Sustainable Lighting: Nano-enabled Lighting and the Rebound Effect

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SNO
4 Nov 2013

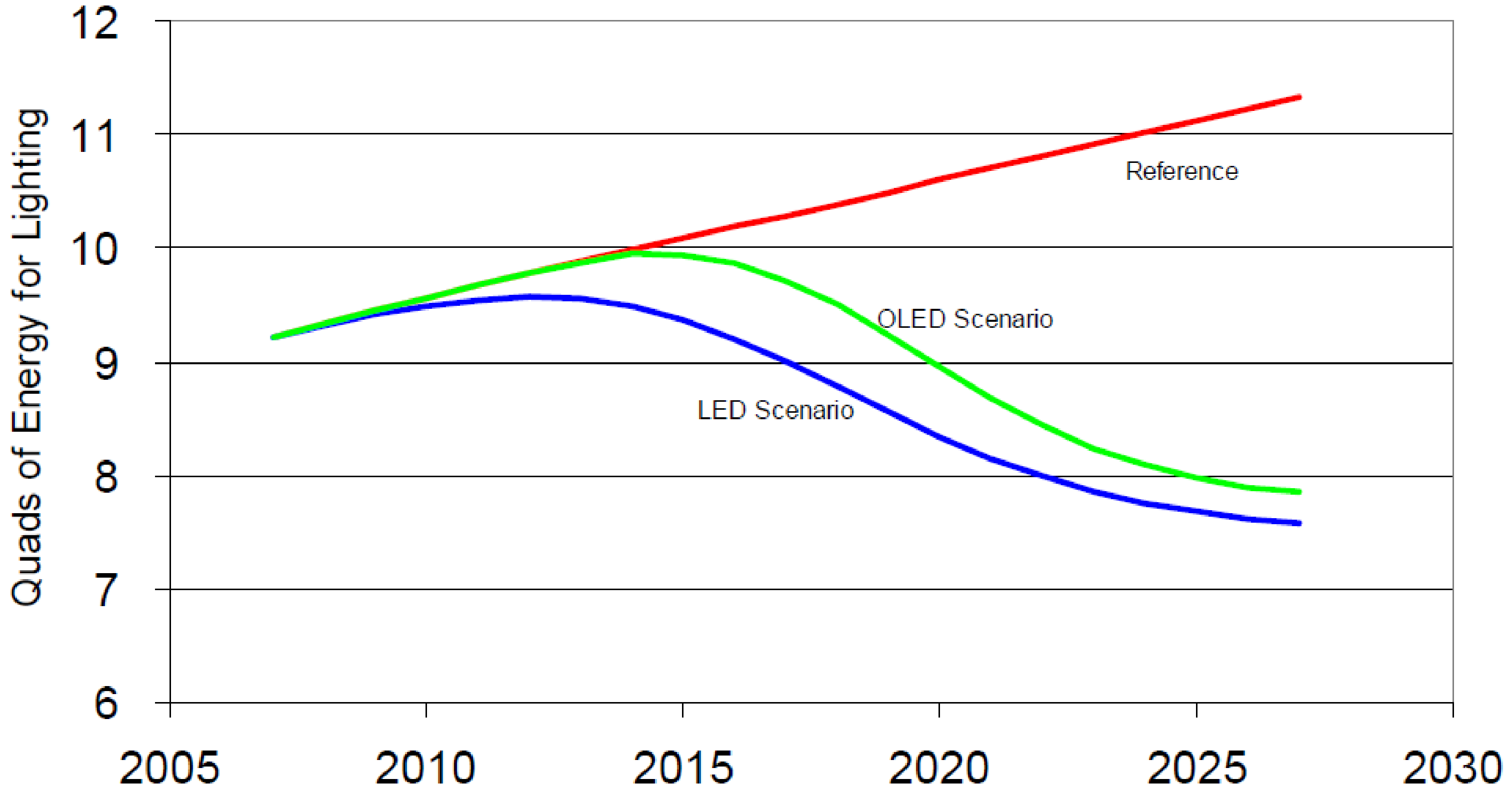
Artificial Lighting

- Accounts for 19% of electricity consumed in US
- Since 1950, cost reduced 3-fold, but per capita consumption increased 2-fold
- Policy trends favor conversion to more efficient forms of light
- Productivity gains (safety, light surroundings, new jobs and products)
- Undergoing a “nano-enabled” evolution to SSL (~2 times efficiency of CFL, lasts ~ 3 times longer than CFL, promises much greater functionality)

