

# Technology Migration and Disruption: A Case Study of the Solid State Lighting Industry

by

Edward Alan Dowdell

B.S. Electrical Engineering  
Louisiana Tech University, 1988

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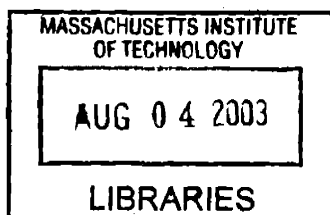
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## ABSTRACT

Geneticists study fruit flies due to their rapid lifecycles. Therefore, it follows that those interested in disruptive innovation study technologies with fast moving clock speeds. The pace of technology in solid state lighting (SSL) is an excellent subject for that purpose. Wherever one looks today, this technology, which has actually been with us since the early 1960's, is quickly affecting our lives. New traffic signals, architectural lighting solutions, theater lighting and even lights in our local restaurants are now cool, efficient and pleasing to the eye.

This thesis is intended to establish the state of the art of SSL and to provide a palette for future scenarios and ways to navigate the coming changes. The crux of the discussion is to provide considerations for managers faced with rapidly evolving technologies. Two richly detailed scenarios for the future of SSL are presented. After an analysis of the industry, a template for resolving a product portfolio with explicit examples is developed. Using those possible products as a launching platform, basic foundations of several possible business plans lay the groundwork for the next steps of a firm considering entry into the SSL industry. Finally, lessons for managers participating in rapidly innovating industries are discussed.

Thesis Supervisor: James M. Utterback

Title: David J. McGrath Jr. Professor of Management and Innovation

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I would first like to thank my partner and future wife, Tara. She has been more than ultra-patient during the entire year. In addition to looking after me, she has worked full time and pursued her own studies in marketing. I am very lucky to have found her and even more lucky to have kept her.

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## **1.0 Introduction**

### **1.1 Motivation**

Geneticists study fruit flies due to their rapid lifecycles. Therefore, it follows that those interested in disruptive innovation study technologies with fast moving clock speeds. The pace of technology in solid state lighting (SSL) is an excellent subject for that purpose. Wherever one looks today, this technology, which has actually been with us since the early 1960's, is quickly affecting our lives. New traffic signals, architectural lighting solutions, theater lighting and even lights in our local restaurants are now cool, efficient and pleasing to the eye.

This thesis is intended to not only establish the state of the art of SSL, but to provide a palette for future scenarios. The important upshot of the discussion is to provide considerations for managers faced with rapidly evolving technologies. Additionally, the basic foundations of several possible business plans lay the ground work for the next steps of a firm considering entry into the SSL industry.

### **1.2 Structure of the thesis**

A reader interested in history and roadmaps of SSL might be read Chapter 2 which contains a detailed timeline and establishes the current state of the art in light emitting diodes (LEDs) and organic light emitting diodes (OLEDs). Market diffusion modes and product synthesis are also discussed. Based on current trends and a unique approach to forecasting technology, Chapter 3 develops the future possibilities of SSL in the context of scenario planning – a process that managers tasked with “predicting” technology evolution might find interesting. Those wanting to learn about the current

state of the lighting industry may find the analysis in Chapter 4 helpful. If the reader manages or develops products, the product portfolio development in Chapter 5 that stems from observing current products, new energy sources, and various application spaces might generate new ideas in his or her own business. In particular, school and university designers and administrators may want to turn to a new design of classroom lighting (Section 5.7). If the reader is interested in developing a new business to create value with SSL technologies, Chapter 6 outlines significant portions of a business plan including target areas of the value chain, SSL value proposition generation, new lighting designs and a new paradigm in personal lighting. Finally, Chapter 7 is a more general discussion that summarizes recommendations for managers and provides one view of the future of the SSL industry.



## 2.0 Innovations in Solid State Lighting

### 2.1 History

It is amazing that a phenomenon originally discovered in 1907 should be causing such a stir nearly 100 years later. It is believed that Captain R. J. Round, an assistant to Guglielmo Marconi (known as the father of radio) and holder of 117 patents, was the inventor of the LED. He observed “bluish” light well before Dr. Shuji Nakamura and Nichia (and Cree) began their intense intellectual property battle<sup>1</sup> over the silicon-carbide based blue LED in 1993. In a letter to the Editors of *Electronic World*, Round wrote:<sup>2</sup>

On applying a potential of 10 volts between two points on a crystal of carborundum, the crystal gave out a yellowish light. Only one or two specimens could be found which gave a bright glow on such a low voltage, but with 110 volts a large number could be found to glow. In some crystals only edges gave the light and others gave instead of a yellow light green, orange or blue. In all cases tested the glow appears to come from the negative pole, a bright blue-green spark appearing at the positive pole. In a single crystal, if contact is made near the center with the negative pole, and the positive pole is put in contact at any other place, only one section of the crystal will glow and that the same section wherever the positive pole is placed.

Following the initial discovery, a number of researchers moved the science of solid state light emission forward:

- 1921 – O.V. Lossew, a German researcher, rediscovered light emission from silicon-carbide, coined the “Lossew” effect.

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<sup>1</sup>Ralph Cunningham, LED Inventor Fights for Ownership, *Managing Intellectual Property*, London, Oct 2002.

<sup>2</sup> *Semiconductor Devices: Pioneering Papers*, Edited by S.M. Sze, World Scientific Publishing, 1991, page 879. Note: Carborundum is silicon-carbide

- 1927-1942 – O.V. Lossew continues work with light emission and further hopes to “transmit the news” by use of a *drehspiegel*, or “trick mirror” and reports in Physik Journal of Physics.
- 1935 - G. Destriau investigates electroluminescence and crystal lattice structures as reported in Philosophical Magazine (Cambridge, England)<sup>3</sup>, coined the “Destriau” effect.
- 1951 – K. Lehovec, C. Accardo and E. Jamgochian report light emission from silicon carbide crystals at varying currents and temperatures. Again, these researchers were able to generate “bluish” light, as well as “yellow” light. It is also notable that this paper was the first to begin to explain quantum physics underlying the phenomena.
- 1962 – Nick Holonyak and co-workers with the General Electric Corporation demonstrated controlled light emission from an LED at Solid-State Device Research Conference in New Hampshire, July 1962. It is worth noting that the development of the transistor, the laser and the LED were inextricably entwined. Holonyak also reports being recruited by Dave Packard to join Hewlett-Packard (HP) and run the internal startup focused on developing LEDs for displays on HP equipment. Later in 1962, General Electric begins marketing sample LEDs at \$260 each – the true first commercial offering of LEDs.<sup>4</sup>

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<sup>3</sup> Selected papers on phosphors, light emitting diodes, and scintillators :applications of photoluminescence, cathodoluminescence, electroluminescence, and radioluminescence. Marvin J. Weber, editor. Bellingham, Wash. ; SPIE Optical Engineering Press, c1998

<sup>4</sup> Nick Holonyak, Jr., *From Transistors to Light Emitters*, IEEE Journal of Selected Topics in Quantum Electronics, vol. 6, no. 6, November/December 2000.

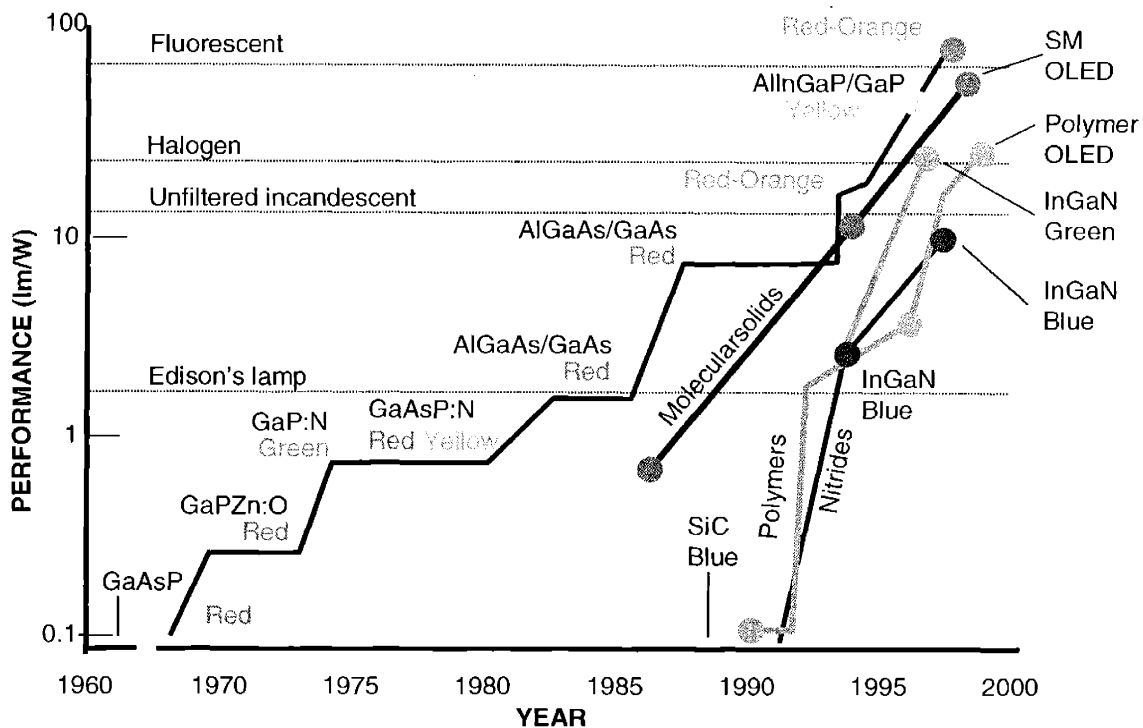
- 1962 – Lincoln Labs (MIT) demonstrates GaAs transmission and reception over “thousands of yards.” Holonyak marks this as the beginning of opto-electronics.<sup>5</sup>
- 1963 – First discovery of light emission from organic crystals by Pope, H.P. Kallmann, P. Magnante.
- 1968 – HP and Monsanto offer red indicator lamps for sale.
- 1971 – Yellow, green and orange LEDs available from GaAs and GaP crystals.
- 1980-1982 – Increased effectiveness from AlGaAs luminescence crystal LEDs.
- 1987 – Ching Tang and Steven Van Slyke of Eastman Kodak Co., Rochester, N.Y., successfully produced the first efficient light emission from a two-layer organic structure resembling a p-n junction.<sup>6</sup> 1% efficiency obtained.
- 1990 – Researchers at Cambridge University in England under the direction of Richard Friend reported reasonable efficient light emission in a semi-conducting organic polymer film consisting of poly para-phenylene vinylene, or PPV.
- 1990-1992 – AlInGaP LED again increased effectiveness and efficacy substantially

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<sup>5</sup> R. J. Keyes and T. M. Quist, “Recombination radiation emitted by gallium arsenide,” in IRE Solid-State Device Research Conf., Durham, NH, 1962.

<sup>6</sup> C.W. Tang, S.A. VanSlyke Organic electroluminescent diodes. Applied Physics Letters 1987.

- 1993 – Dr. Shuji Nakamura of Nichia Chemical invented and introduced blue and green spectrum emitting InGaN diodes LEDs. With the advent of blue LEDs, white light was possible by combining red, green and blue.
- 2001 – Partnership for Solid-State Lighting Workshop held.
- 2001 – Optoelectronics Industry Development Association set technical roadmap targets (presented later).
- 2002 – Researchers at GE develop an OLED panel with 1.3% efficiency and 1080 cd/m<sup>2</sup> brightness.
- 2003 – Nichia announces 60 lm/W white LED with 34% quantum efficiency using concavity and convexity shaping.



**Figure 1.** Historical Progression of Solid State Lighting Efficacy.<sup>7</sup>

<sup>7</sup> George Craford, LumiLeds Lighting

## 2.2 Current Technology Roadmaps (Inorganic and Organic)

The following two tables outline the technical roadmaps of both inorganic and organic LEDs.

### Inorganic Roadmap (LED)<sup>8</sup>

Attribute	State of the Art	Target	Comments
Luminous Efficacy (lm/W)	White: 60	White: 200	Combines electrical to optical power conversion with the ability of the human eye to detect. The real idea is to match emitted light with this response curve. <i>Is 200 lm/W really necessary?</i>
Lifetime (khrs to 50% depreciation)	20	>100	SSL don't fail – they just dim away. 20 khrs in normal office setting is about 7 years. <i>Do all applications require 20khrs?</i>
Flux/Lamp (lm/lamp)	100	1,500	Targeting output package similar to incandescent bulb. Assumption is that humans need kilo-lumens to light their environments.
Purchase Cost (\$/klm)	200	5	Combined with ownership to be competitive with fluorescent lamps
Ownership Costs (\$/Mlm-hr)	16.00	0.63	Cost of ownership = cost of capital + cost of operating. SSL is expected to overtake incandescent in 2005 and fluorescent in 2010. Note that at the limit, all costs are driven by operating costs. <i>Question: What if operating costs were minimal?</i> A more in depth analysis of the economics of LEDs is presented in Chapter 5.
Color Rendering (CRI)	75	>95	Color rendering is the ability of light to faithfully render color of non-white objects. CRI is an index of 0 – 100, 100 being 5,000K sunlight. By combining RGB sources, SSL can attain high CRIs. <i>What is "good enough"</i>

<sup>8</sup> LEDs for General Illumination Update 2002 – Tutorial. Optoelectronics Industry Development Association, Washington DC. Jeff Tsao, editor.

			<i>CRI?</i>
Color Temperature (CT) (°K)	3900	3900	Appearance of the light when viewed directly, or when illuminating a pure white body (how “warm” or “cool” the light appears). Again, by combining RGB SSL sources, any CT over the human visual range can be attained, although efficacy inherently degrades at higher CT

### Organic Roadmap (OLED)<sup>9 10</sup>

Attribute	State of the Art	Target	Comments
Luminous Efficacy (lm/W) and Brightness (cd/m <sup>2</sup> )	White: 20, 1080	White: 150,	Combines electrical to optical power conversion with the ability of the human eye to detect. The real idea is to match emitted light with this response curve. <i>Is 200 lm/W really necessary?</i>
Lifetime (khrs to 50% depreciation)	10	>100	Big challenge for OLEDs as they suffer a “steady, monotonous, irritating” degradation.
Flux/Lamp (lm/lamp)	Depends upon size	Depends upon size	OLEDs have an inherent advantage in that they are manufactured in “sheets” and therefore emit diffuse light.
Purchase Cost (\$/m <sup>2</sup> )	>120	30	Combined with ownership to be competitive with fluorescent lamps.
Ownership Costs (\$/Mlm-hr)	16.00	0.63	Cost of ownership = cost of capital + cost of operating. SSL is expected to overtake incandescent in 2005 and fluorescent in 2010. Note that at the limit, all costs are driven by operating costs. <i>What if operating costs were minimal?</i>
Color Rendering (CRI)	75	>90	Again, here the tradeoffs of quality vs. flexibility will be important.

<sup>9</sup> J. Norman Bardsley, International OLED Technology Roadmap: 2001-2010 U. S. Display Consortium.

<sup>10</sup> Partnership for Solid-State Lighting: Report of a Workshop. Washington DC, March 2001. National Academy Press

			<i>But, if the light is very flexible and has the ability to integrate with other materials, how important is CRI?</i>
Color Temperature (CT) (°K)	3900	3900	Similar to LEDs – color temperature is addressable by combining different colors.

While these roadmaps lay the ground work for what may be possible in the future, there are still a number of challenges that SSL must overcome. The following two tables outline both the inherent advantages as well as the challenges of SSL.

### **Inorganic SSL Advantages and Challenges**

<b>Inorganic LED Advantage</b>	<b>Comment</b>
Exceptionally long lifetime.	Dims over time, rarely “burns out.” Last 100 times longer than incandescent.
Low power requirements. Highly efficient (30% vs. 5%) conversion of electrons to visible photons.	Two times lower power than incandescent. Gross saving of \$10 billion per year.
Cool operation.	Safe. Ability to put light where you can use it.
Rugged. No breakable glass bulbs or tubes.	Safe and accessible. Smaller form factor. Can be placed in adverse environs.
Small sizes. Lightweight	Flexible form factors, no luminaries.
Environmental advantages	No mercury (0.5% of mercury released in 1999 from lighting). Ability to free over 125 GW of power (125 large power plants) and reduce CO <sub>2</sub> emissions by 200 million tons per year. Advantages are offset by losses in SSL manufacturing process.
Directional.	Light can be efficiently placed where needed. Although a fluorescent lamp typically emits 8,000 cd/m <sup>2</sup> , while the effective light output is about 25% of that 8,000 cd/m <sup>2</sup>
Color Changing Capability	Using RGB emitters and intensity control, programmers can control lighting color and CRI.
Fast switching (on/off) times.	Useful in brakelights and also in other applications.

<b>Inorganic SSL Challenge</b>	<b>Comment</b>
Output (lm/W)	Although directional, light output needs to be increased. Historically increasing at 10x per decade.
Costs	Decreasing at 30x per decade, but gross lightout is \$500 per kilolumen vs \$1 per kilolumen for incandescent
Packaging	Although many degrees of freedom here, no dominate package has been selected
Standards	Although more of a mental hurdle, NIST and other organizations need to help establish industry standards as appropriate.
Color Rendering	Current white LEDs tend to be “bluish” and cannot address the entire color spectrum at reasonable costs.
Lighting Energy Infrastructure	Most LEDs operate on DC voltage while most electron grids are AC.
Psychological Barriers	Consumers are not keen to invest upfront, even when longterm savings more than cover capital costs.

### **Organic SSL Advantages and Challenges**

<b>Organic LED Advantage</b>	<b>Comment</b>
Simple and elegant	Light, designed by nature.
Flexibility. Thin.	OLEDs are amorphous and bendable. Embeddable in glass, metal and silicon.
Cool operation.	Safe. As with displays, these light emitters are cool to touch and harmless.
Transparent.	Transparent to their own radiation. Allows monochrome layers to be manufactured to create white light.
Small sizes. Lightweight.	Flexible form factors, no luminaries.
Environmental advantages	No mercury (0.5% of mercury released in 1999 from lighting). Ability to free over 125 GW of power (125 large power plants) and reduce CO <sub>2</sub> emissions by 200 million tons per year. Advantages are offset by losses in SSL manufacturing process.
Low turn on voltages	3 volts and lower.
Color Changing Capability	Using RGB emitters and intensity control,



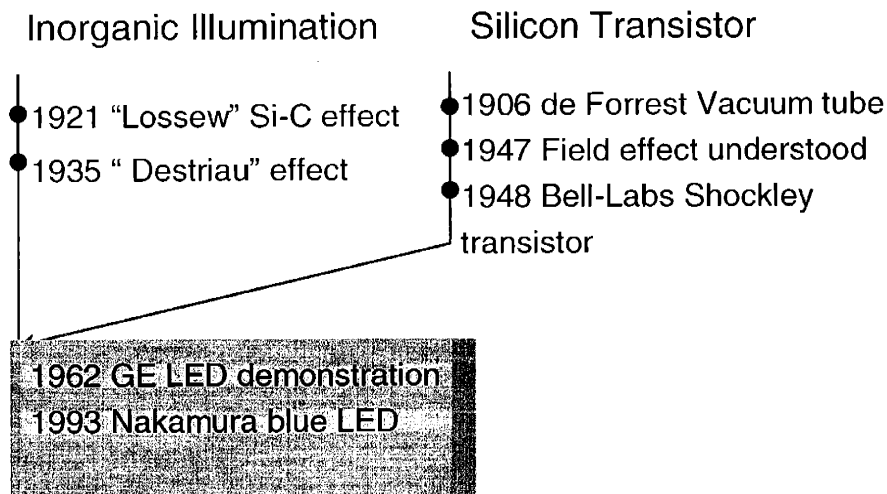
	programmers can control lighting color and CRI.
Highly efficient electron to photon conversion	80% efficiencies have been demonstrated.

