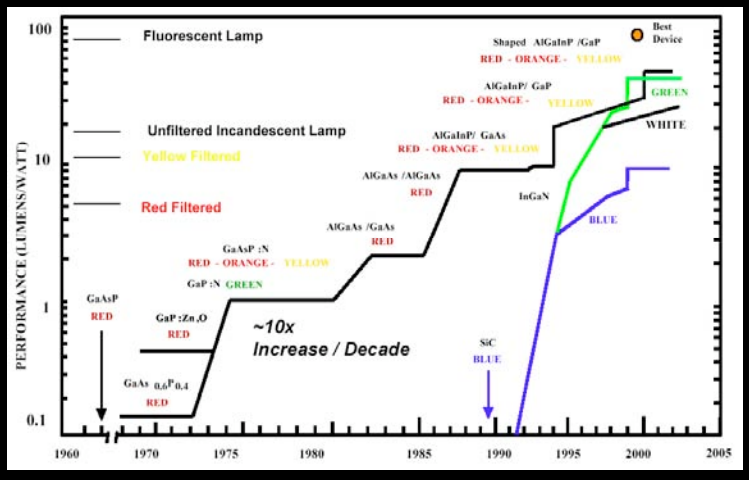




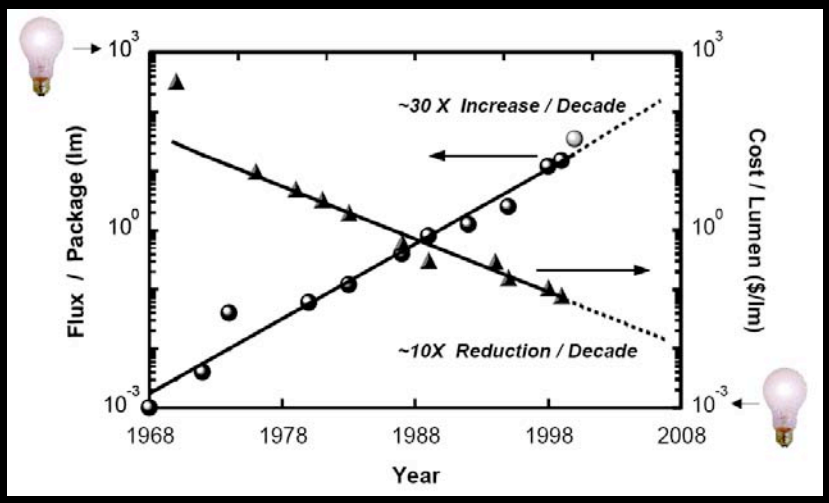
With optics, LED => 100x more useful lighting service than flame

LBNL Analysis

LEDs Have Evolved from "Indicator" Lights into Highly Efficient Sources for Illumination