Some predicted nano-enabled efficiency improvements

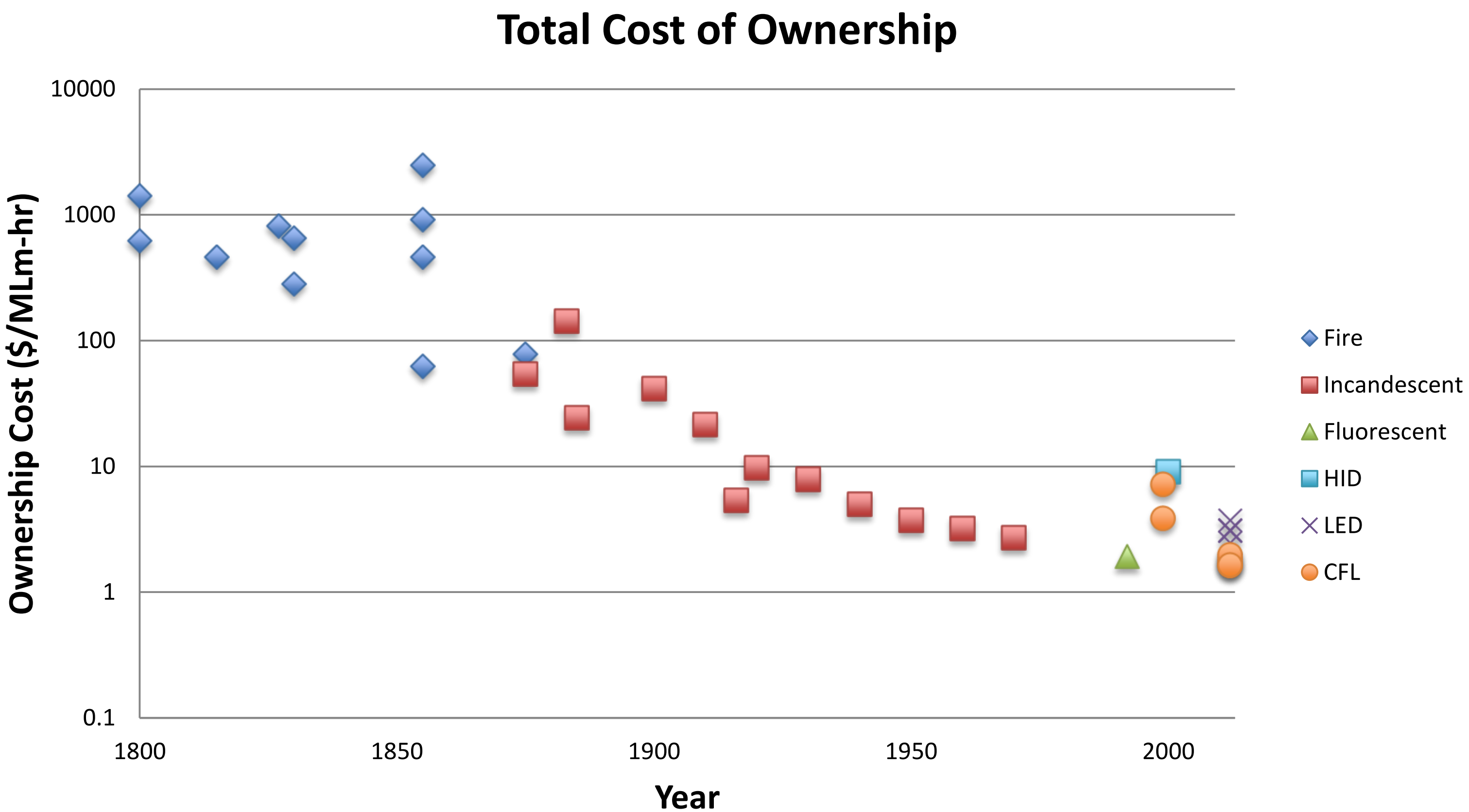
APPLICATION	Energy Savings (quads/year)	Reference
Building technology	10	GTF 2007
Lightweight materials in transportation	6.2	EIA, 2005
Solid State Lighting	3.5	DOE, 2013
Self-optimizing motor systems (sensors)	1.2	Brown, 2005
Catalyst efficiency, coatings, membrane technology	0.70	LANL 2006
Transmission line conductance	0.2	Brown, 2005

Projections for Energy Consumption for Lighting Through 2027 (US)



"Energy Savings Potential of Solid State Lighting in General Illumination Applications", Navigant Consulting, Washington DC (2006)