<b>Organic LED Challenge</b>	<b>Comment</b>
Lifetime	About one order of magnitude increase is needed <i>to compete with traditional lighting.</i>
More brightness	Relatively dim.
Packaging and encapsulation	OLEDs are very sensitive (darken) to moisture (they are a better indicator than currently available moisture detectors).
Edge emission	Much of the light “leaks” out of the edges of the package.
Color and color rendering	Multiple methods exist to generate white light. Unclear which will prevail.
Efficiency	Needs to be increased to 40% from 5%.
Manufacturing costs	Need to continue to decrease.
Materials	Increased stability.
Processing	Drive toward bulk roll processing.

### 2.3 Solid State Lighting as an Emerging Technology

Although much of the early work with electro-illumination was specifically to investigate the emission of light, research in the electrical switching disciplines (i.e. vacuum tubes to transistors) was the true genesis of LED breakthroughs. In the early 1960s, it was specifically the work toward developing a more useful electrical switching circuit that begat LEDs. In 2000, Dr. Holonyak (one of the GE inventors of LEDs) reported to the IEEE society in an invited paper how the development of lasers, transistors and LEDs were being pursued by many of the same people.<sup>11</sup>

<sup>11</sup> Nick Holonyak, Jr., *From Transistors to Light Emitters*, IEEE Journal of Selected Topics in Quantum Electronics, vol. 6, no. 6, November/December 2000



**Figure 2.** Genesis of SSL began at the same time as the development of transistors.

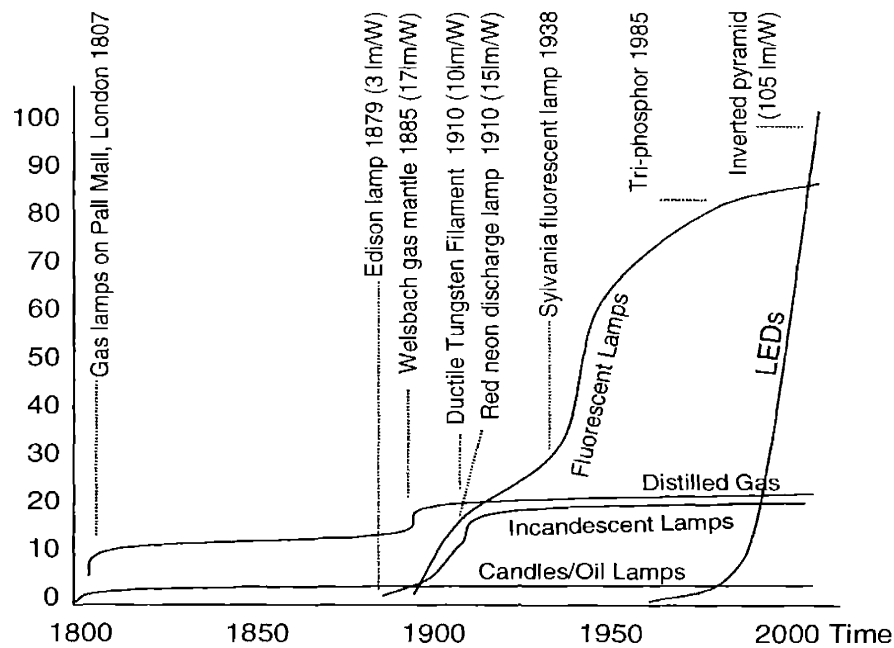
As with many other examples in technological evolution, the drive to deliver value for one purpose has created innovation in an entirely different application space. In SSL, the desire to create small and fast electrical switching devices, with an eye toward replicating mechanical computation electrically, along with the want to create a coherent light source "laser" resulted in advances in solid state light emitters. Some other examples follow:

- **Steel Industry.** The need and desire for transportation drove innovation in steam engines and railways that required new ways of forming and working steel. These innovations in steel then disrupted and displaced the timber industry, as well as allowing a whole new application in bridges and skyscrapers.
- **Nuclear Power.** From Einstein's first letter to the US Government explaining the possibility of unleashing large amounts of energy from a

nuclear reaction to the Manhattan Project came an entire industry of nuclear power.

- **Post-it-notes.** From the laboratory of one scientist at 3M working on very strong chemical bonding material came a not-so-strong glue that opened an entirely new way of keeping track of items, thoughts, and reminders.

Utterback (1994) discusses “waves” of innovation that periodically sweep through industries: word processing, photography, plate glass, ice, and lighting.<sup>12</sup> Figure 3 shows the historical waves of innovation that have swept the lighting industry. Although it remains to be seen just how disruptive the SSL technologies of inorganic and organic LEDs will be, displacement of some incandescent applications has already occurred.



**Figure 3.** Waves of product innovation in the lighting industry.<sup>13</sup>

<sup>12</sup> James Utterback, *Mastering the Dynamics of Innovation*. (Harvard Business School Press, Cambridge, MA, 1994). Chapter 8.

<sup>13</sup> Data for chart from multiple sources: 1 candle = 12 lumens; Gaslight America Inc, History of Gas Lighting, 1 mantle = 680 watts (website); Smithsonian Institute of American History (Lighting); OSRAM Sylvania History ([www.sylvania.com](http://www.sylvania.com)); Peter Kilby, ElectroLink Magazine, *The Age of Light*, (Parts 1-6) 2000 – 2001.

These “discontinuities” in innovation have been studied by Utterback (1972, 1993 and 1994); Christensen (1997); Foster (1986) and others. For managers, the largest value comes in the ability to predict or at least prepare for these discontinuities. Later, ways to foresee potential disruptions will be discussed.

## 2.4 Response of Current Lighting Technologies

As with other historical examples (gas lamps, disk drives, dry plate photography and ice harvesting), the lighting industry has made many improvements in current technologies. It is too early to tell if these advances are in direct response to the “threat” of SSL or if the intensely competitive nature of the industry has facilitated the improvements. As the following examples highlight, it is probably a combination of both:

- **Fluorescent ballasts.** A major draw back in the use of fluorescent lamps is that a “starter” and “ballast” are required to control the flow of electricity to the gas during discharge. Fluorescent ballasts, although inherently magnetic, have become digital (solid-stage), and therefore smaller, more efficient, and lighter in size.<sup>14</sup>
- **Incandescent filaments.** Researchers at Sandia National Laboratories (an institution well aware of the advances in SSL technologies) have developed a new tungsten filament for incandescent lamps using

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<sup>14</sup> Universal Lighting Technologies. *Why Low Profile is Having a High Impact on the Industry: A new profile for a new millennium.* Bill Kirkland, Vice President Sales and Marketing.

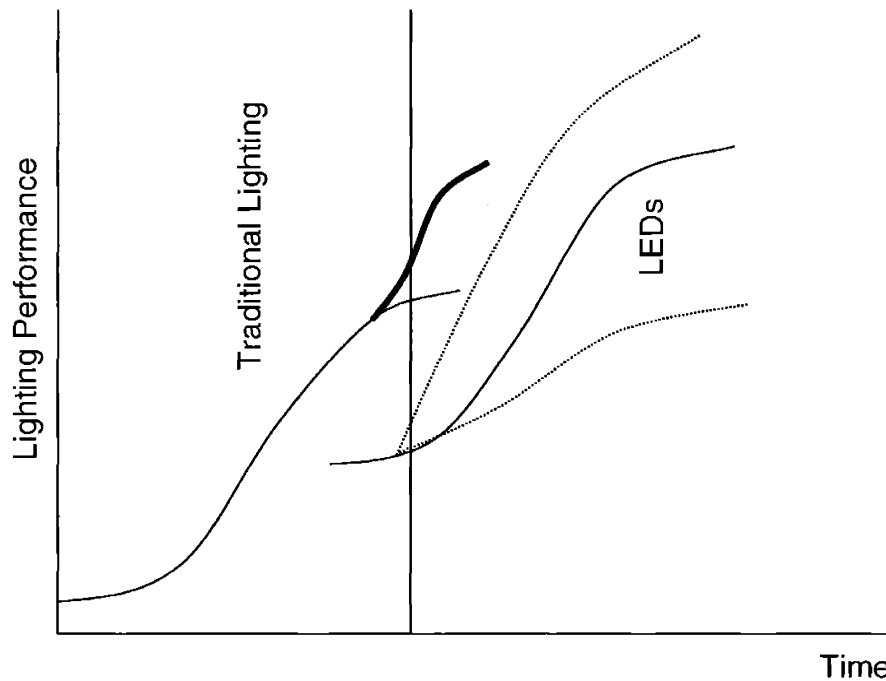
techniques normally reserved for making semiconductors as well as new nano-technologies. Energy savings of up to 60% are possible.<sup>15</sup>

- **Discharge Lamps.** GE, Osram, and Philips developing ever smaller metal halide discharge lamps with greater efficiency and better color rendering. Low voltage halogen lamps, such as the tiny Iwasaki MR8 25mm, can go where other lamps can not.
- **Dielectric barrier discharge lamps (DBD).** These “light tiles” are flat glass panels filled with xenon, no mercury. Although relatively expensive, they mimic the light output which is thought possible from OLEDs.
- **Fluorescent advances.**<sup>16</sup> Many advances are around form factors, but several involve dramatic “system” level advances. For instance, Osram’s ICETRON lamps have no electrodes (the major failure point) and therefore last much longer than traditional fluorescent lamps. Matsushita has created a dual fluorescent lamp with a color temperature change capability from 2500K to 5500K. Additionally, phosphor technologies continue to innovate as new formulas (and new color spectrum profiles) have recently been invented.

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<sup>15</sup> John Kialka. *How to Build a Better Light Bulb: Use the Original.* The Wall Street Journal. New York, N.Y.; May 2, 2002

<sup>16</sup> Carl Gardner. *Sources for courses.* Light, November, December 2002.



**Figure 4.** Competition in traditional lighting as well as threat of a new entering technology cause traditional players to respond. Graph is conceptual from author's analysis – does not constitute data.

## 2.5 The Predator, Prey, and New Markets

Pistorius and Utterback develop the ideas of multi-mode interaction among technologies where there are at least three modes, using *growth rate* for a metric:<sup>17</sup>

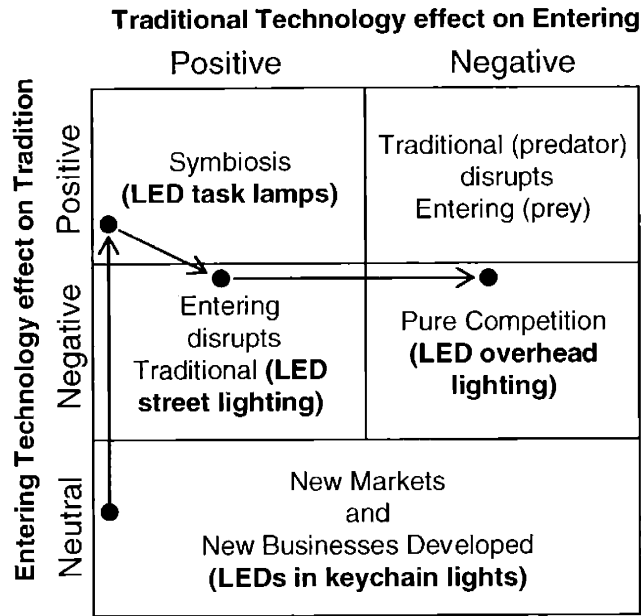
- **Pure competition.** One of the most common interactions where each technology combats the other, as in the substitution of flat panel displays for CRTs in computers.

<sup>17</sup> C.W.I. Pistorius, J.M. Utterback. Multi-mode interaction among technologies. *Research Policy* 26 (1997). pp. 67-84.

- **Symbiosis.** A prime example is how new computer software drives computer technology innovation, and new computer technology drives new software development.
- **Predator-Prey.** The examples here can be somewhat subtle in that the predator-prey relationships can exist during short periods of time, and can even reverse as the interaction continues. Some examples include attack of high temperature steel alloy engine components by ceramic components. Another classic example is termed the “sailing ship” effect after the development of fast sailing clipper ships to counter the attack by steam ships.

A third type of response by the incumbent technology is not reacting at all, or neutral response. Although some scholars give this situation its own descriptive mode, Pistorius and Utterback include it in the predator and prey mode.

Applying the concepts of multi-modal technology interactions to the solid state light industry, one can argue that the first entries of LEDs into the market were neither affected by nor affected traditional lighting as they were in novel and niche applications like key chain lights. Then, SSLs may be seen moving to applications like laptop task lights where co-existence with small, traditional lights is symbiotic. SSL further moves to a predator-prey mode in markets traditionally served by incandescent and fluorescent lighting such as street lamps and landscape lights. Finally, SSL are projected to compete head to head with traditional lights in their home markets of general indoor lighting. While there is a general trend of shifting toward pure competition over time, these modes do co-exist in time.



**Figure 5.** Temporal shifts of solid state lighting.

Ron Adner and Daniel Levinthal (2002) discuss technology innovation in terms of genetic events, specifically *speciation* events and *punctuated equilibrium*: the separation of one evolving population from its antecedent population. They liken this analogue with the application of a technology to a new domain where it evolves in different directions. Our example of SSL separating from solid state transistors and being applied to lighting is one such speciation event (see Figure 4 above).

More interesting are cases where the new technology that spawned from the existing technology evolves in other applications only to invade the mainstream application that spawned it.<sup>18</sup> This is a twist on Christensen’s thesis that disruptions come from “crummy” technologies – according to Adner and Levinthal, the disruptors

<sup>18</sup> Ron Adner and Dan Levinthal, *The Emergence of Emerging Technologies*. California Management Review, vol 45, number 1, Fall 2002.



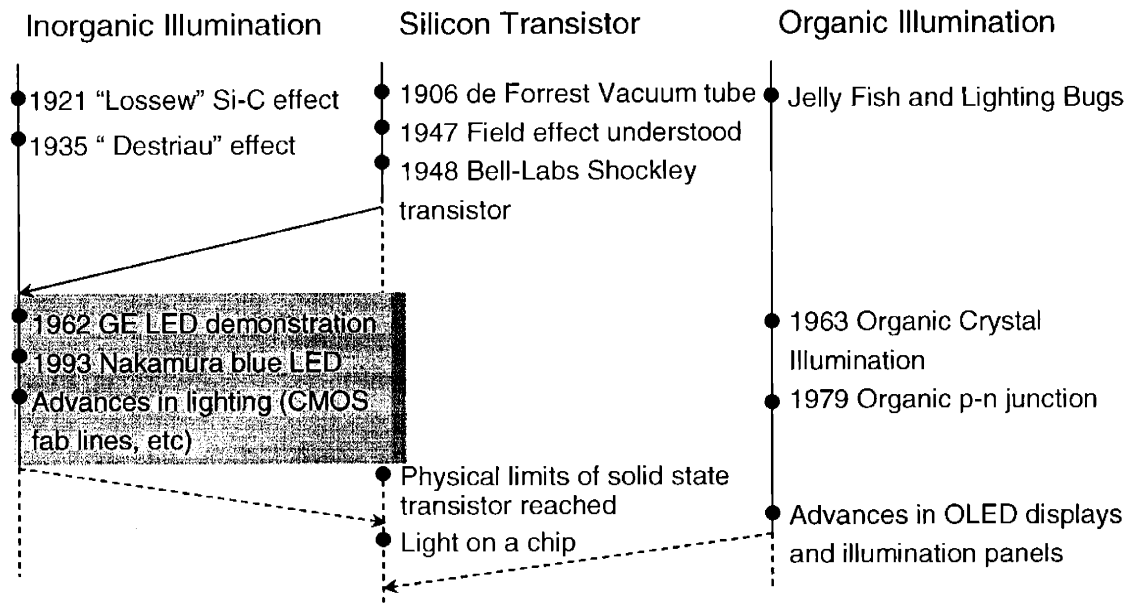
often are niche technologies that originally came from the same innovations that begat the mainstream.

This “creative disruption” may hold to be true in SSL. As transistor based on semiconductor technologies begins to face physical limits in space and speed, optoelectronic technologies have the potential to deliver additional degrees of freedom to the computing industry. Companies such as LNL Technologies (Cambridge MA) have already developed prototypes delivering 3,000 light chips on a single wafer.

And, with thin-film flexible organic materials, computational circuits may dissolve *into* the products they control. *Why have separate silicon driver circuits for an OLED display when the computer itself can be integrated into the display?* Although it is unclear whether small molecule or polymer technologies (or both) will prevail, organic circuits are becoming a reality.<sup>19</sup> The only hanging question is in which lighting applications they will begin to disrupt first.

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<sup>19</sup> Stephen Forrest and Paul Burrows, *The dawn of organic electronics*. IEEE Spectrum, August 2000.



**Figure 6.** Possible creative disruption avenues of the silicon industry by inorganic and organic opto-electronic technologies.

## 2.6 Innovation through Synthesis

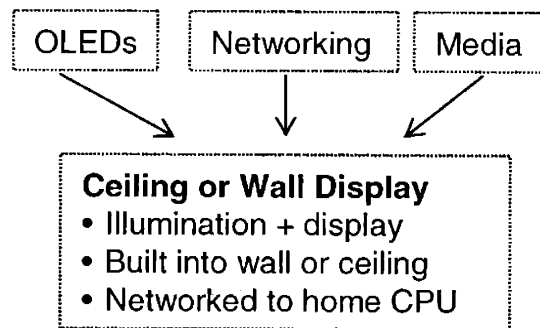
The combination of emerging and existing technologies which form new, innovative technologies that then disrupt current industries (or more interestingly create entirely new application spaces) have been studied by Utterback and Christensen. The following emerging (in some cases, emerged) technologies that deal the generalities of the transfer or movement of electrons, photons, information, and energy might be synthesized either two at a time (bi-synthesis) or in multiple combinations (poly-synthesis) to form new illumination technologies:

- Optical fiber (emerged)
- Photovoltaics (inorganic and organic)
- Fuel cells (applied to off-grid systems)
- Other battery/power cell technologies

- Wireless networking
- Advances in fabric materials: nano-materials
- Advances in building materials: plastics
- Wireless networking
- Advances in fabric materials: nano-materials
- Advances in building materials: plastics

## 2.7 Some Examples of Bi-synthesized and Poly-synthesized Technologies

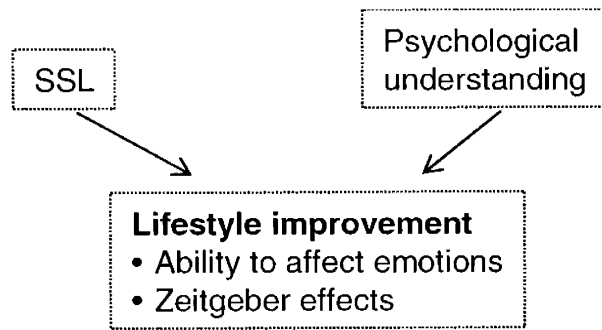
**Wall or Ceiling Media Display.** Simply by combining OLED technology with existing network and computer technology, a wall sized or ceiling sized display can be created. The user can receive news, internet and other network based information when it functions as a display, and soft, programmable light when it functions as an illumination device.