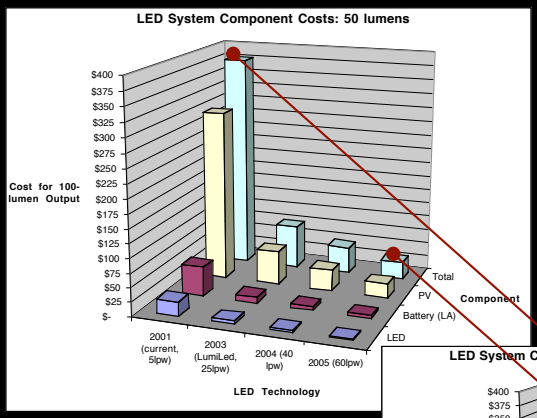


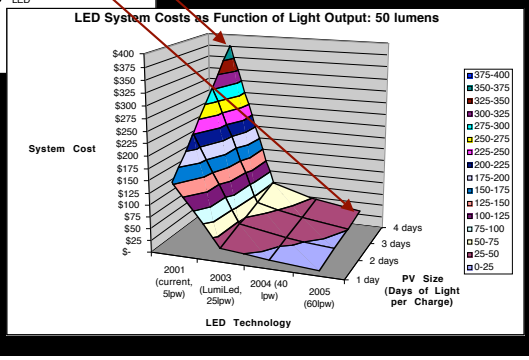
Rising Light Output; Falling Cost



Source: Lumileds

Solution Space





LBNL Analysis

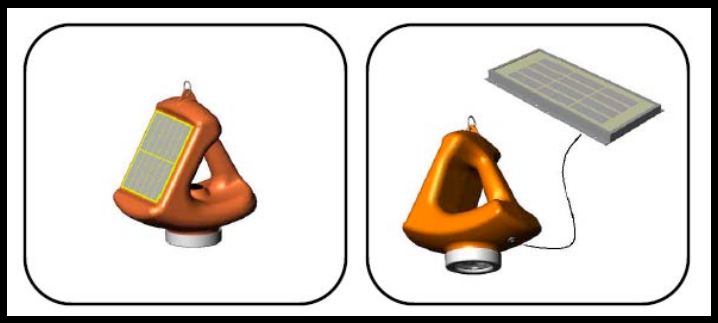
LEDs - Desirable Properties:

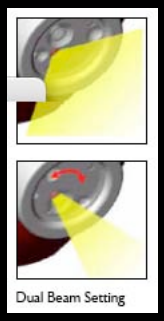
- **Efficiency**
- **Low voltage**
- **Directionality**
- **Portability**
- **Ruggedness**

[Issues: glare; heat]

Stanford + Ideo + LBNL + Solectron (and others…)