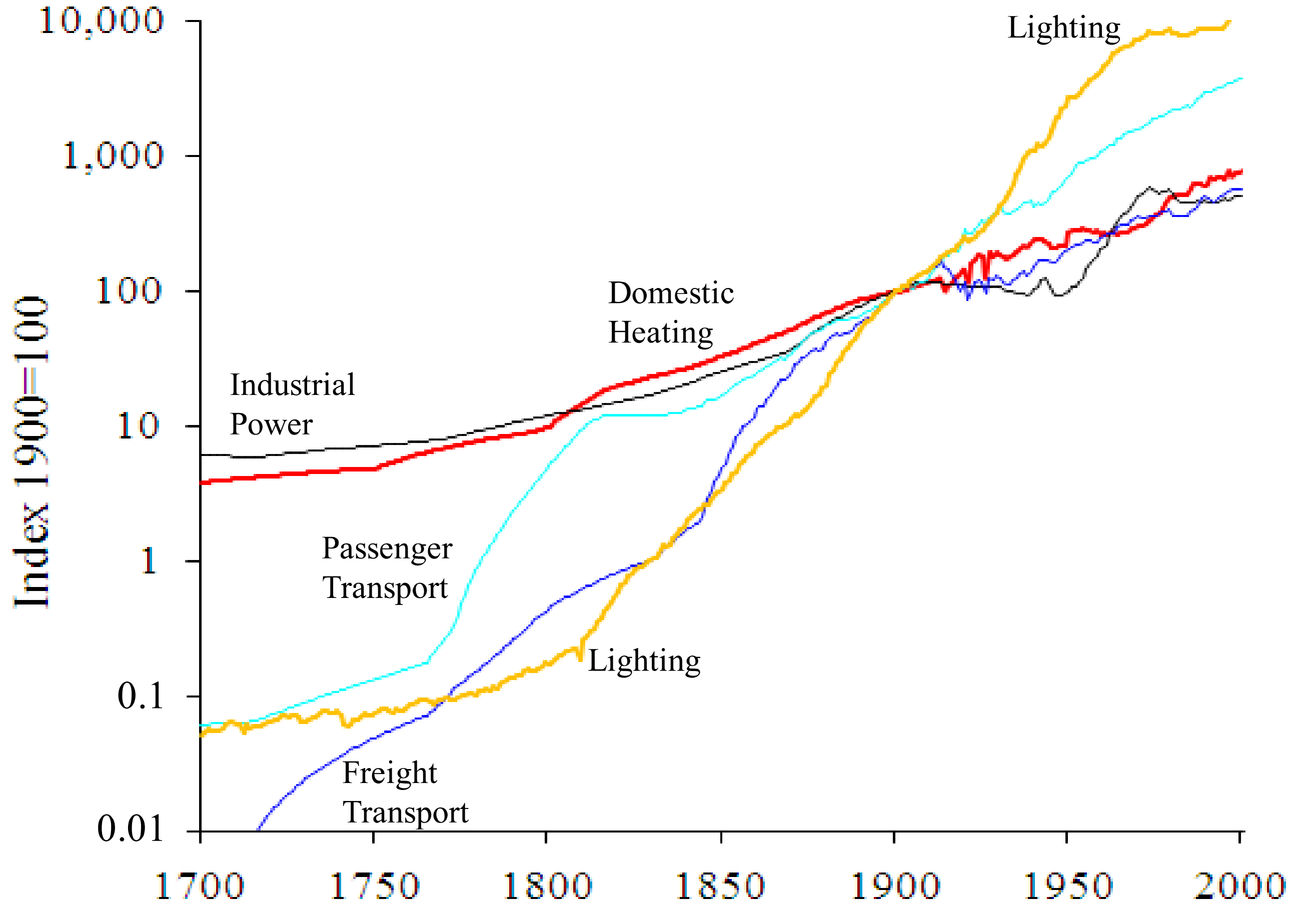
United States Cost of Lighting 1800-2010