**Figure 7.** Wall or Ceiling Media Display.

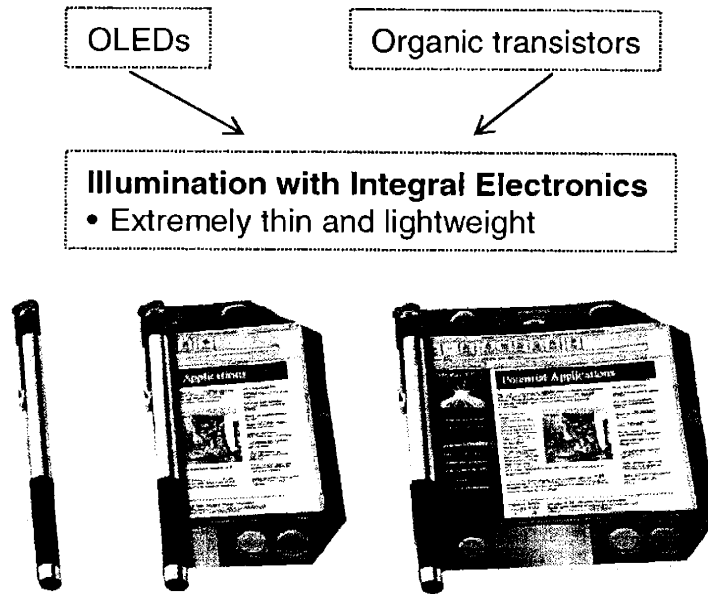
**Lifestyle Lighting.** As fundamental understanding is gained in the area of the psychological influences of light on human beings, these advances can be combined with a ability to program exact color temperatures and chromaticity. The new “flavors” of light may give rise to a whole new language about how we describe light. The more

sources of light, the easier the entire “addressable” range of colors can be attained. People could more easily overcome the effects of jetlag, remove seasonal affective disorder (SAD – more commonly known as the “winter blues” and associated with vitamin D deficiency), and overcome the effects of depression.



**Figure 8.** Lifestyle lighting synthesis and color chromaticity chart. Light “flavors” such as *sunlight*, *sunset*, *twilight* and others can be designed using multiple SSL sources.

**Illumination Panels with Integral Electronics.** One tends to think of driver circuits as separate entities from display (or illumination devices) but with thin-film circuits on the rise, these pieces can become one elegant assembly. Once the learn curve for manufacturing is solved, the price-experience curve will be very steep. Past this tipping point, the applications for thin, flexible panels that can display information as well as provide illumination are unbounded.

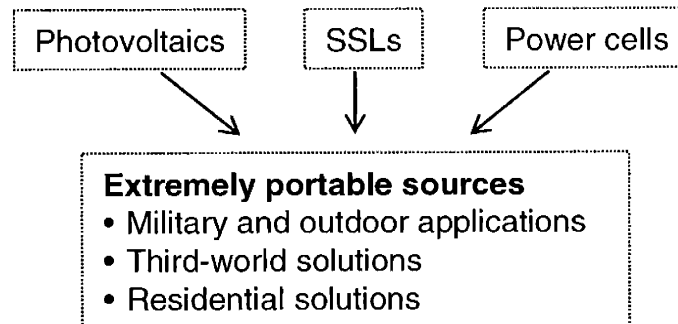


**Figure 9.** By combining thin-film light emitting technologies with thin-film electronics, possibly organic, flexible and portable products with fewer subsystems can be developed. (Source of image: Cambridge Display Technologies Ltd).

**Photovoltaic Powered Portable Illumination Sources.** An entirely new capability is available by combining new and efficient solar-cells, very efficient solid state lights, and new power cell technologies. These “off-grid” sources can be used where they are needed most: military, outdoor, boating and third-world solutions. Over one-half the world lives in darkness – this technology could change the lifestyles of billions of people. Already a consortium of entrepreneurs and volunteers are moving in this direction: Light Up The World, Solid State Lighting for Human Development is an organization chartered to use SSL technologies to enhance the quality of life of the poor in the developing world. The cost per year of lighting a home is expected to drop to \$35

from \$60 during 2002 only. The potential for this one application is summed up in the following quote:<sup>20</sup>

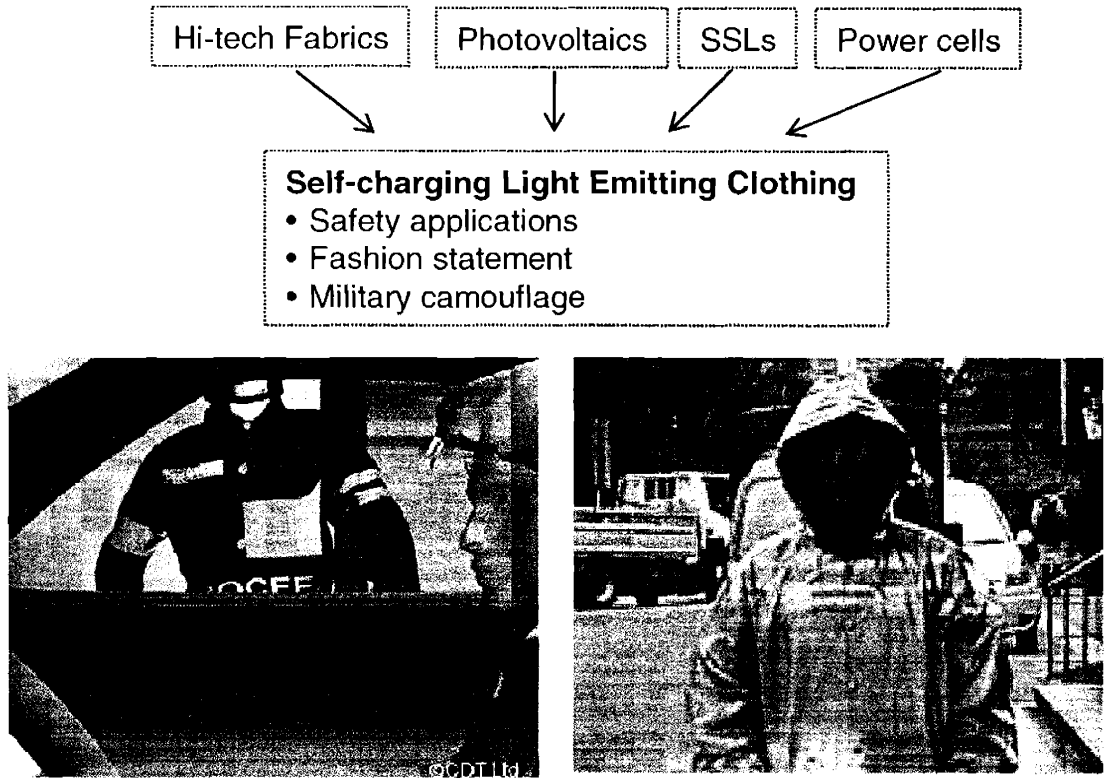
*“We always pray to God for you and your family for sending us the beautiful gift of light.”* St. Alphonsus Social & Agricultural Centre – Kurseong, West Bengal, India 2001.



**Figure 10.** By combining solar cell technology, new power cell technology and SSLs, a new paradigm of portable lighting sources will soon be available.

**Solar Powered Active Clothing.** As each individual sub-system becomes more elegant and simple, the combination of elements can become more complex. For instance, combining new fabric technologies, photovoltaics, SSL and rechargeable power cells can result in new active illumination clothing. One can imagine highway or other construction personnel working by the light of their own clothing, while also bringing attention to themselves for increased safety. Clothing that presents images of emotion, camouflage, and the literal “fashion statement” as well as the possibility of taking our light with us wherever we go could also be an advantage.

<sup>20</sup> Ken Robertson et al, Light Up The World - Update (2001 – 2002). [www.lutw.org](http://www.lutw.org)



**Figure 11.** By combining multiple emerging technologies, solar powered light emitting clothing may change the way we see each other (or not see each other). (Sources for images: Cambridge Display Technologies Ltd (left) and Professor Susumu Tachi Optical Camouflage Project, Graduate School of Information Science and Technology(IST), The University of Tokyo (right)).

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### 3.0 Two Scenarios for the Future of Lighting

#### 3.1 Long Lived Companies

The Royal Dutch Shell Corporation has long been known for its scenario planning department and unique approach<sup>21</sup>. Arie de Geus and Peter Schwartz, both previous planners at Shell, have researched long lived companies with an eye to understanding what underlying key factors cause companies to last for hundreds of years. The average life of a corporation today is 40 to 50 years (and will probably trend downwards as the collapse of the 2000 tech bubble takes its toll).

The results of de Geus's study of over 200 companies that have lasted over 100 years shows that companies survive not by focusing on short term profits, share price or even innovative technologies. They are long lived because each held the following key factors important:

- **Sensitivity to the environment.** These companies existed in harmony with the environment, both ecological and social, and reacted to the trends of society.
- **Strong, cohesive identity.** Each company developed a community where members felt they belonged and where managers advanced from within. The priority of the overall institution was overriding.
- **Tolerance to decentralization.** Attempts to diversify the company should not be centralized. Management should be tolerant to outliers at the margins of the corporation, and experiments and eccentricities that stretch the understanding of possibilities should be allowed.
- **Conservative in Financing.** Frugality in the risk of capital and old fashioned money management were found in nearly every example. The long lived companies grasp their own opportunities without the aid of third-party financing.

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<sup>21</sup>. Arie de Geus, *The Living Company*. (Harvard Business School Press, Boston, Massachusetts, 1997).

Even more surprising were the aspects that did not correlate with corporate health:

- Ability to supply return capital to shareholders
- Accounting figures – they are only a measure of past performance
- Material assets or resources, specific industry, product line or country of origin

### 3.2 Clock Building

Similarly, James Collins and Jerry Porras underscore the approaches that long-lived companies should take.<sup>22</sup> In fact, their research finds a negative correlation between early success and “visionary companies.” Most very successful companies did not start with a great idea or technology, but rather a persona of persistence, drive and long term ambition. Hewlett Packard started out with automatically flushing toilets and bowling lane fault detectors before moving on to more recognizable products.

Companies should be *clock builders*, not simply time tellers. By the time you can read the indications of change, it is too late. Leaders should think in terms of decades versus quarters. One pivotal point that Collins and Porras make is that companies must build their leadership from within – a visionary persona and culture takes time to develop and introducing external contaminates is detrimental in the long run. In a letter to Harvard Business Review, Collins expresses the fact that lasting companies, rather than being soft on people, actually demand very high performance standards, and require leaders to be culturally fit.<sup>23</sup> In short, great companies have demanding cultures.

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<sup>22</sup> James Collins and Jerry Porras, *Built to Last: Successful Habits of Visionary Companies*. (Harper Collins, New York, 1994)]

<sup>23</sup> Letters to the Editor, By: Collins, James C. Harvard Business Review, May/June 1997, Volume 75 Issue 3

### 3.3 Tools for Foresight and Strategy

If companies are to survive the long-haul, there must be internal mechanisms that guide a company to the next generation of technology, the next great value adding product or the next fruitful market. These tools and systems should take the entire global environment into account. The following is a non-comprehensive list of some tools a manager might want to include in technology strategy evaluation:

Technique or Approach	Comments
<b>Time-series forecasting:</b> Evaluation of trends and projection into future using historical growth rates	<ul style="list-style-type: none"> <li>▪ Good for short term forecasting where markets are stable</li> <li>▪ Facilitates use of quantitative analysis</li> <li>▪ Poor predictor of cycles and market discontinuities</li> <li>▪ Simplistic view – does not address horizontal aspects of business</li> </ul>
<b>Econometric Prediction Methods<sup>24</sup>:</b> Lotka-Volterra, Fisher-Pry, Pearl-Reed, Box-Jenkins, Regression	<ul style="list-style-type: none"> <li>▪ Formulates a behavioral relationship between history and future</li> <li>▪ Accuracy depends upon how data fits to model</li> <li>▪ Often non-linear</li> </ul>
<b>Probability Models<sup>25</sup>:</b> Decision Trees, Bayesian Methods, Game Theory, Game Trees, Structural Forecasting <sup>26</sup>	<ul style="list-style-type: none"> <li>▪ Introduces real world effects and tradeoffs</li> <li>▪ Difficult to apply to long run</li> </ul>
<b>Dynamic Rule Based Methods:</b> System Dynamics	<ul style="list-style-type: none"> <li>▪ Not a prediction tool, but rather tools for learning about how decisions may affect a system</li> <li>▪ Allows the user to generate complex non-linear models</li> <li>▪ Establishes mental maps</li> <li>▪ Helpful in establishing policies</li> </ul>
<b>Delphi Models:</b> Semi-analytical, expert panel based method of forecasting. Iterative. <sup>27,28</sup>	<ul style="list-style-type: none"> <li>▪ Long used “soft” technique</li> <li>▪ Generates “expert” opinion</li> </ul>

<sup>24</sup> Andrew C. Harvey, *Time Series Models*. (MIT Press, Cambridge, MA, 1993).

<sup>25</sup> Ahmet Aykaç and Carlo Brumat et al, *New Developments in the Applications of Bayesian Methods*. (North-Holland Publishing Company, Amsterdam, New York, Oxford, 1977).

<sup>26</sup> Francis Dicbold and Glenn Rudebusch, *Business Cycles: Durations, Dynamics, and Forecasting*. (Princeton University Press, Princeton, New Jersey, 1999).

<sup>27</sup> Gordon A. Welty, *The Selection and Deflection of Expertise in Delphi Exercises*, presented at the 1972 Joint National Meetings of the Operations Research Society of America and the Institute of Management Sciences, Atlantic City, New Jersey, November 8, 1972.

	<ul style="list-style-type: none"><li>▪ Panel selection process influences outcome</li><li>▪ Time consuming</li></ul>
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### 3.4 Forecasting and Scenarios

In technical environments, it is important for managers to pay attention not only to the innovations that are occurring within their discipline but also in many other industries that could spawn technologies that either directly or indirectly disrupt their strategy. Based upon research that has shown disruptive technology innovations exist in various forms well before they actually are perceived to be a threat, Utterback and Brown (1971) present an approach using “signals” – phenomena that could possibly affect current technology.<sup>29</sup> As these “straws in the wind” are identified, they are also monitored for progress and directional movement. Following James Bright, there are four steps to technological forecasting:<sup>30</sup>

- i. Search the environment for forerunners or precursors for technology change
- ii. Identify the possible consequences
- iii. Choose the parameters, policies, events, and decisions that should be followed to verify the true trajectory and speed of the technology trend, and the consequences of deploying it
- iv. Present these data in a timely and concise method to effect decisions

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<sup>28</sup>Ken Goldfisher, Modified Delphi: A concept for new product forecasting  
The Journal of Business Forecasting Methods & Systems; Flushing; Winter 1992-1993

<sup>29</sup>J. M. Utterback and J. W. Brown, Profiles of the Future: Monitoring for Technological Opportunities, Business Horizons, Vol 15, Oct 1972.

<sup>30</sup>Bright, James R., *Practical technology forecasting, concepts and exercises, with notes on anticipating sociopolitical interactions with technology*, Austin, Industrial Management Center, 1978.

The real power of this forecasting technique is the ability to develop a *hypothesis*, and then to develop a process of checking the environment for evidence to support or dispute the hypothesis. In essence, it is the *scientific principle* applied to technology innovation. A hypothesis can be restated as a *scenario*, as will be demonstrated below.

De Gaus and Schwartz argue that traditional forecasting methods are mostly a waste of time and resource. They propound that even if a forecaster was able to predict the future precisely, *a manager presented with the information would not be able to act on it*. In any given time period, a manager gets numerous inputs from strategic thinkers, sales managers, customers, more senior executives and his own instinctive feelings. How could she be expected to act on one set of information when even her own decisions will potentially affect that same information?

One solution is not to forecast, but rather to establish realistic *scenarios* of the future. These scenarios have two specific purposes: the first is to change the way people think when they envision the future, and the second is to use the scenarios to test ideas and draw conclusions. With scenarios, a manager is able to weigh each decision and action against whether it is moving her closer or further away from the favorable scenario; it additionally allows managers to internalize the risks entailed by endogenous decisions as well as exogenous effects. By communicating and publicizing the scenarios, an organization creates a “memory of the future” whereby each member can better recognize the subtle changes in technology, competition, and the overall global markets. Relative to forecasts which are rendered immediately inaccurate and out of date as decisions are taken by managers, scenarios guide the decisions and provide a mental map for strategies. It is important to note that scenarios are not predictions, but rather vehicles

to help people learn. The end result is not an accurate picture – the endgame is *better decisions about the future*.

Using scenario techniques, Royal Dutch Shell was able to foresee the energy crises of 1973 and 1979, the growth of energy conservation and the reduction of demand for oil, the evolution of the global environmental movement, and even the breakup of the Soviet Union. These techniques clearly gave Shell an important competitive advantage, as reported in the November 11, 2002 edition of *The International Journal of Future Studies*:

In the early 1980s, one of the scenarios written by the Shell planners foresaw the likelihood of a rapid and dramatic decrease in the price of oil as the result of the discoveries of new fields outside of the OPEC sphere of influence, in combination with the energy conservation measures increasingly taken by consumers who did not want, after the debacle of the 1970s, to remain overly dependent on imported oil, and who were increasingly aware of the finite nature of "non-renewable" resources such as oil. Positioning itself accordingly, Shell rose from fourteenth to second place among the oil multinationals during the mid-1980s as prices fell and other companies, heavily over-invested, lost billions.

Peter Schwartz has outlined the basic process for scenario planning – a tool he defines as a set of organized ways for us to dream effectively about our own future environments in which one's decisions might be played out.<sup>31</sup>

- i. Identify Focal Issue or Decision. Begin with a specific decision or issue and then build outward to the environment.
- ii. Local Forces. Determine the Key Forces in the Local Environment, internal to the issue or decision.

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<sup>31</sup> Peter Schwartz, *The Art of the Long View*. (Doubleday, New York, NY, May 1991).

- iii. Driving Forces. Trends in social, political, economic, technological and environmental that affect the local forces.
- iv. Rank by Importance and Uncertainty. Identify the two or three factors and trends that are most important and bear the most uncertainty.
- v. Selecting Scenario Logics. Results of ranking are the axis' along which the scenarios differ.
- vi. Flesh out the Scenario. Weave in key factors and trends into the form of a narrative.
- vii. Implications. What vulnerabilities have been revealed? How do decisions look against the scenario? Tells the degree of a high risk gamble. How do you hedge?
- viii. Selection of Leading Indicators and Signposts. Previously selected factors should serve as sign posts and act at leading indicators.