Second-generation Prototype

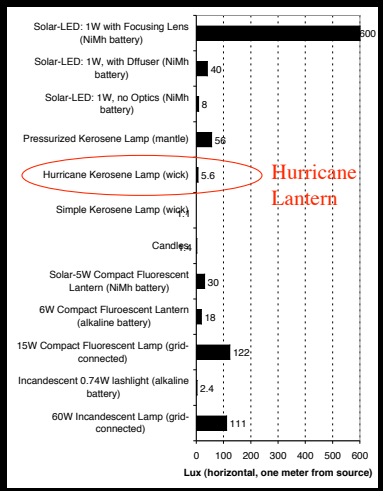




Traditional Solar-Fluorescent Systems Have 0.1% Market Penetration

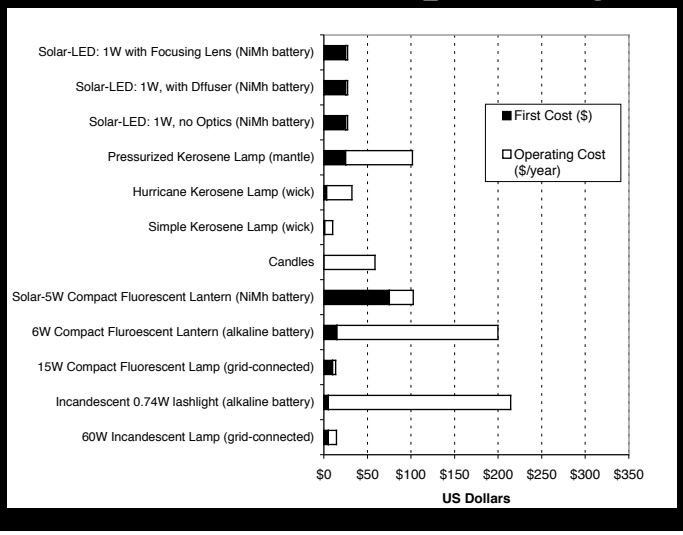
Photos: Evan Mills ©

LED Has Far Higher Service Levels than Flame-Based Sources



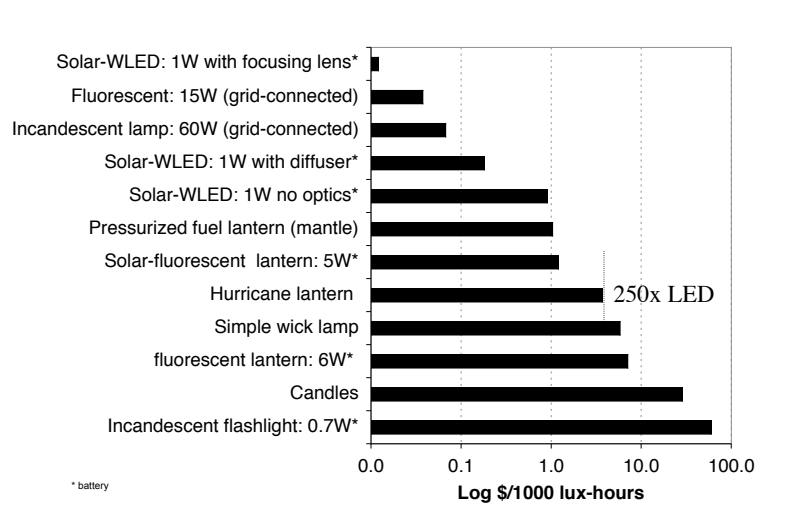
LBNL Analysis

Among Off-Grid Solutions, LED Approach Has Lowest Operating Cost



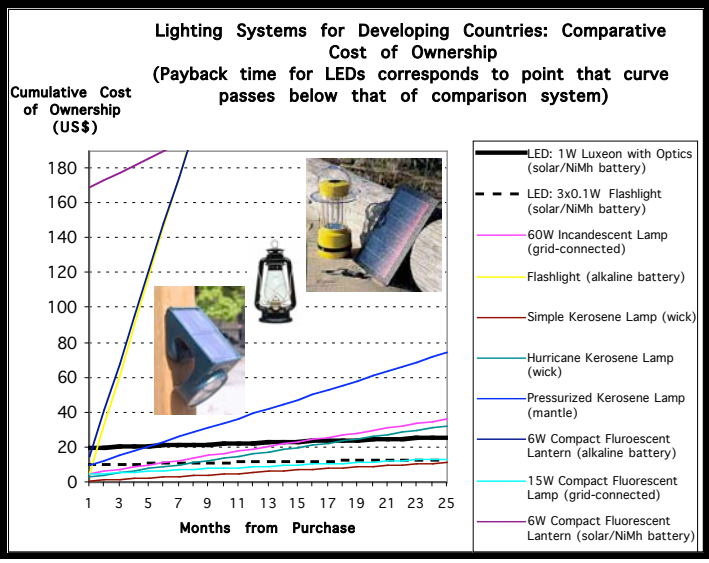
LBNL Analysis

LED: Lowest Cost of Energy Services



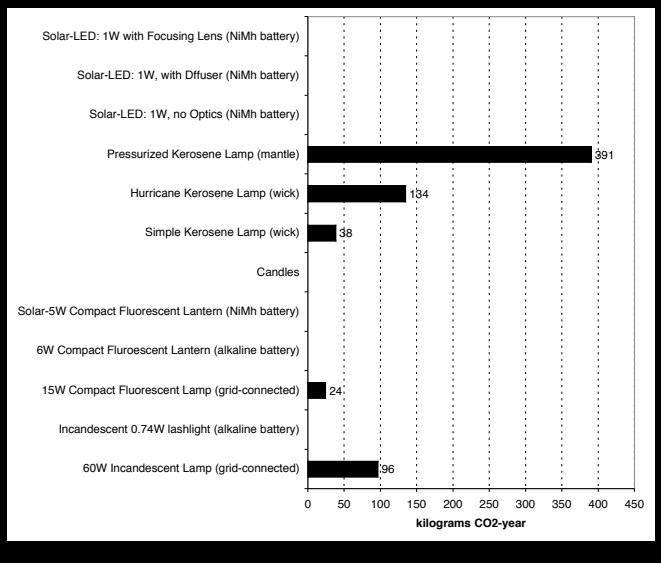
LBNL Analysis

LED Payback Time: 0.5-2 Years



LBNL Analysis

Dramatic GHG Reductions



LBNL Analysis

Existing Sales Channels

Photo: Evan Mills ©

Kerosene Kommerce (Can existing sales channels be re-purposed?)

Northeast Viet Nam

Photos: Evan Mills ©

Refugee Camps

Photo: Salgado

Refugee Camps

Non-Energy Drivers
(e.g. fire safety in temples)

Photos: Evan Mills ©

What's Needed?

- Better define markets (res'l, non-res'l)
- Better define lighting needs/uses
- Develop and field test prototypes
- Explore alternatives to batteries
- Market/distribution challenge is greater than the engineering challenge
- Non-charity business models

More Information

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http://eetd.lbl.gov/emills