Ownership Cost =

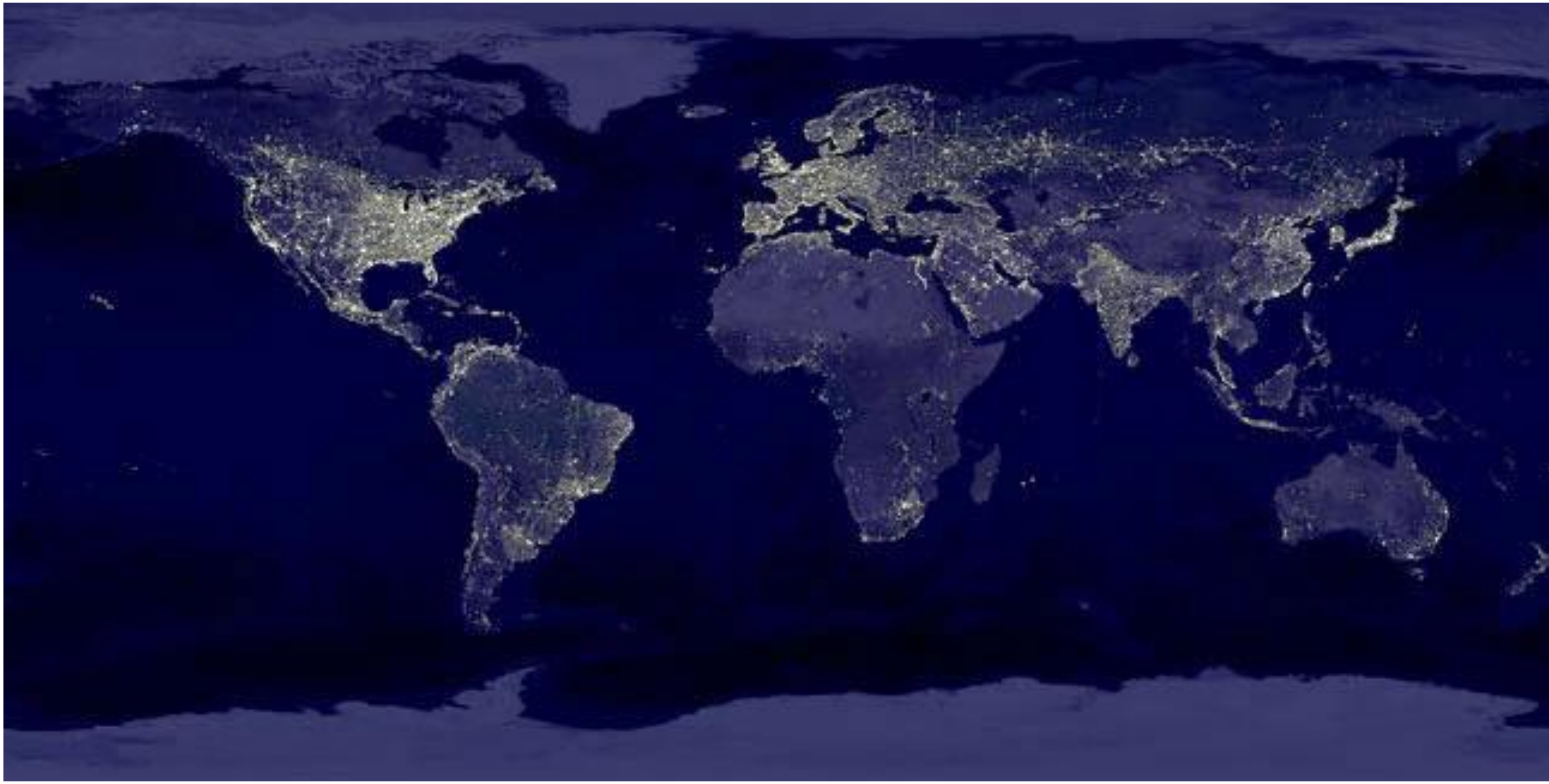
*[Capital Cost + (lifetime lumens *(Cost/lumen))]/(lifetime lumens)*

(Nordhaus, 1996; Bardsley Consulting et.al, 2011)



Source: Fouquet (2008)

Figure 1. Consumption of Energy Services in the United Kingdom, Index 1900=100, 1700-2000



Rebound Effect

“Jevon’s Paradox”, named after the 19th century British economist Stanley Jevons, who first described it:

An increase in the technological efficiency of a process that uses a resource tends to *increase* the rate of consumption of that resource in excess of simple engineering calculations.

How come?
Efficiency gains look very much to consumers like price reductions, thereby stimulating more consumption than before,

i.e. real reductions in price for the same level of utility,
or increases in utility at constant or in some cases higher prices.

Rebound Lexicon

- $R = 1 + \eta^{E}_{\tau_E}$
- $\eta^{E}_{\tau_E} = \frac{\tau_E}{E}\frac{\partial E}{\partial \tau_E}$ (elasticity of energy use changes with respect to a technology gain)

- R>1 Backfire
- R=1 Full Rebound
- 0<R<1 Partial Rebound
- R=0 Zero Rebound
- R<0 Super-conservation

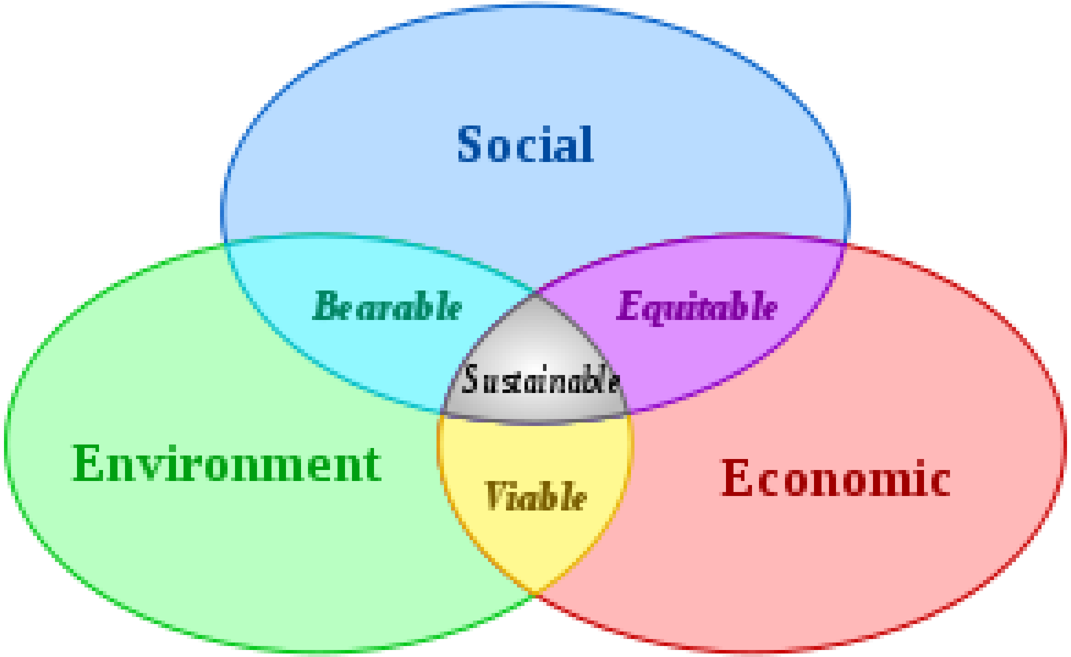
Artificial Lighting Displays the "Rebound" Effect