### **3.5 Technology Scenarios**

While a number of companies other than Royal Dutch Shell have integrated Scenario Planning into their strategy portfolio, there is a dearth of the application of this powerful tool with regards to technology strategy planning. Most scenarios, such as those from the Scenario Planning Group (a worldwide organization convened by the Stockholm Environmental Institute with a secretariat in Boston, MA: [www.gsg.org](http://www.gsg.org)) are broadly focused and consider future world, market or economic policies and developments. There are some examples of scenarios focused on *disciplines* of technology innovation such as nano-technology, renewable energy, information technology and similar fields. Very few scenarios have been applied to specific emerging technology applications such as solid state lighting.<sup>32</sup> Additionally, no examples of technology scenarios were found that incorporated the current research in disruptive

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<sup>32</sup> One example: *Telecom scenarios for the 4th Generation Wireless Infrastructures*. Maxime Flament et al, KTH SE-100 44 Stockholm, Sweden.

technologies, organizational design, competitive forces, innovation strategy, and dominate designs.

### **3.6 Trends in Lighting**

#### *Knowledge Based Society*

As globalization moves peasants, farmers and laborers to cities and factories, humans are becoming more tasked-orientated as they participate in the knowledge-based society. For the increasing population, which is spending increasing amounts of time indoors, the need for placing general lighting where work is done is increasingly important. Additionally, the quality of lighting is becoming increasingly important as discussed below.

#### *Energy Conservation*

As humans become more environmentally conscious, there is increased focus on green house gas formation, renewable resources, and longevity of consumable products. Personal utility will continue to be influenced to an increasing degree by products and concepts that effect the environment.

#### *Quality of Lighting Demanded*

In line with other trends, humans are demanding higher quality goods and services. Results of ongoing research in psychological and psychosomatic effects will continue to enter the mainstream and influence utility decisions. Lights in the future must deliver more than just illumination - they will need to become substitutes for the sun, sky, windows, and entertainment. Normal people analyzing the flavors of light emissions the way an oenologist samples wine is not impossible.



### *Mobility of Lighting Sources*

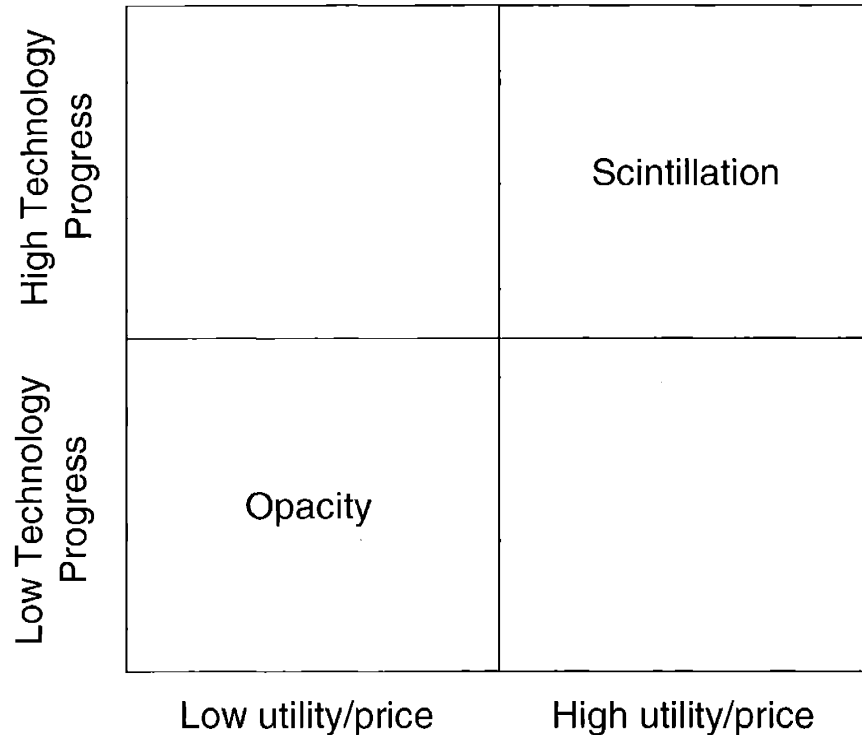
The industrialized world is becoming addicted to handiness. Specifically, people are fascinated by combination devices where they introduce simplicity, such as the coalescence of multiple functions into PDAs, cell phones, laptops and even clothing. This is not to say that the future of lighting should be *portable*, but rather *accessible*. Placing the type and style of lighting where it will be used, rather than just applying broadband, overhead is the trend here.

### **3.7 Influential Variables**

There are a number of possible variables that may interact to generate future outcomes for solid state lighting:

- Utility and Applications. The new methods of delivering light and new form factors will drive diffusion and modes of diffusion.
- Cost and Price. Research, development and manufacturing costs affect purchase prices. Ownership costs affect utility.
- Technology, Efficacy and Quality. Robustness of solid-state lighting sources including perceived brightness, temperature controllability, stability and color rendering index.

Taking the three most important variables of price, utility and technology, a matrix of futures can be created. The two most interesting of the future possibilities the author will call **Opacity** and **Scintillation**.



**Figure 12.** Possible future scenarios based on technology, utility and price. The top-right and bottom-left scenarios will be discussed.

### 3.8 Opacity Scenario: A Future of Mundane SSL Technology and Low Diffusion

SSL has found its way into many niche specialty applications, with a focus on retail lighting, and architectural lighting. Just about everywhere you look at night, the high-margin application spaces employ color changing and white LEDs. While the early years of the SSL illumination industry promised the possibility of the wide application of controlled white lights that would replace incandescent and fluorescent lights, the high-brightness white LEDs remain relatively expensive (>\$50/klm) and the stability issues that were encountered early have never been fully been solved. A trip to the local Home Depot or True Value will reveal some novelty LED lights that are set atop Edison-style sockets and even a few by larger companies that are inside fluorescent style tubes.

In the few years after 2003, hundreds of millions of dollars from the big three lighting companies and a number of newer startups was funneled into the attempt to *replicate* the familiar broadband sources of traditional lighting. When the forecasted market did not materialize, research and development dollars were slowly adjusted downwards. Now, 10 years later, investment in SSL technologies is similar to that prior to 2000. On the other hand, there have been a number of step improvements in the ballast devices for fluorescent lights and new, exotic phosphor combinations have opened up the choices of “flavors” of the old tube lights. Home and specialty lighting abounds with options and choices of high intensity discharge (HID) lamps that employ exotic metals to generate more colors of light, unique form factors ranging from flat and spherical to helical, and increased for all types of traditional lights.

The largest manufacturers have continued to focus on a direct replacement strategy for LEDs, targeting expensive controllable white lights at 150 <sup>lm</sup>/w and lamenting over the difficulty of replacing the current lighting infrastructure. The wholesale “cash cow” business of the replacement of incandescent and fluorescent bulbs . A senior executive for one of the big three recently commented that the *incentive structures* for LED and OLED diffusion are in the wrong place. “Why would we want lights that last ten-times as long?” Specifically, the fear of disrupting current traditional businesses has the lighting industry in a grip of innovation immobility. Other positive results from the diffusion of SSL technology are not available to lighting companies. The benefits of possible energy savings flow to consumers, energy companies and to some extent, governments. New broadly ranged markets have not opened, so the industry remains in a “dog-eat-dog” battle for same old share.

Similar to the case with the compact fluorescent “green” lamp (CFL), consumers have had a difficult time putting up the cash at point of purchase of LED lamps, even though both the CFLs and the LEDs will save over \$40 during the life of the lamps, over and above the cost of the lamp.<sup>33</sup> Manufacturers have resorted to adding “bells and whistles” to these ecological wonders, such as programmable colors in the case of LEDs and dimmers for the CFLs. Customers have not been impressed. They are not exactly sure what to do with these “mood lights,” and are bemused at the effects of changing colors as they bounce off walls and alcoves.

OLEDs displays command a solid niche market in small displays on portable devices such as phones and PDAs. Widespread penetration into the large (>15 inch) display market has not occurred. The major hurdles of color tuning, light quality degradation, brightness, and encapsulation were only partially overcome. As with LEDs, a lack of innovation funded by additional applications never really pushed the technology past a tipping point where wider spread diffusion was possible.

Because the inventions and decreasing experience curves for OLED displays has not occurred, there was really no hope of getting to OLED general illumination. Much promise is still heralded for OLEDs, but without progressive, scalloping S-curves of innovation, OLEDs for illumination are still a long way off.

### **3.9 Scintillation Scenario: A Bright Future for Solid-State Lighting**

During the past decade an interesting diffusion of photon emission technology has taken the general illumination industry by surprise. The truth is that they should have

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<sup>33</sup> C.J. Campbell, *Perceptions of Compact Fluorescent Lamps in the Residential Market*: Update 1994, Palo Alto, CA: Electric Power Research Institute, 1994.

seen it coming. Most established industry players, many of whom participated in the one-day forum of Partnerships for Solid State lighting in 2001, set their sights on what was then called the “Holy Grail” of lighting: the \$12 billion market for white incandescent and fluorescent lights. On one hand, they continued to pour money into R&D for HID, dielectric barrier discharge and exotic phosphor cocktails for fluorescent lamps while also spending serious money on a half-hearted effort to develop LED and OLED technologies to replace the “cash cows.” Their focus was getting to 150 <sup>lm</sup>/w, sunlight-like white light, and longevity that would allow SSL to “pay for themselves.”

While the big players attempted to disrupt themselves, a drove of companies led by technologists and fueled by advances in the silicon, polymer, material science, and organic chemistry disciplines diligently introduced new light emitting products targeted at different application spaces than that served by traditional lighting.

In 2005, light emitting fabrics and clothing began to show up in military uses, outdoors suppliers, safety clothing and designer canvas for architectural applications. Hobby and specialty companies embraced the new lights and quickly found more and more uses: sails and canvas covers for boats, light emitting table cloths, shower curtains, rugs and carpets, and a new generation of luminescent room dividers for the home. The combination of polymer electroluminescent materials with wood veneers and different types of plastics has generated new markets where designers and architects can put light where people need it most.<sup>34</sup> It was amazing to see how the safe, cool-to-touch displays and lights developed a whole new category of children’s toys and educational devices that were previously impossible with breakable glass and heat producing lights. Granted,

in the early days these products appeared fairly low tech, didn't last too long, and gave off eerily greenish and bluish light. But, the technology quickly progressed and by the mid-2000s, descent white light was available in form-factors such as plastic on rolls and as thicker sheets, canvas materials, and water proof nylons.

On the LED front, there are really two stories to tell. The first is generally referred to as *Installed Base Retrofit* where the focus is on developing standards and approaches to replace standard light bulbs. Decisions by industry organizations such as the National Electrical Manufacturers Association (NEMA) to require that LED lights must operate on 120V at the point of connection versus establishing new direct current (DC) lighting standards for commercial and residential applications have hindered diffusion via renovation and refit of electrical, décor and lighting infrastructure. This strategy has exacerbated one of the most difficult aspects for LEDs to overcome – the high first installed cost.

The second story is how *New Installations* have at their disposal a wide range of choices in lighting materials including accent lights, spot lights, panel lights and less traditional form-factors such as embedded illumination in ceiling tiles, wall paper and flooring. As early innovations in new lighting materials improved the color rendering index (CRI), the color temperature control, lifetime and stability, and durability of materials, these improvements made possible the more demanding aspects of commercial and residential lighting. Now nearly every office space, library workspace and assembly line worker position employees a movable lighting panel that can be positioned for optimal illumination and for optimal color and rendering. Analysts attempting to predict

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<sup>34</sup> Many conceptual uses for LEDs and OLEDs can be found in the excellent work by Harvard University Graduate School of Design: *bugs, fish, floor & ceilings: luminous bodies and the contemporary problem of*

the future of SSL failed to recognize that the true reasons lights are placed in ceilings where they are often wasteful, ineffective and inflexible at getting light to the work space. It is a result of the space and connections required by 4 inch deep luminaries, the heat generated by the lights themselves, and the necessarily high AC voltage. With the advent of safe low voltage SSL, the traditional luminaries are no longer required. In fact, the lamps themselves become the luminaries. These additional degrees of freedom allows designers to put the light where it is most useful and efficient, without the hardware and bases required to position 120v and the related ballast and sockets above a workspace.

As with many technology developments, SSL has had the opportunity to combine multiple technologies into illumination that is present today:

- Colored SSL and networked commands
- SSL and high-tech fabrics and other new wearable materials
- SSL, new electrical storage techniques and photovoltaics

This last combination means freedom from the electron power grid: the ability to allow a light to “charge” via sunlight, and essentially re-emit that light in a different format. This new combination has opened up entire new markets for portable and essential lighting in military, boating, residential landscape, and other outdoor applications.

Another very exciting area for illumination is the recent combination of SSL and infoimaging. For a reasonable price, it is now possible to have a building material that functions both as a light and as a medium for entertainment, personal information, communication and news. One popular technique is to replace the ceiling area above the bed with a SSL material that is capable of addressing the entire human visual system. After watching the evening news or a latest release in near real-life quality, the panel can

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*material presecnce..* Sheila Kennedy, editor. (President and Fellows of Harvard College, 2000).

be tuned to emit light that replicates that of twilight from a favorite holiday beach or that of the night sky. Although, psychologists continue to endeavor to understand the human psyche response to different light emissions, the fact that proper lighting can evoke emotions and affect health is undisputed.

Over the past 5 years, while the SSL technologies were being developed and expanded into new markets and applications, the large light bulb manufacturers have begun to see their volumes and revenues decline. The competition for traditional lighting has become even fiercer as manufacturing capacity is freed up. Their stake in the SSL businesses, while respectable, is not growing at the rates of companies with roots in non-lighting materials. The tipping point of the expanding SSL market was reached probably about three or four years ago. It seems that once the encapsulation issues of OLEDs were solved and large scale manufacturing of shaped LEDs converged to designs prevalent throughout the industry, the number of industry players began to decline. While that shakeout is still happening, given the velocity of growth, the traditional manufacturers will not be able to catch up. The strongest of the new entrants, most of which entered only four years ago, enjoy high returns to R&D and evolving generations of innovation.<sup>35,36</sup>

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<sup>35</sup> James Utterback, *Mastering the Dynamics of Innovation*. (Harvard Business School Press, Cambridge, MA, 1994). See Chapters 2, 7 and 9 regarding market discontinuities and dominate designs.

<sup>36</sup> Clayton Christensen, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. (Harper Business, New York, 2000).



## **4.0 A Pragmatic View of the SSL Industry**

Does it make sense to enter the SSL industry? Taking the technology trajectories of SSL to a practical level, one will outline a plan to understand the attractiveness of the industry, generate a technology and product strategy, and finally present an overall strategy for sustainability for a company entering the SSL market in 2003-2005.

### **4.1 Industry Attractiveness**

Hax and Majluf (1991) present a straightforward method of scanning an industry at the business level to determine attractiveness.<sup>37</sup> Following a method modeled after Porter's five-forces approach, the barriers to entry, barriers to exit, rivalry among competitors, powers of buyers, power of suppliers, availability of substitutes, government actions and summary of factor attractiveness will be analyzed.

### **4.2 Barriers to Entry**

The prospect of entering the market with differentiated products with unique value propositions will probably decrease in the future as concepts and learning spread. Currently, the largest brands in SSL core products are associated with the largest traditional lighting manufacturers: GELcore from GE, Osram with Sylvania (in the US, Osram itself in Europe), and Lumileds from Phillips. Color Kinetics has become well known in architectural and retail lighting, but has enjoyed relatively little success penetrating the mass market. Access to the latest technologies is restricted currently, but will open up it become more prevalent. More important is the ability to uniquely design and deploy lighting solutions that bring value to customers. Lastly, the experience curve is moving from very steep to steep: companies that are able to understand how to provide

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<sup>37</sup> Arnaldo Hax and Nicolas Majluf, *The Strategy Concept and Process: A Pragmatic Approach*. (Prentice Hall, New Jersey, 1996).

SSL solutions that bring real value at low costs will find success. Taking all barriers to entry into consideration, entering sooner rather than later is better.

			Highly Unattractive	Mildly Unattractive	Neutral	Mildly Attractive	Highly Attractive			
Economies of scale	Small	Current Future								Large
Product differentiation	Little	Current Future								Big
Brand identification	Low	Current Future								High
Switching costs	Low	Current Future								High
Access to distribution channels	Ample	Current Future								Restricted
Capital requirements	Low	Current Future								High
Access to latest technology	Ample	Current Future								Restricted
Access to raw materials	Ample	Current Future								Restricted
Government protection	Non-existent	Current Future								High
Experience effect	Not important	Current Future								Very important

**Figure 13.** Barriers to Entry are moving from mildly attractive to neutral/unattractive.

### 4.3 Barriers to Exit

In general, exiting a business in the early stages of its life cycle is much less painful than exiting once the management team is entrenched in the ongoing concern of the business. Depending upon the amount and costs of capital investment, retaining a 'real option' to exit is a workable solution. On one hand, if the knowledge that the company may exit the business is on the minds of employees, suppliers and customers, the ability to create a long term successful vision is obviously compromised. On the other hand, blatantly ignoring the options to exit can create un-necessary costs if exiting becomes a reality. Given the early stages of this industry, barriers to exit are relatively low currently but will move toward unattractive in time.

			Highly Unattractive	Mildly Unattractive	Neutral	Mildly Attractive	Highly Attractive			
Asset Specialization	High	Current Future	[Bar chart showing shift from Mildly Attractive to Mildly Unattractive]					Low		
One-time cost of exit	High	Current Future	[Bar chart showing shift from Mildly Attractive to Mildly Unattractive]					Low		
Strategic interrelationship	High	Current Future	[Bar chart showing shift from Mildly Attractive to Mildly Unattractive]					Low		
Emotional barriers	High	Current Future	[Bar chart showing shift from Mildly Attractive to Mildly Unattractive]					Low		
Government and social restrictions	High	Current Future	[Bar chart showing shift from Mildly Attractive to Mildly Unattractive]					Low		

**Figure 14.** Barriers to Exit are lower in the early stages of an industry such as SSL.

#### 4.4 Rivalry among Competitors

Given that there are relatively few competitors in the SSL lighting industry, the rivalry isn't very intense. If the actual chip manufacturers are separated from the application and solution providers, the number of participating companies goes down as does the rivalry. The stakes will increase as time progresses resulting in increased rivalry. It is important to note that patent position and technology are most important as companies attempt to find their comparative value. Rivalry will tend to move from attractive to unattractive.