Over 300 years, 6 continents, and 5 technologies, and over data spanning several orders of magnitude, lighting has historically been observed to exhibit ~100% rebound

Tsao, J. Y. et al. (2010). "Solid State Lighting: An Integrated Humans Factors, Technology, and Economic Perspective", Proceedings of the IEEE , 98 (7), 1162-1179

Question: Will this continue with the transition to SSL?

The Sustainability Paradigm



UCN. 2006. The Future of Sustainability:
Re-thinking Environment and Development in the Twenty-first Century.
Report of the IUCN Renowned Thinkers Meeting, 29-31 January, 2006

Integrative Approach

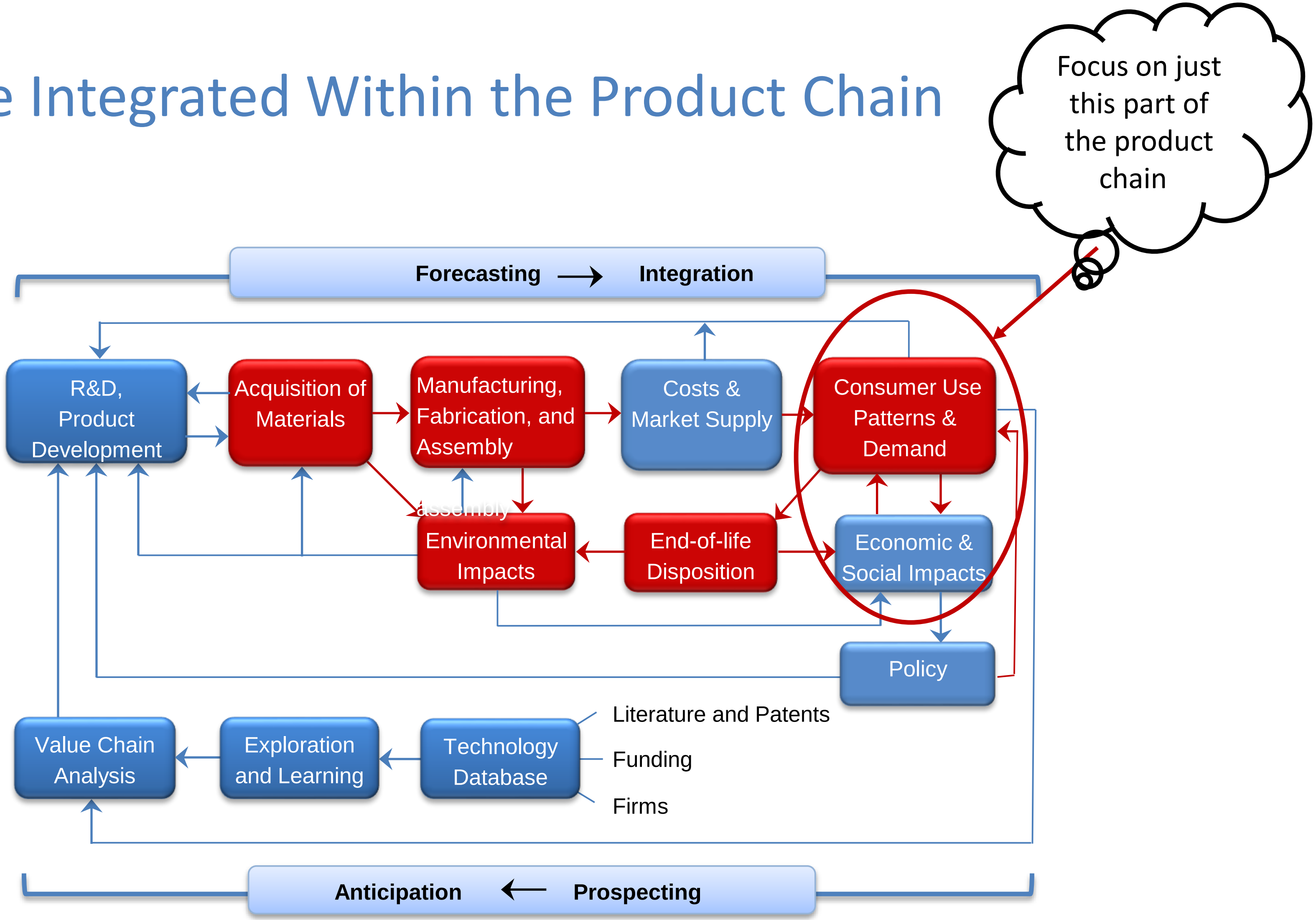
Social: Ask consumers what their preferences are

Economic: Translate social preferences into economic demands

Technological: Project economic demands forward to environmental life cycle impacts

Policy: Explore policy options (*LCA speak = improvement analysis*)

Life Cycle Integrated Within the Product Chain



Methods—Survey/Agent-based Modeling

Survey: If it is cheaper will you use more light?