			Highly Unattractive	Mildly Unattractive	Neutral	Mildly Attractive	Highly Attractive			
Number of equally balanced competitors	Large	Current Future	[Bar chart showing shift from Mildly Attractive to Mildly Unattractive]					Small		
Relative industry growth	Slow	Current Future	[Bar chart showing shift from Mildly Attractive to Mildly Unattractive]					Fast		
Fixed or storage cost	High	Current Future	[Bar chart showing shift from Mildly Attractive to Mildly Unattractive]					Low		
Product features	Commodity	Current Future	[Bar chart showing shift from Mildly Attractive to Mildly Unattractive]					Specialty		
Capacity increases	Large increments	Current Future	[Bar chart showing shift from Mildly Attractive to Mildly Unattractive]					Small increment		
Diversity of competitors	High	Current Future	[Bar chart showing shift from Mildly Attractive to Mildly Unattractive]					Low		
Strategic Stakes	High	Current Future	[Bar chart showing shift from Mildly Attractive to Mildly Unattractive]					Low		

**Figure 15.** Rivalry among competitors is moving from attractive to more unattractive as new entrants bring strong IP and technology positions to the table.

#### **4.5 Power of Buyers**

Currently the number of important buyers is few since the technology is not pervasive. Depending upon which application space is entered, there can be very few substitutes. Although it is expected that the number of available substitutes will grow significantly, there may be applications where a monopoly power can be gained through inherent technology advantages as well as design. Of course, early days in a business tend to exist in a threat environment of upward, backward and sideways integration. This analysis doesn't hold tight for newly formed businesses, but the concept of distributors and other buyers gaining value from the introduction of new technology has been demonstrated many times over in other disciplines. Technology discontinuities enable new players both on the supply side and on the downstream side.

It may be more important to think about the choices that customers have. For instance, if a very high tech flat lighting panel (that could also bring info-imaging value) is compared to traditional lighting technologies, a buyer must make a value/reward decision at the point of purchase. If the point of purchase happens to be during the design phase of a commercial construction project versus at a Home Depot, the criteria for decision making can be very different. A longer view process of costs and benefits where the costs are amortized over 30 years may enable a decision very different than a cash outlay. In SSL, the real power of the buyers is in the choices of products and technology that are available.

One key advantage that should be established is access to decisions makers in commercial lighting design centers. Although the lighting industry is very fragmented

with a close knit culture, access can be easily gained to conferences, symposiums and partnerships (such as the Partnership for Solid State Lighting). Here, new products can be displayed with immediate feedback. The cost is low, the risk is low and the payoff could be significant.

			Highly Unattractive	Mildly Unattractive	Neutral	Mildly Attractive	Highly Attractive			
Number of important buyers	Few	Current Future	[Bar chart showing high unattractiveness]					Many		
Availability of substitutes	Many	Current Future	[Bar chart showing low unattractiveness]					Few		
Buyer switching costs	Low	Current Future	[Bar chart showing high unattractiveness]					High		
Buyers' threat of backwards' integration	High	Current Future	[Bar chart showing high unattractiveness]					Low		
Industry threat of forward integration	Low	Current Future	[Bar chart showing high unattractiveness]					High		
Contribution to quality or service of buyers' products	Small	Current Future	[Bar chart showing high unattractiveness]					Large		
Buyers' Profitability	Low	Current Future	[Bar chart showing high unattractiveness]					High		

**Figure 16.** The Power of Buyers is fundamentally driven by the choices of technology and products (for each application) that are available.

#### 4.6 Power of Suppliers

Suppliers here are defined as the manufacturers of LEDs and eventually OLEDs. Some examples include Nichia, Osram, Lumileds and GELcore. From the five forces model, the power of suppliers poses the greatest risk. A new entrant must protect itself from loss of channel, technology value added, and most importantly, loss of unique product designs. The experience curve is very steep for the suppliers of both inorganic and organic SSLs. As the margins decrease, suppliers will try to find value in other parts of the chain. If the established companies are able to provide product substitutes to

compete in parts of the value chain closer to the end user, new companies will find their price structure, brand, and growth potential rapidly eroding.

Additionally, the dominate designs for both OLEDs and LEDs have not been established. Although more on this topic is covered later, there will be continued new entrants to the SSL technology and manufacturing sector. One result is that these suppliers are very technology focused, devoting much less time to *design and application of the way light can potentially be delivered to the end users.*

				Highly Unattractive	Mildly Unattractive	Neutral	Mildly Attractive	Highly Attractive		
Number of important suppliers	Few	Current	Future	[Bar chart showing shift from Unattractive to Attractive]					Many	
Availability of substitutes	Few	Current	Future	[Bar chart showing shift from Unattractive to Attractive]					Many	
Differentiation or switching cost of suppliers' products	High	Current	Future	[Bar chart showing shift from Unattractive to Attractive]					Low	
Suppliers' Threat of Forward Integration	High	Current	Future	depending upon protection mechanisms					Low	
Industry Threat of Backward Integration	Low	Current	Future	Exit Strategy?					High	
Suppliers' contribution to quality	High	Current	Future	[Bar chart showing shift from Unattractive to Attractive]					Low	
Total industry cost contribution by suppliers	Large Fraction	Current	Future	[Bar chart showing shift from Unattractive to Attractive]					Small Fraction	
Importance of the industry to suppliers' profits	Small	Current	Future	[Bar chart showing shift from Unattractive to Attractive]					Large	

Figure 17. The Power of the Suppliers, particularly the possibility of forward integration is very favorable for entering firms.

#### 4.7 Availability of Substitutes

Obviously, there are many substitutes available for lighting. If one establishes a limit to substitutes that are somewhat similar now but very different in the future one can appropriately analyze the effects that near substitutes have on SSL lighting. The number of substitutes will decrease rapidly as new, unique lighting solutions are introduced in various form factors. For SSL specifically, switching costs will be much higher during

the early period when new delivery systems and luminaries will be required. If history is a lesson, the incandescent and fluorescent providers will fight back with both performance improvements and drastic price decreases. Given that the traditional technologies have been around for decades, one would expect that manufacturers have run short of innovations. But, as Utterback points out, the mantle for gas lamps wasn't invented until 1885 (by Auer von Welsbach) well after the first electric lamps had been demonstrated. So, in addition to the ability to fight back with price decreases, one can expect further improvements in non-SSL type lighting.

The initial consumer utility of SSL is expected to be marginal, but will increase over time. Diffusion modes should occur first to lead users in niche markets and then move to early adopters.

			Highly Unattractive	Mildly Unattractive	Neutral	Mildly Attractive	Highly Attractive		
Availability of close substitutes	Large	Current Future							Small
User's switching costs	Low	Current Future							High
Substitute producers' profitability/aggressiveness	High	Current Future							Low
Substitute value	High	Current Future							Low

**Figure 18.** Availability of substitutes is strong in the early days of SSL product life cycles, but weakens in time.

#### 4.8 Government Actions

Reasons for government interaction in SSL initiatives abound:

- Energy savings
  - \$30 - \$100 billion in energy savings<sup>38</sup>
  - Ability to replace 93 – 133 1000MW nuclear power plants<sup>39</sup>

- Eliminating 258 million metric tons of carbon emission
- Cumulative financial savings of \$115 Billion (1998 dollars).
- Applications of opto-electronics for defense<sup>40</sup>
- Defense application of nitrides<sup>39</sup>

The case for energy savings via a move to SSL is pervasive. As detailed in the following chronology, the US Government at least appears to be more than interested in catalyzing a movement toward SSL:

- March, 2001. Department of Energy's Office of Building Technology, State and Community Programs and the Optoelectronics Industry Development Association published the results of an 18-month co-sponsored Solid-State Lighting Technology Roadmapping effort. The bill would authorize \$30 million for fiscal year 2002 and \$50 million per year for fiscal years 2003 through 2011.
- July, 2001. Senators Jeff Bingaman of New Mexico and Mike DeWine of Ohio introduced a bill to the Senate, S.1166 which called for the establishment in the Department of Energy of a "Next-Generation Lighting Initiative" (NGLI).
- April 25, 2002. The portion of the Senate bill relating to the "Next Generation Lighting Initiative" was incorporated into the engrossed Senate amendment of H.R. 4, The Energy Policy Act of 2002.

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<sup>38</sup> Mark Ginsberg, US Department of Energy (Comments at seminar: Partnerships for Solid State Lighting, 2001).

<sup>39</sup> Steven DenBaars, University of California at Santa Barbara (Comments at seminar: Partnerships for Solid State Lighting, 2001).

<sup>40</sup> Al Romig, Sandia National Laboratories (Comments at seminar: Partnerships for Solid State Lighting, 2001).



- May 30, 2002. OIDA and the National Electrical Manufacturers Association (NEMA) hosted a LED workshop in Albuquerque, NM. At this workshop, sponsored by the U.S. Department of Energy Office of Building Technology, State and Community Programs (DOE-BTS), technology targets and challenges were debated by experts from universities, industry, and national laboratories.
- June 12, 2002. Secretary of Energy, Spencer Abraham, recently described current energy policy and the exciting possibilities of solid-state lighting in a speech to the National Press Club.
- Department of Defense: The Defense Advanced Research Projects Agency's SUVOS Program aims to develop semiconductor UV optical sources for bio-agent detection. These UV sources may also be useful, after phosphor down-conversion, for Solid-State Lighting.
- Department of Defense: The Office of Naval Research has been a long-standing champion and supporter of wide-bandgap semiconductor materials research, including the GaN-based materials on which most commercial blue and green light emitters are based
- Department of Energy: Sandia National Labs has initiated a Grand Challenge Laboratory-Directed Research and Development project called "A Revolution in Lighting: Building the Science and Technology Base for Ultra-Efficient Solid-State Lighting".

- Department of Energy: Lawrence Berkeley National Labs has an active effort in Solid-State lighting with an emphasis on organic light-emitting diodes, and on light distribution systems.
- The U.S. is not alone in recognizing the possibilities for Solid-State Lighting. The Japan Research and Development Center of Metals established, in 1998, the five-year national project "The Development of Compound Semiconductors for High Efficiency Optoelectronic Conversion", also known as the "Light for the 21st Century". The project brings together thirteen member companies and universities, and targets an energy efficiency twice that of traditional fluorescent lamps through the use of long-life, thin, lightweight, GaN-based high-efficiency blue and ultraviolet LEDs.

As one can see from the momentum of government involvement, the SSL industry is getting as much attention as the SEMATEC initiative that is credited with fostering innovation and investment in the semiconductor industry.

An entering firm must be able to leverage government funds and expertise in one of the following ways:

- Obtaining investment funds from venture capitalist with strong contacts to government agencies
- Via board of advisors, gain credibility with government leaders
- Via joint venture, gain access to the partner's strong governmental ties

The goals and favorable results would entail the following:

- Protection from foreign entities

- Access to participate in industry regulation establishment
- Visibility to capital movements within countries
- Visibility to assistance provided to competitors
- Early access to military and government markets
- Finally, potential access to R&D funds

#### 4.9 Summary of Factor Attractiveness

Based on this formal analysis, and compared to traditional industries, the SSL industry appears to move temporally from attractive to unattractive. The key to sustainable success for this (and other new markets) will be the ability to achieve some monopolistic power of intellectual property, technology, design, cost position or culture.

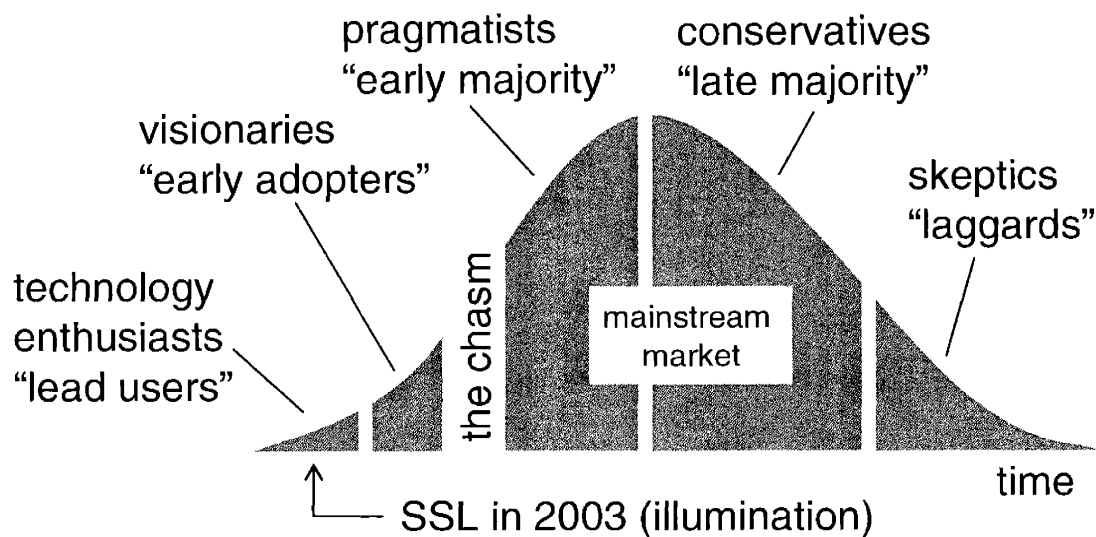
			Highly Unattractive	Mildly Unattractive	Neutral	Mildly Attractive	Highly Attractive	
Rivalry among competitors	Large	Current Future	[Shaded area]					Small
Barriers to entry	High	Current Future	[Shaded area]					Low
Barriers to exit	High	Current Future	[Shaded area]					Low
Availability of substitutes	Commodity	Current Future	[Shaded area]					Specialty
Power of suppliers	Low	Current Future	[Shaded area]					High
Power of buyers	High	Current Future	[Shaded area]					Low

**Figure 19.** Although Summary of Factor Attractiveness shows that the SSL market becomes more unattractive in the future, there is more to the story if an entrant is able to create some advantage in product, design, cost or culture.

#### 4.10 Market Diffusion

Based upon the roadmaps and industry attractiveness presented earlier, there are two separate avenues to the Scintillation scenario: *price breakthrough* (the stronger path)

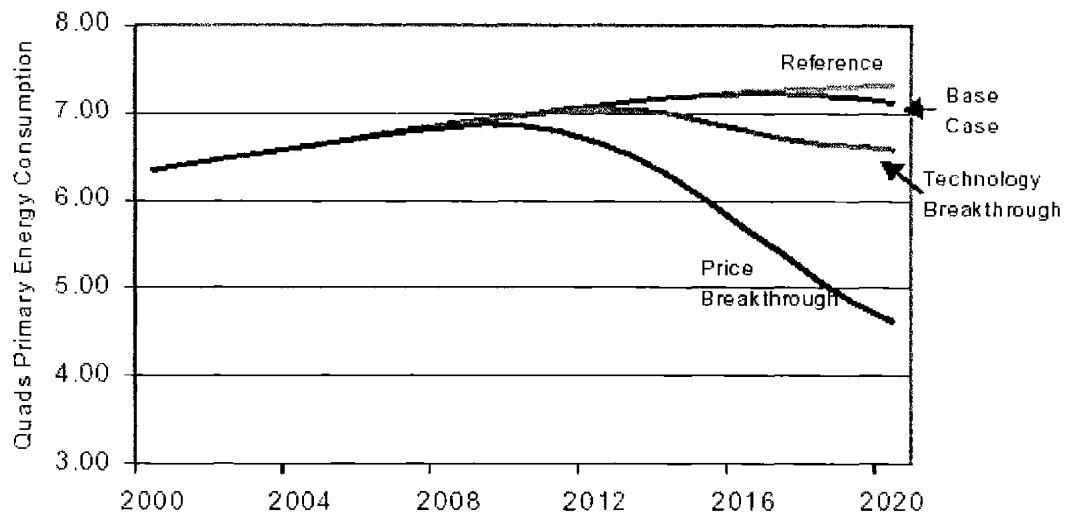
and *technology* breakthrough. Both breakthroughs generate earlier diffusion via technology innovation, but the price breakthrough path is more dependent upon manufacturing technology breakthroughs. Although rapid innovation in price and brightness will facilitate adoption, characteristics of user preference and utility will ultimately allow SSL to cross the chasm from early adopters to early majority.<sup>41</sup>



**Figure 20.** SSL vendors must prepare to provide value such that market diffusion allows the technology to cross from early adopters to the mainstream market.

The vision presented by the major LED vendors, the majority of participants at the Partnership for Solid State Lighting conference, many industry authorities as well as the media is that SSL must attack traditional lighting sources head-on. The ultimate argument is that SSL will save more than enough in electricity costs to justify any investment. The following model shows what may be possible.

<sup>41</sup> Geoffrey A Moore. *Crossing the chasm: marketing and selling technology products to mainstream customers.* (New York, N.Y.: Harper Business, 1991).



**Figure 21.** The event of a price breakthrough generates much greater market diffusion resulting in more energy savings sooner.<sup>42</sup>

While the concepts of technology breakthrough and price breakthroughs are important, it is proposed that the reality of diffusion will be not driven by the desire to decrease energy costs, but rather to provide new, novel and useful lighting products that bring value in and of themselves to consumers. Consider the following:

- Many outdoor lighting sources are poorly designed (height, color, lenses), providing much fewer lm/W than otherwise possible with a more elegant design
- Witness the many dim, dirty and permanently frosted lenses and covers on many general lighting installations
- Notice the in-efficient use of current lighting sources

<sup>42</sup> *Energy Savings Potential of Solid State Lighting in General Lighting Applications*. Final Report Prepared by Arthur D. Little, Inc. for the U.S. Department of Energy

- Lights left on during the evenings and weekends when not required for use
- Lack of efficient use of sunlight to complement artificial lighting sources
- Indoor luminaries and sources are harsh and deliver light inefficiently
- Failure to adopt compact fluorescent lighting which has the ability to immediately reduce lighting energy usage by one-half.