Answer: ~50% affirmative (depends on how much)

Survey: Rank order the factors that affect your decision (price, quality of light, failure rate, productivity, etc.)

Result: Decision "typologies"

Agent-Based Modeling:

Models the behavior of agents in space and time

Agents—decision-making entities

Bottom-up (from micro to macro)

Most useful for illustrating emergent properties of complex systems

Decision is Expressed Through Agent Utility Subject to a Probable Course of Action

- $U_i = \prod_{i=1}^{n} F_i^{\,w_i}$ (Cobb-Douglas)

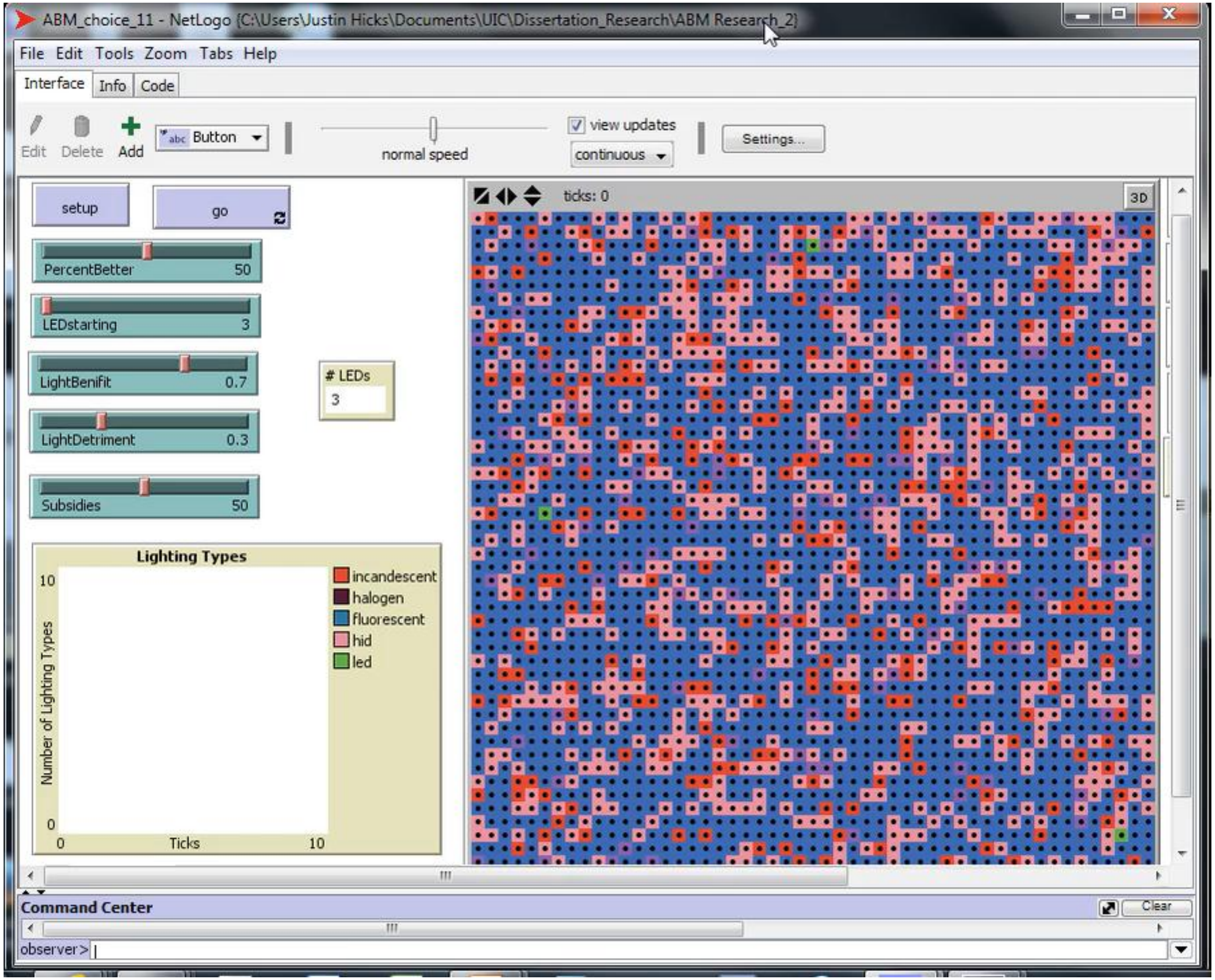
where F is a factor in a decision, w is the weighting

- $P_T = 1 = \sum_{i=1}^{L} P_i = \dfrac{e^{U_i}}{e^{U_i} + e^{U_{i+1}} + e^{U_{i+2}} + \cdots + e^{U_L}}$

P is the probability of a course of action,

L is the number of possible actions

Agent Based Simulation Cellular Automata



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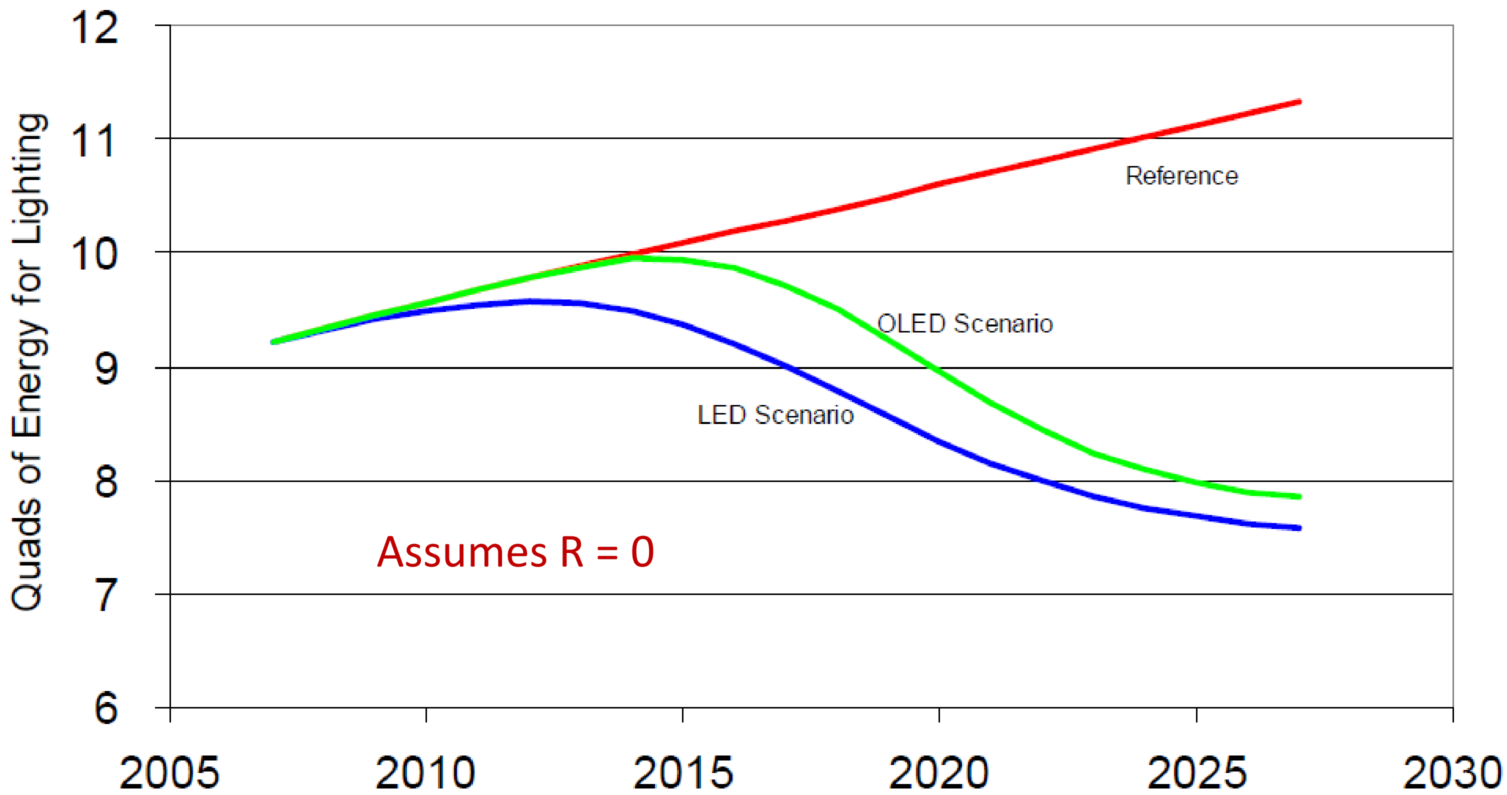

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A Few Scenarios

"Better" if:

- Ownership cost goes down
- Efficiency is greater
- "Greenness" is greater
- Neighbors are adopters