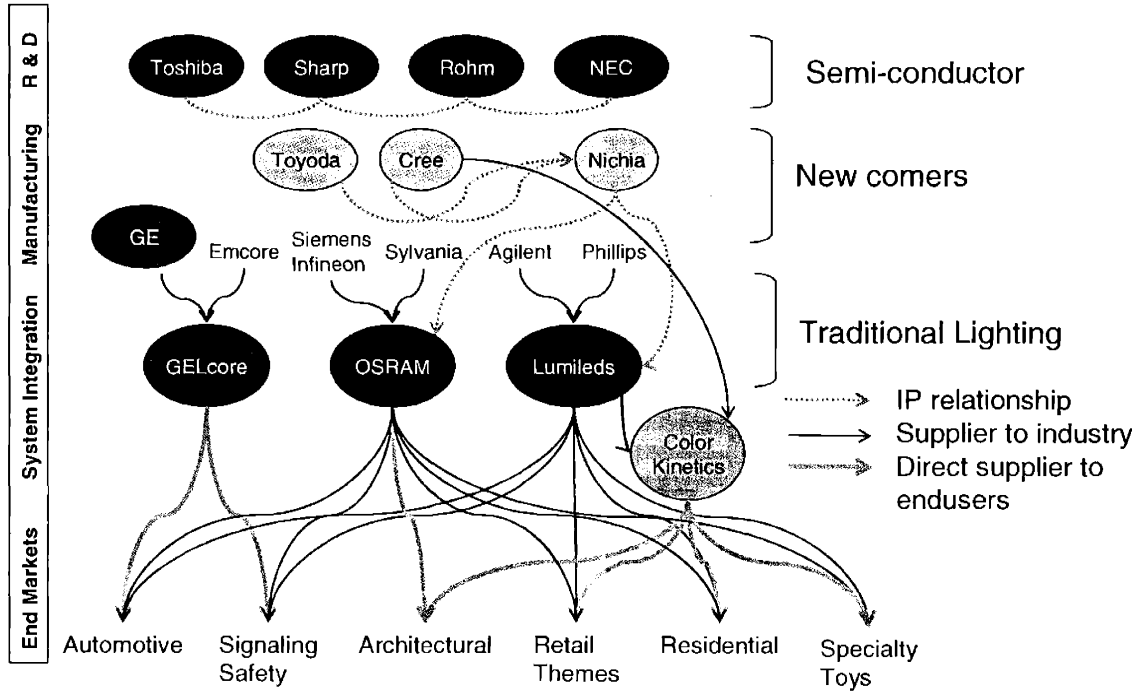
These examples clearly show that although there might be a strong desire to reduce lighting energy usage, the innovations that could be done with today's technology to increase lighting efficiency are not being done. *Therefore, it is not the replacement of current lighting techniques and technologies for the purpose of energy reduction that is the key driver, but rather new lighting products that solve design problems, provide new lighting genres, and uniquely deliver value to the light-user.*

#### **4.11 The Industry and the Players**

Broadly speaking, one can classify the technology providers in the SSL by the following criteria:

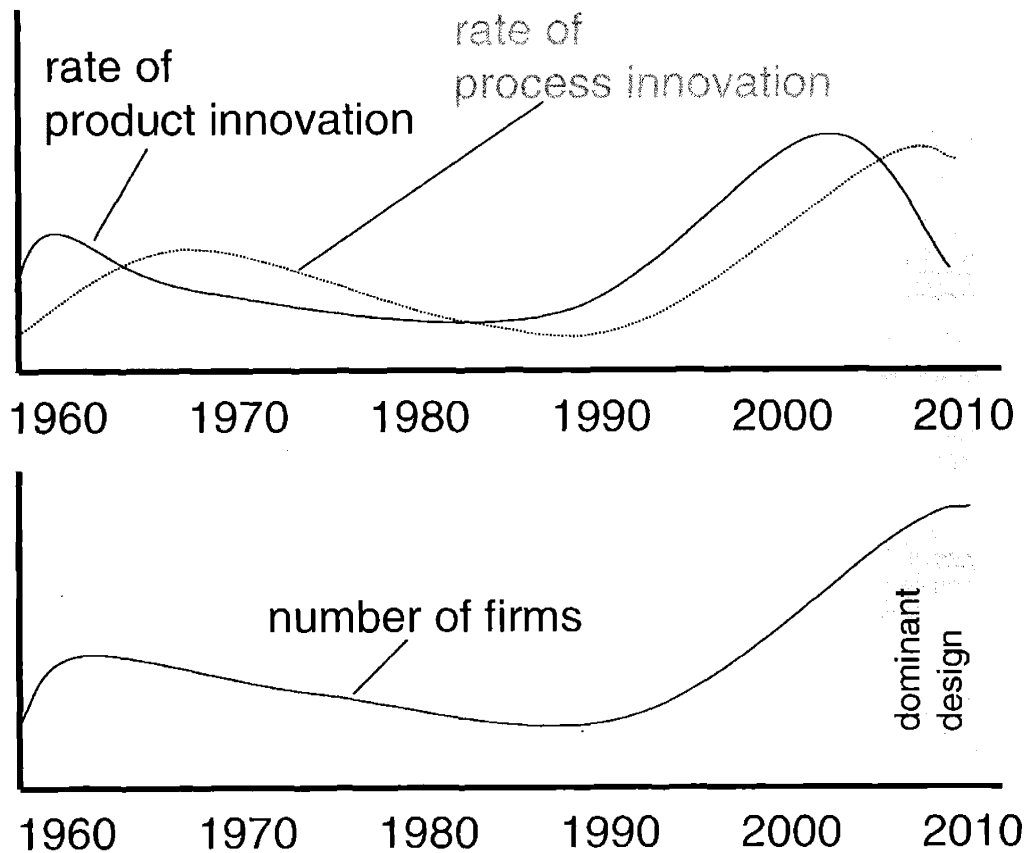
- Region of origin: U.S., Asia or Europe
- Traditional lighting player, traditional semiconductor company, or new emerging startup
- The portion of the supplier chain in which they participate, categorized from upstream to downstream according to the OIDA
  - Substrates, Buffers, Epitaxy

- Physics, Processing, Devices
- Lamps, Luminaries, Systems



**Figure 22.** A non-comprehensive model of the SSL industry based on the author’s analysis from various sources. Substrate manufactures supply to device manufacturers who in turn supply to system aggregators.

As can be seen from the previous industry model, the SSL business is currently extremely fragmented with new players continually entering the market. If one looks back at the beginning of SSL and view the industry through the lens of Utterback’s rate of product and process innovation model, it is found that the industry has experienced two major cycles of innovation. If OLED innovation is separated out from LED innovation, there are three cycles.



**Figure 23.** SSL lighting has experienced two waves of innovation. OLED innovation may constitute a third. If the period of 2005 – 2007 gives “dominant designs” for SSL the optimal time to enter the industry is soon. (Conceptual diagrams based upon the author’s analysis of multiple sources including patent data and company websites).

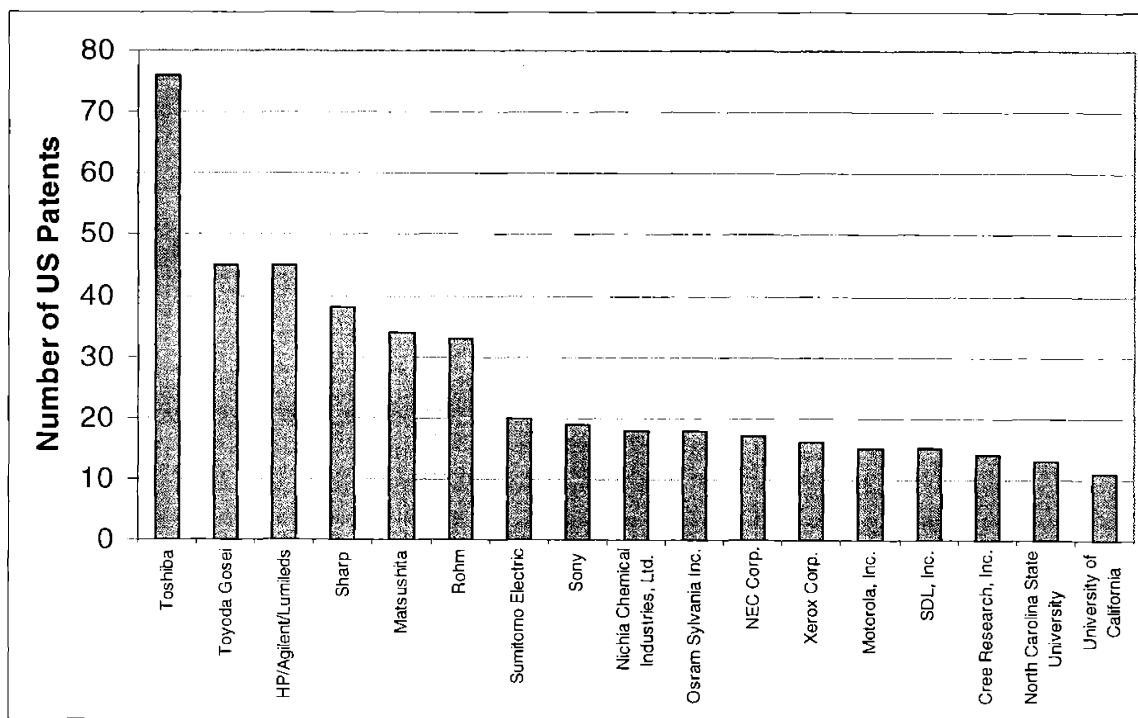
Although one can get a measure of activity in an industry by tracking entering and exiting of firms, the SSL industry has a number of firms entering that do not contribute to innovation progress and would therefore arbitrarily inflate any count. Additionally, there are currently no companies exiting from the industry.

A detailed study of issued US patents should give a better indication of activity in the industry. The investigation of patents is restricted to the US as each serious player



must have protection in the US so will likely file there. From the following graph of firms and patents issued, two interesting phenomena can be seen:

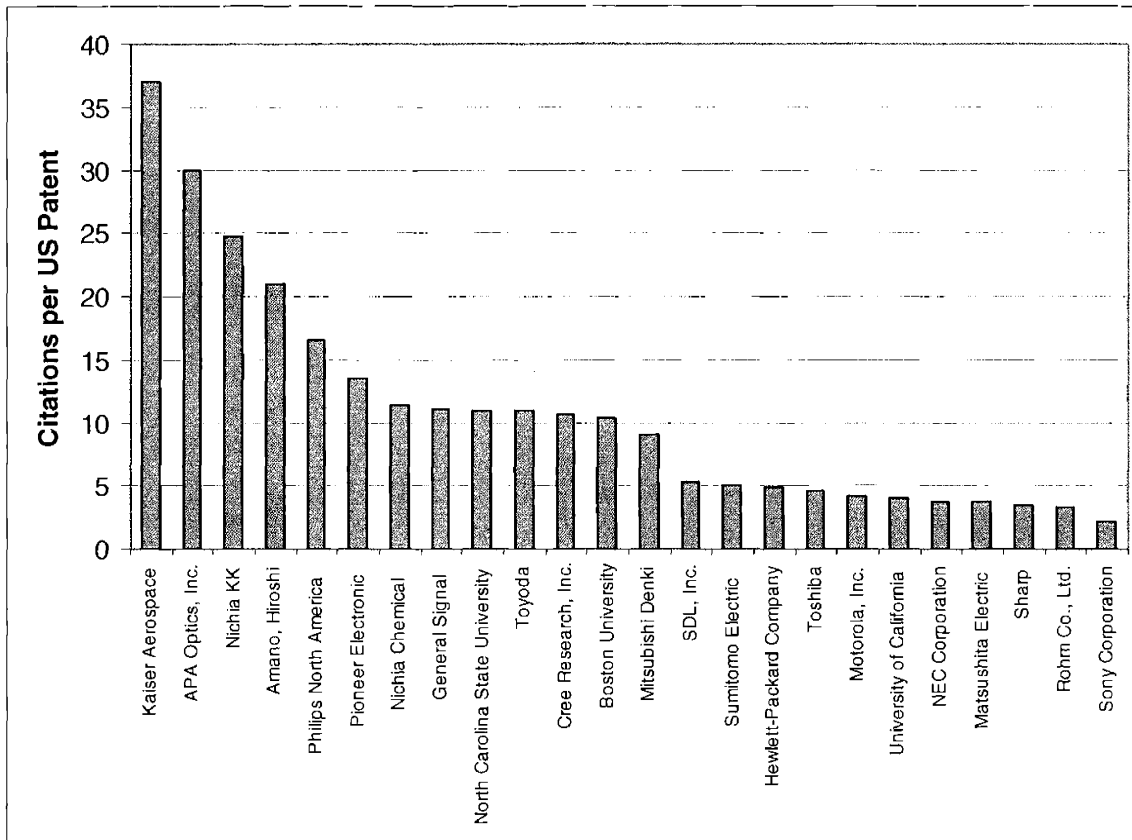
- The most cited names in the technology media are not necessarily the firms with the most patents issued. For example, GELcore (GE), Color Kinetics, Universal Display, and Philips do not make the list.
- Of the top 10 firms, seven are Japanese, two are German, and only one is American.



**Figure 24.** Seven of the 10 most active firms in U.S. SSL intellectual property filings are Japanese and only one is American.<sup>43</sup>

For a sense of which firms have the most important patents, the following graph shows most a metric of citations per patent for each firm in rank order.

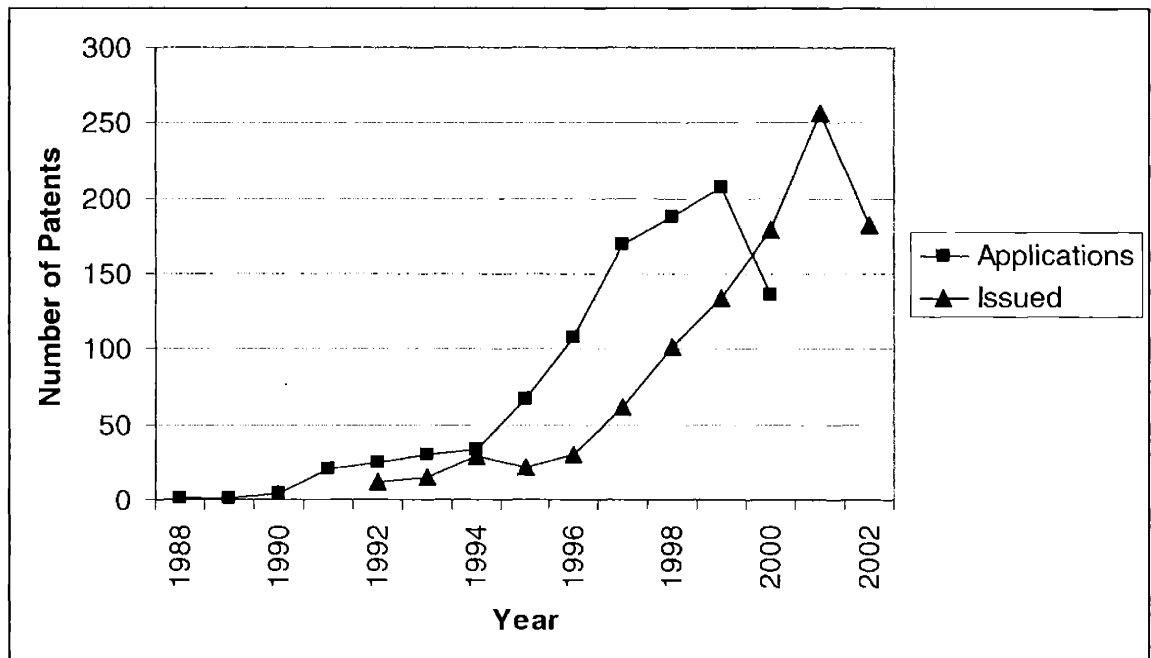
<sup>43</sup> Patent database by Perspectives with help from Sandia Laboratories (Jeff Tsao and Kevin Boyack) Website <http://lighting.sandia.gov/Xlightingpatent.htm> accessed on April 21, 2003.



**Figure 25.** Firms in rank order by number of citations per patent. These companies have the most important patents in the SSL industry.

A more interesting dynamic view of the industry can be seen from a timeline view of patent applications. The following graph, also from the Sandia database, shows the dramatic increase in the number of patents filed during the mid-1990s. Note that the data points are restricted to applications and patents that actually resulted in an issuance of a patent license. Although the number of patent applications and issuances seem to decrease in the early 2000's, it is important to understand that patents may take over two years for approval; i.e. all data for 2000 applications and 2002 patents may not be

reflected in the database. Even so, it does appear that the number of patents, and therefore the chaos of design is slowing. Based on the shape of the curves, one would project that a dominant design in LED chip manufacturing will soon emerge, say before 2005.



**Figure 26.** The number of patent applications and patents that result in an issuance of protection seems to be slowing which may mean that a dominate design for SSL chips is emerging.

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## **5.0 Developing a Product Portfolio**

As established in the preceding chapters, innovation in the SSL industry is moving a very rapid pace; therefore, the challenge for a firm attempting to either enter the SSL market or develop new products can be great. It is difficult to determine the combinations of technologies that will become products that are attractive to buyers, are at the appropriate level of maturity, and especially those that will generate value for the firm. Based upon surveying the current product space and then analyzing the intersection of applications and technologies, the author presents a process to develop a product portfolio that solves customer's problems, brings value to light-users, and that is unique, novel and long-lasting.

1. Identify current products that exist in the following lead-user, niche areas:
  - a. Electronic hobbyists creating SSL devices to solve problems not yet served by the mainstream market.
  - b. Niche users such as scuba diving enthusiasts, aerospace suppliers, camping and outdoor product developers, and military suppliers.
  - c. Cutting edge lighting designers (mostly Italian).
  - d. Non-engineering, liberal arts trained Delphi teams brainstorming new lighting solutions.
2. Scope out product space in the following dimensions:
  - a. Full application space, generically described (do not presuppose forms, places, methods).
  - b. Power supply and grid factors.
  - c. Other technologies with possibility of synthesis with SSL to create new forms.

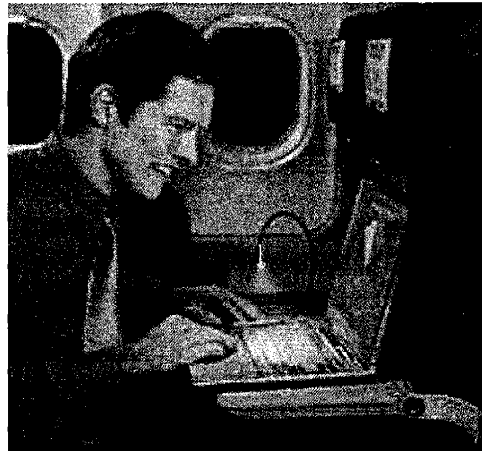
- d. Market segmentation categorized from cheap (commodity) to expensive (premium).
3. Develop and test a selection of products, forcing rapid evolution of improvements to next generations.

### **5.1 Current Cutting Edge and Niche Applications**

The following examples demonstrate current novel and cutting edge lighting solutions.

#### **Laptop light**

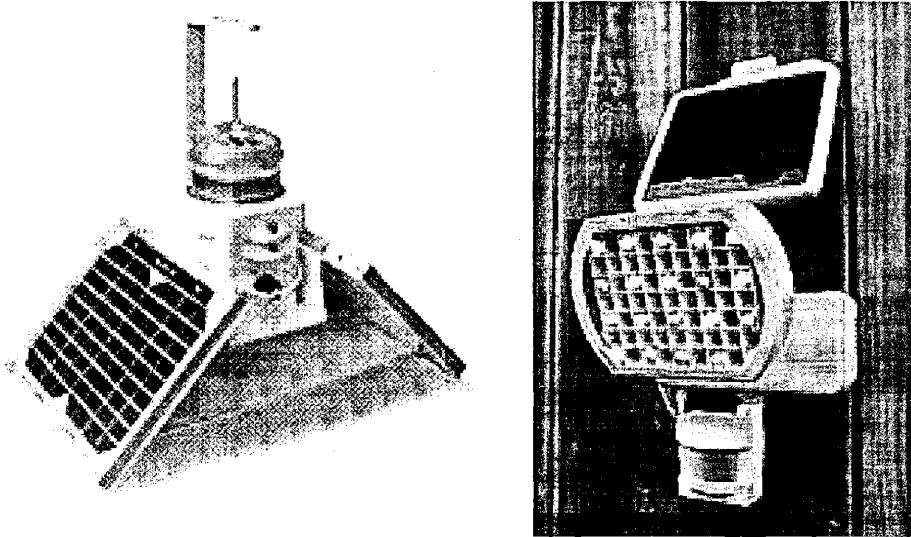
This light, marketed by Kensington for about \$20 provides the light of one white phosphor based LED to illuminate a keyboard or adjacent work space. Although the LED itself is not unique, the power supply is – the flexible light is powered by the laptop's USB port.



**Figure 27.** Kensington Inc. Laptop Light.

## Solar-powered Lamps

For applications ranging from nautical signals, camping table lamps, and landscape lighting, SSL has already attained performance level where current solar panel (photovoltaic) size doesn't need to be much larger than the luminaries to provide enough energy to perform reasonably well.

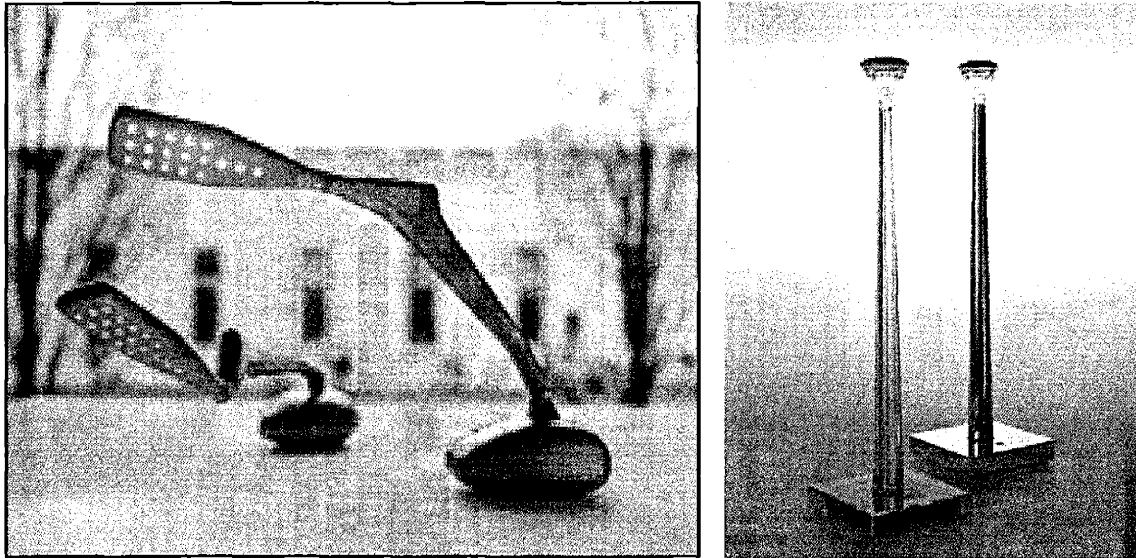


**Figure 28.** Two forms of lighting that combine photovoltaics with LED technologies. Sources: Sealight Pty Ltd (left) and the Sun Ray™ Solar Security light (right).

## Useful Placement of Light

Designers have applied the unique characteristics of LED lighting to table lamps with their own form of unique characteristics. In both of the examples shown below, the lamps are not connected to any power grid – instead, the bases are recharged by simply placing the lamp on top of a inductive source. No plugs, no wires, no connections: a step toward the

freedom of light. Additionally, the lamps use the most recent high-brightness LED lights based on blue source and phosphor technology.

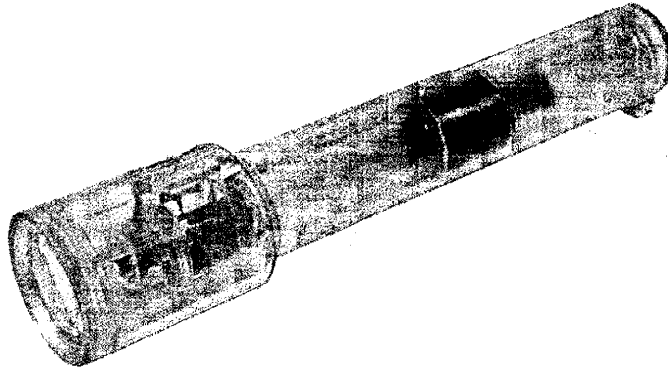


**Figure 29.** The SUI™ by Artemide (left) and Luceplan Star-LED (right) are new cordless, rechargeable lamp designs that put light where it is best used.

### **New Energy Sources**

The flashlight in the following image (The Nightstar) is not too different than other LED flashlights, except that its energy source comes from *shaking*. An elegantly designed magnet-inductor system (with cushioning end magnets) allows the light to operate with just a few silent shakes. A step in the right direction, but is it good enough?





**Figure 30.** The Nightstar is a “shake light” that requires no batteries and lasts indefinitely.

## 5.2 Approach to New Products

With a view to entering the SSL business, one will first determine what new and novel lighting products could be made with never-before-available technologies. First, SSL application spaces were graded on a visual scale in the dimensions of 1 to 4 in power, technology and premium as described in the following chart. The darker areas of the chart indicate a good fit of technologies or applications. Although the chart is not all-inclusive, it provides a base to think about how different technologies may be combined to solve lighting problems.

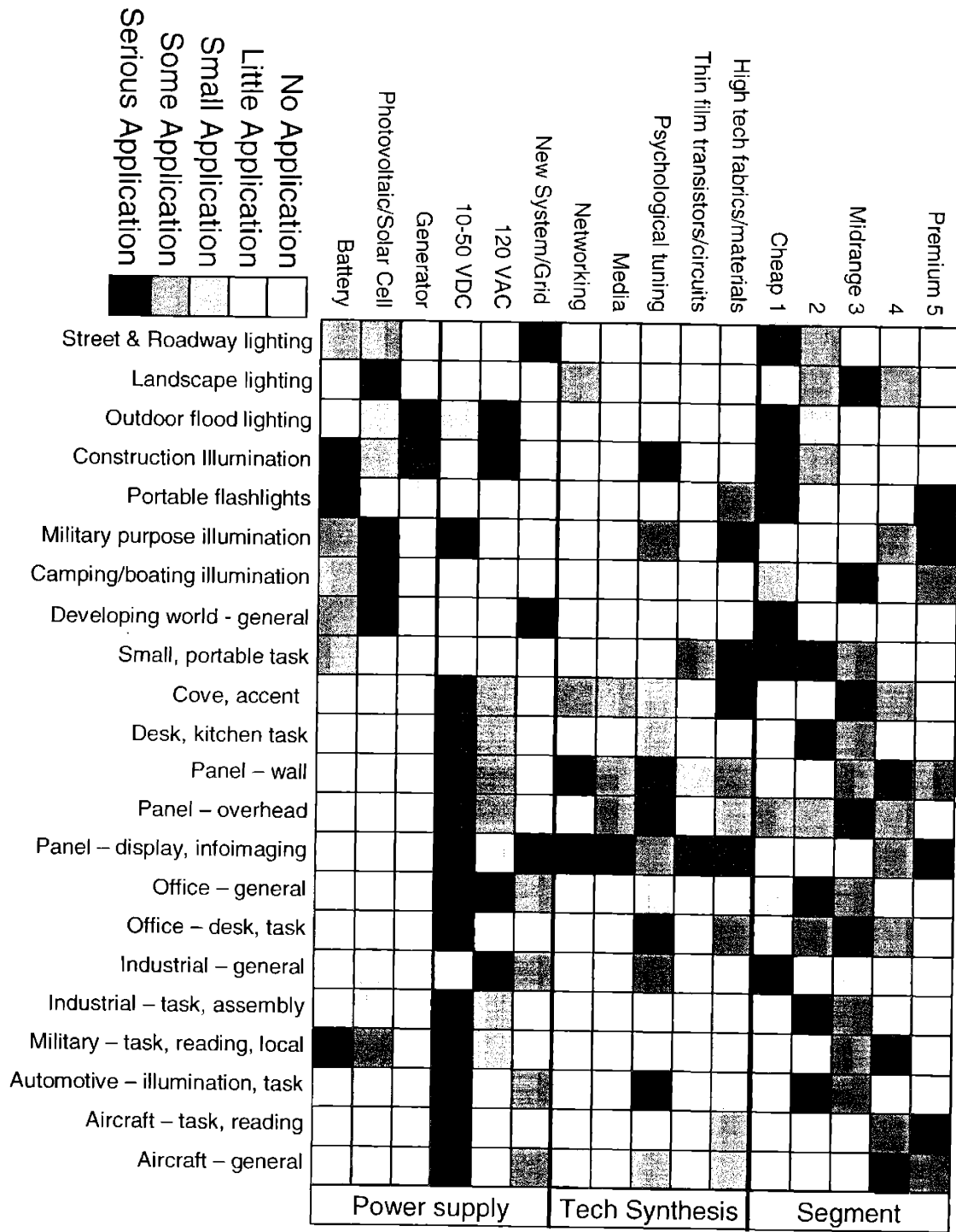
Second, areas where there is already a prominent player or players with competitive advantage are ruled out.

Third, combinations that should provide 1) a function and associated premium for which users are willing to pay 2) a position that can be maintained through unique competencies and 3) products with niche applications that can eventually lead to a more mainstream market.

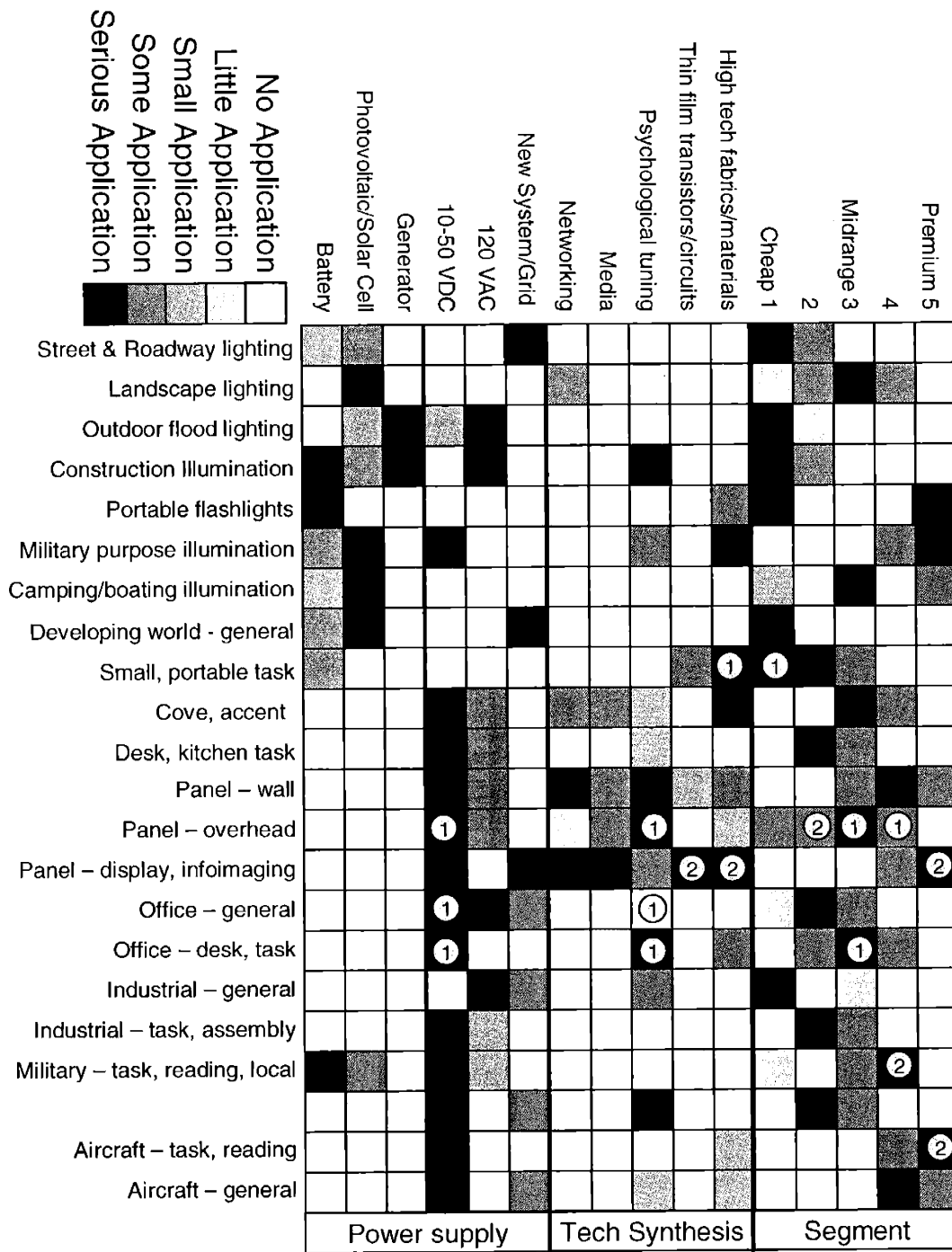
At the end of the product portfolio analysis, a roadmap results that focuses on the following primary areas, as indicated by “circle-1’s” in the above chart:

- Panel lighting that is color controllable for specific tasks
- Off-grid, portable lighting that is optimized for reading and task work
- Permanent fixture lighting that is optimized for workspaces

The following secondary portfolio, indicated by “circle-2’s,” should be introduced as the organization learns from developing and marketing the primary technology portfolio: 1) lighting panels that double as information displays (info-illumination) and 2) highly specialized military and aerospace uses.



**Figure 31.** A graphical approach to determining new product spaces.



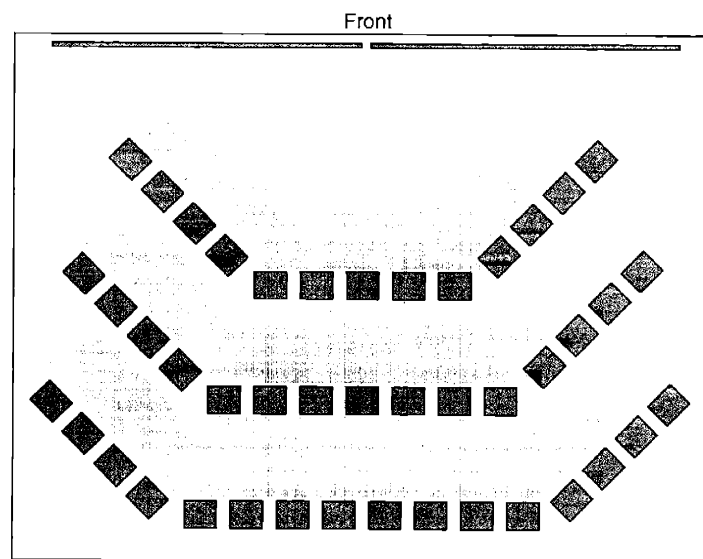
**Figure 32.** Product portfolio with highest first and second value.

### 5.3 An Example Project Application

Now that the general outline of the product portfolio has been described, one shall embark on a project with the following challenge:

*Take a traditional setting and design new and elegant lighting solutions assuming that the technical roadmaps for SSL (LED and OLED) are 90% complete. Create multiple solutions for each application that can be tested via focus and user groups.*

The setting to be studied is a modern (but generic) university classroom, with the assumption that the room has no access to sunlight neither via windows nor sky lights. The following diagram shows the general layout of the room (top view), with fluorescent (generally 4500K with CRI of 85).



**Figure 33.** Project Classroom layout.

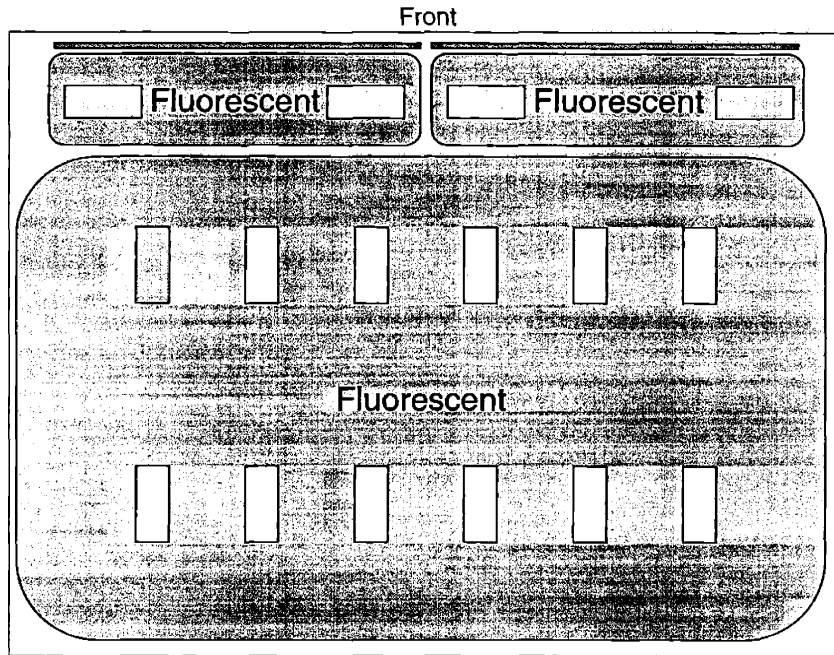
In addition to relatively low CRI, fluorescent lighting exhibit “spikes” in the light spectrum that are suspected to give negative psychological effects. In fact, in a 1999

study, the consulting company Heschong Mahone Group analyzed test score records for more than 21,000 students in three school districts in San Juan Capistrano, California; Seattle, Washington; and Fort Collins, Colorado. The Capistrano study found that students with the most day-lighting in their classrooms progressed 20% faster on math tests and 26% faster on reading tests over the course of one year, compared to students in classrooms with the least day-lighting.<sup>44</sup> While it is possible to purchase daylight-simulating halogen lamps, they are typically short lived (1000 – 3000 hrs) and relatively expensive.

Control of the classroom lights is also typically poor. The placement of overhead lights fluorescent light near the board tends to place a glare on the boards. When the lights are turned down for presentations, the speaker cannot see the audience. Fluorescent lights are not dimmable and only deliver 25% of the light output to desktops and other surfaces. The following diagram shows location and coverage of typical classroom lighting.

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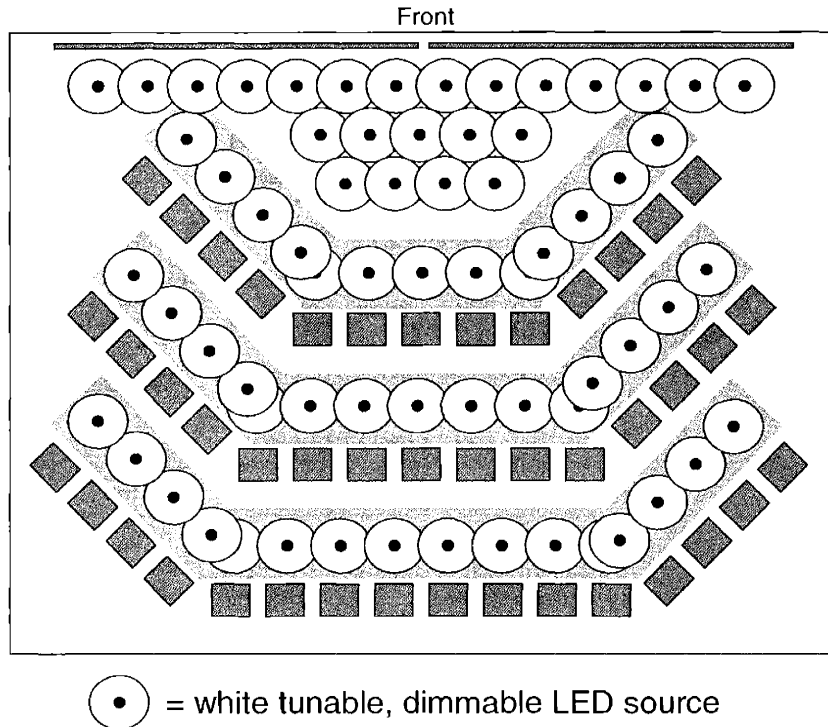
<sup>44</sup> Re-Analysis Summary Daylighting in Schools, Additional Analysis, February 14, 2002. Summary prepared by New Buildings Institute on behalf of the California Energy Commission PIER Program.