Scenario 1

- % better: 50
- Productivity>1
- Subsidy: 0

Scenario 3

- % better: 50
- Productivity>1
- Subsidy: 25

Scenario 2

- % better: 0
- Productivity<1
- Subsidy: 0

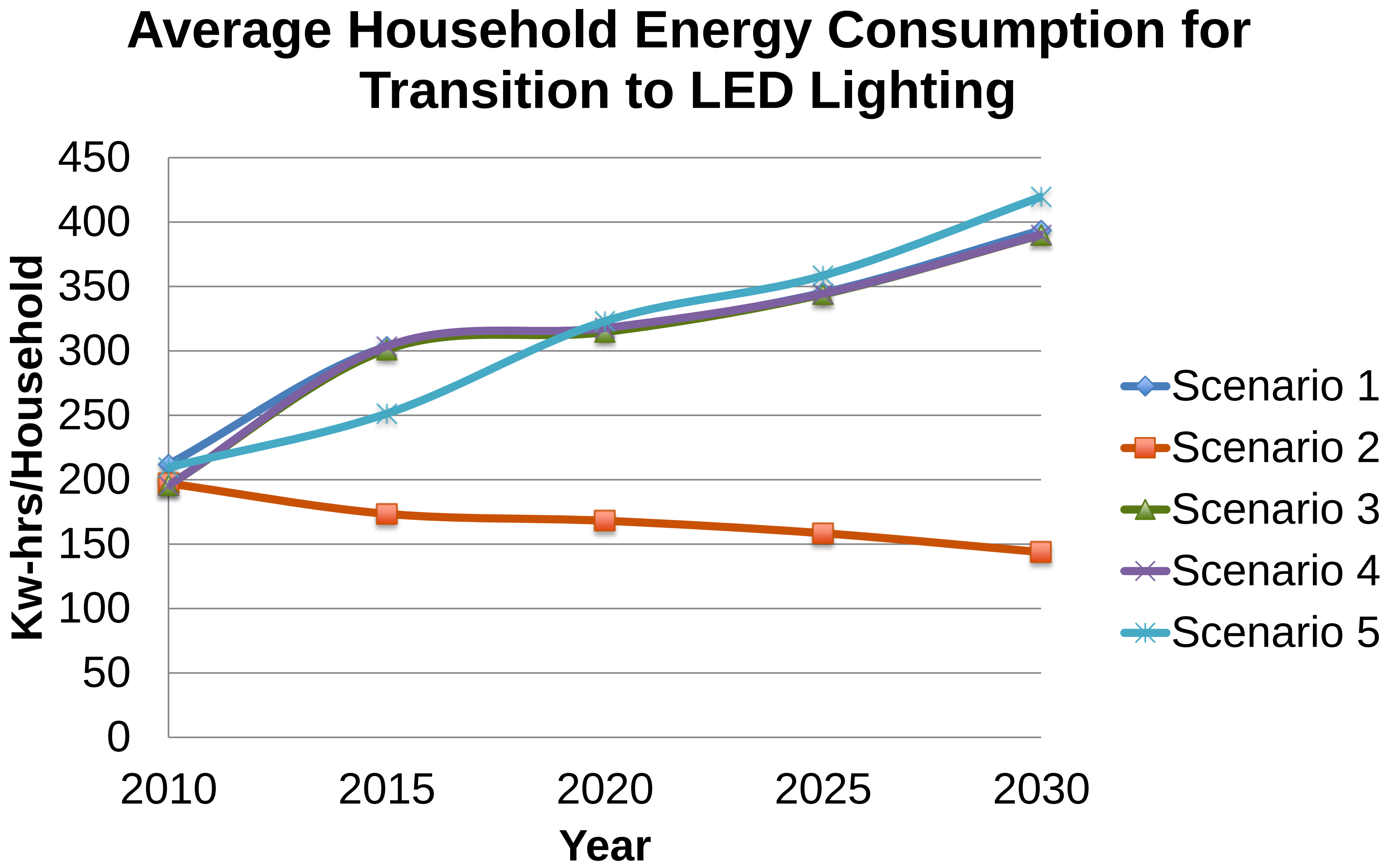
Scenario 4

- % better: 50
- Productivity>1
- Subsidy: 50

Scenario 5

- % better: 25
- Productivity>1
- Subsidy: 25

Outcomes are non-obvious



These results point to three general directions for sustainable product-chain research:

(1) Stronger interdisciplinary effort to understand the complex factors emergent across the complete product chain (including human behavior) that contribute to resource consumption, environmental degradation, and human health risk, while recognizing benefits to society,

(2) Expansion of “green” design for the environment, and organizational eco-design principles beyond their traditional focus on increasing efficiency and lowering pollutant loads per unit product to include economic and behavioral factors, and

(3) Investigation of the impacts of more highly integrated policies, based on the sustainability paradigm, that are able to meet human needs while capturing economic excesses and decoupling environmental degradation that have their roots in over-consumption.

What Do People Think About Artificial Light?

- A commodity that has improved the general well-being of society in numerous ways through empowering humans to control the use, productivity, and safety of spaces on a near-continuous basis
- A cultural symbol of enlightenment, modernity, urbanity, and security, with its symbolism as important as the achievements it has enabled