**Figure 34.** Typical fluorescent layout. Luminaries in ceiling.

Applying the lighting solution possible with SSL, the overall student – teacher experience can be substantially enhanced.

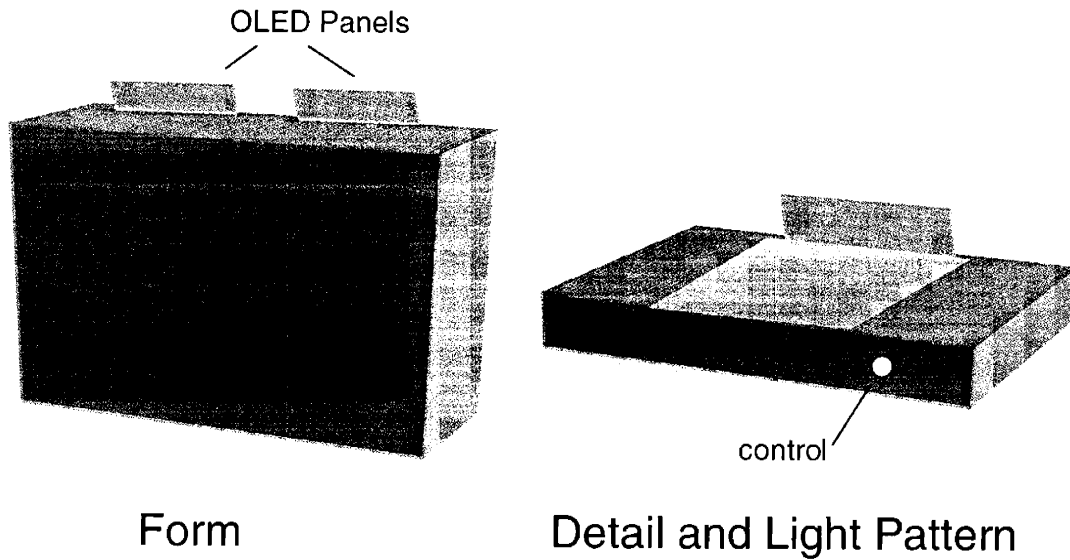
**Possibility 1:** Narrow field “tuned” LEDs spotlights, one per seat. These lights can be hung individually on thin wire from the ceiling, placing the light where the students can use it. Additionally, these narrow beam lights can be used to illuminate the front portion of the classroom. Each light can be individually controlled from each seat or controlled in a bank by the instructor.



**Figure 35.** Light patterns for individually and bank controllable LEDs sources.

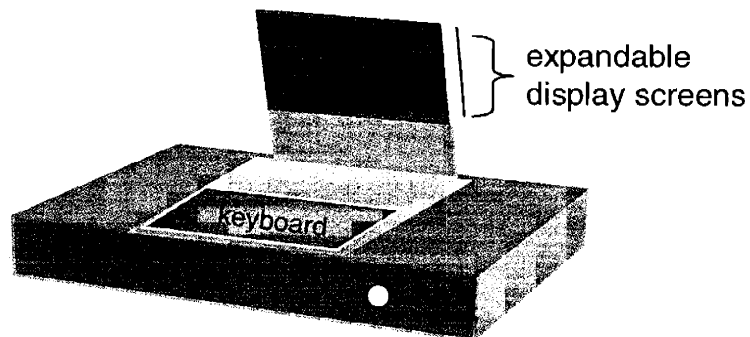
**Possibility 2:** Task lighting at each seat provided by OLED-style light flaps. These flaps would be adjustable, allowing the user to direct exactly where the light would be directed. An intensity control would be placed at each seat. Depending upon costs and technology, the light could be tuned for each person. An added benefit might be the ability to make the panel dual-sided such that the identity tag for the occupant could be shown on the opposite side.





**Figure 36.** OLED type panels could provide individual lighting to each student. The light would be tunable in intensity as well as color temperature.

Expanding on this possibility, the OLED panels could be extendable such that they become information displays if the instructor is displaying multi-media. Students already approximate this functionality today with open laptops at their desks. The forms of the panels would of course have to be sturdy and nearly unbreakable. With today's given technology trajectories, this aspect is certainly possible.



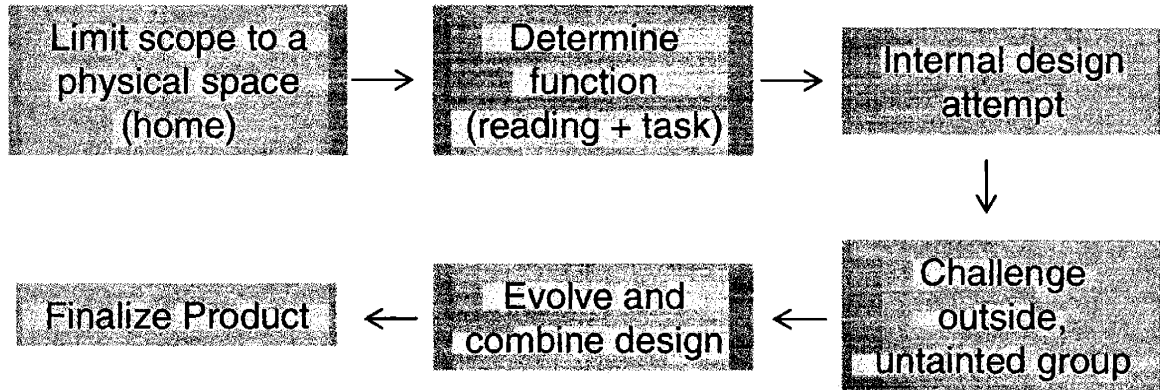
**Figure 37.** Extendable OLED screens could provide both light and interactive displays for students at their desks.

A better option would be to make the panels portable. Many universities require their students to place a nameplate sign in front of their seats. What if the students were issued their own personal light with their illuminated name on the other side? The power supply could either be built into the light (recharged at night) or built into the student's desks. Or, like our "shakable" flashlight above, the students could give it a quick shake before each class.

#### **5.4 Getting Outside of the Box**

While studying a project in this straightforward way certainly generates new concepts and ideas for products, it is often useful to leave the left-brained engineering world and canvas other groups for ideas. Striking the right balance between communicating the bounds of the functional problem without tainting the design process is important. The process should provide enough discipline and rigor without leading the designers too far. Once the basic concept of function is determined, the following types of individuals and teams would be useful to consult:

- Design firms like IDEO and Small Inc.
- Ergonomic Specialist
- Furniture Manufacturers (e.g. Herman Miller)
- Building Materials Suppliers (e.g. Armstrong)
- Architectural Design Firms
- High School Design Teams



**Figure 38.** A design process that strikes a balance between bounding the function and allowing full freedom of exploration is important.

### 5.5 A Shifting Industry

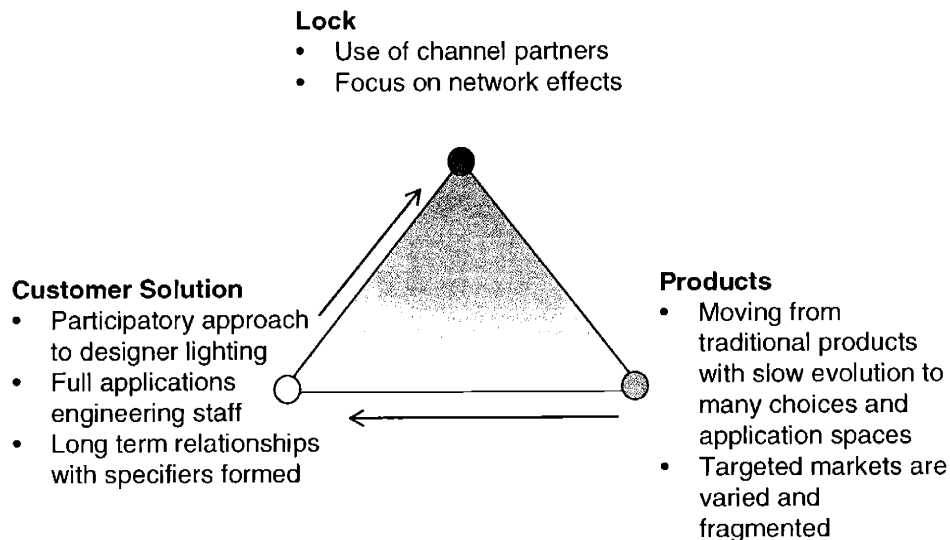
The upshot is that movement in this industry is *from one of products to one of service*. Consider that traditional lighting companies made their money by designing and selling products in volume. Each year there are new incremental designs in form factor, more efficient power usage, and smaller and lighter packaging. The old industry is purely one of commodities and small margins. While the suppliers often bid on the projects available, competition is fierce and most of the value is in replacement lamps. Therefore, the firm that wins the initial bid cannot count on being the future and on-going supplier of lamps.

As new opportunities to provide long lasting, portable and tunable lighting solutions present themselves, companies must move to a more service-centric model. No longer will money be made by selling replacement lamps manufactured in China or Taiwan. Value creation will be entirely based on the ability to deliver new solutions.

In *the delta project* (2001), Arnolddo Hax and Dean Wilde present the argument that companies must find a 10X force (introduced by Andy Grove in *Only the Paranoid Survive*) to separate themselves from the competition. They further develop the idea that

highly fragmented industries offer exceptional value today since fragmented customers can be accessed efficiently via existing networks such as the internet.

The opportunities presented by the forthcoming technical discontinuity in the lighting industry fix Hax and Wilde's *Delta Model* well.<sup>45</sup> First, as discussed in Chapter 2, substantial product benefits can be gained over traditional products. Second, after establishing a beachhead of best products, a firm can also create customer solutions that absolutely add value via by providing new and unique services. And third, through the use of complementors (such as architects, designers and distribution channels), a firm can create a lock-in where they continue to be the "go-to" premium source for lighting solutions.

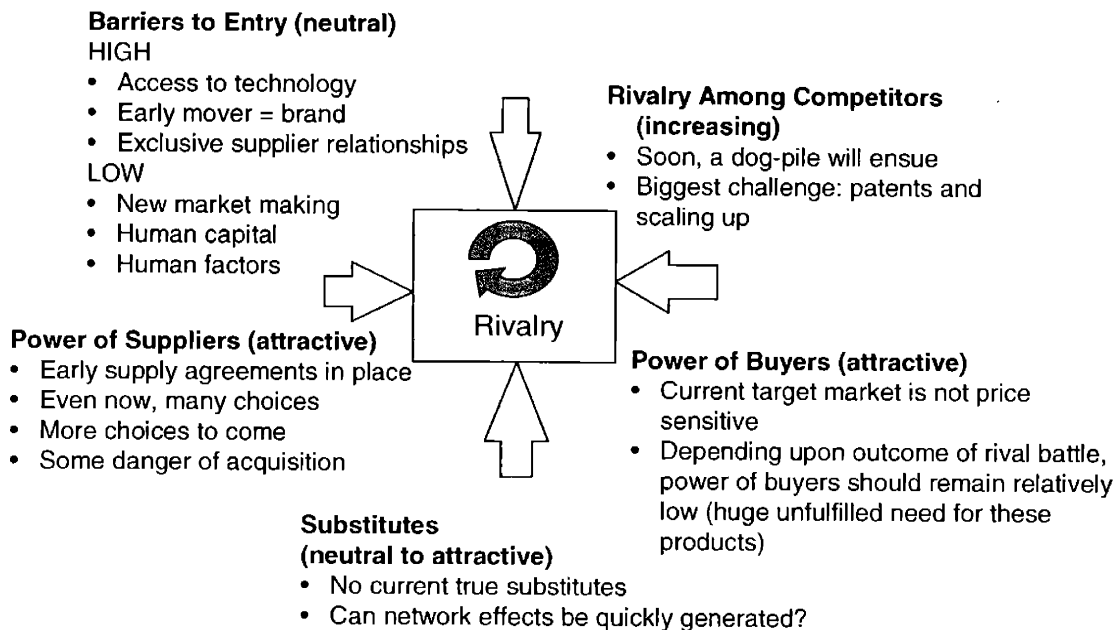


**Figure 39.** The successful lighting firm of the future will move from a product orientated strategy to one where service and customer solutions are dominant.

<sup>45</sup> Arnaldo Hax and Dean Wilde. *The Delta Project*. (Palgrave, Hampshire and New York, 2001).

## 6.0 A SSL Business Model

From the industry factor analysis in Chapter 4, one has a summary of the dynamics present in the SSL industry:



**Figure 40.** An industry factor analysis shows that the state of the SSL industry is currently attractive, but moving toward unattractive.

Once it is determined that entry into this industry is attractive, what explicit steps should be taken to mitigate risk, create value and ensure a long-lived venture? The following discussion outlines important areas to focus upon.

### 6.1 Solid Team

The management team should consist of strong, highly motivated individuals with the following expertise:

- **President.** Experienced general manager and strategic thinker from industry with history of technical discontinuities. Start up experience required.

- CEO. Passionate leader with consulting experience with high-tech startups.
- CTO. Leader in SSL industry. Experience establishing intellectual property strategy. Recruited from a top 10 firm.
- Business Development Manager. Passionate salesperson with ability to pitch and close deals, including contract negotiation.
- Design Manager. Traditionally non-technical, creative person from outside the lighting industry. Ability to find unique and novel solutions to problems.

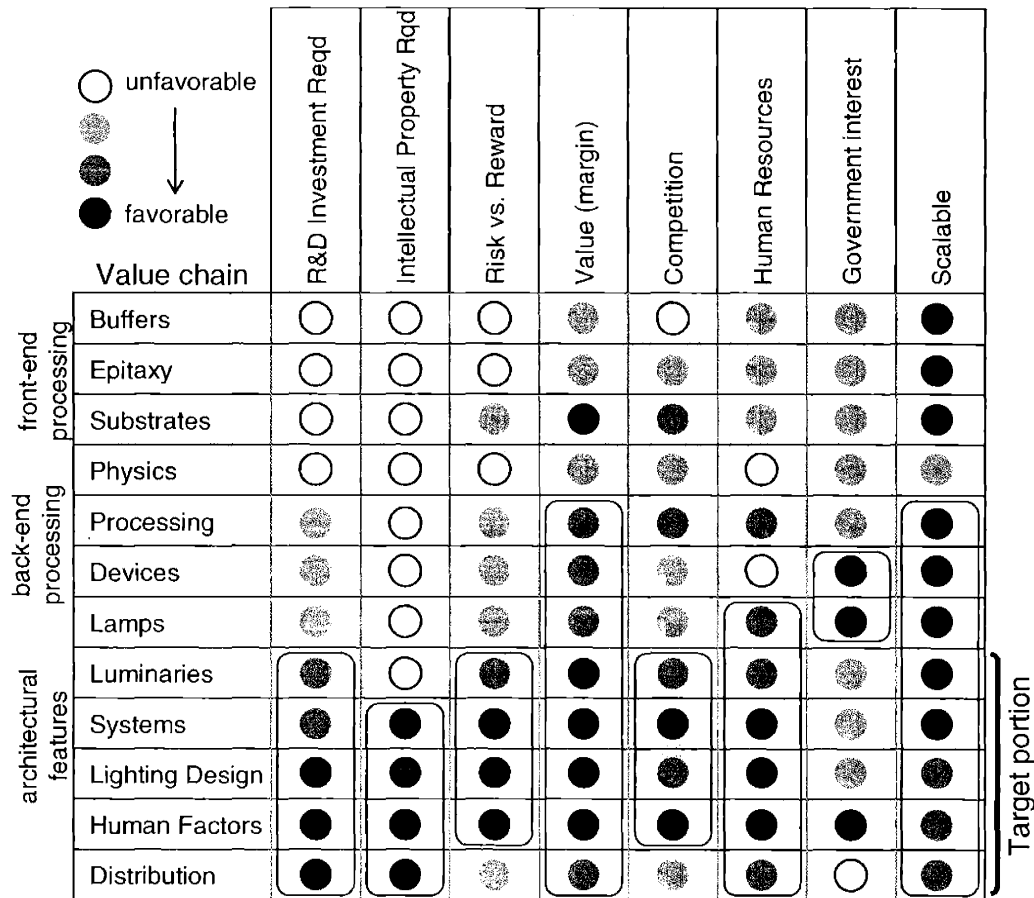
## **6.2 Value Chain**

The value chain of the SSL industry ranges from buffer materials to distribution and channel marketing. In order to decide what portion of the value chain is the best to enter, the following criteria were considered:

- R&D investment required
- Intellectual property required
- Risk versus reward
- Value creation possible
- Competition
- Human resources
- Government interest
- Scalability

Each portion of the chain was analyzed for attractiveness for a new entrant. It is readily apparent that most of the value resides in the portion of the value chain closest to the customer. It is further evidence that adding value via service is the most successful model. Providing service (via both great products as well as unique solutions) is very

different than what has been experience by the traditional lighting industry. In the next sections, various sample models of “light service” that might be provided are discussed.



**Figure 41.** Each portion of the value chain was ranked in terms of attractiveness for each important functional area of business. In nearly each area, the most favorable portion of the value chain resides nearest the customer.

### 6.3 Ground Rules for Business Models

- Initially limit to commercial market segmentation (B to B model)
- Model must reflect service orientation
- Model must be scalable (or at least replicable)

- Most importantly, the business must differentiate itself through *offering products and services not available before the advent of SSL*

#### **6.4 Economic Value Available (SSL Value Proposition Generation)**

In the first iteration, the energy savings associated with the full replacement of any given lighting solution will provide an upper bound to the economic rents available to a solution provider. From a macro viewpoint, illumination accounts for about 16% of U.S. electrical energy consumption. If the energy required to cool lighting is also considered, then 19% of electrical energy is directly related to lighting.<sup>46</sup> This cooling load represents approximately an additional 15% of lighting costs in order to offset the heat generated from lighting. Focusing on the commercial sector, illumination accounts for over 28% of energy usage. While this data is useful from a macro view, it needs to be broken down a bit in order to generate a value proposition for SSL.

Quantitative sources of lighting costs for any particular installation can be defined in the following way:

$$\mathbf{NPV} = \mathbf{C}_{\mathbf{capital}} + \mathbf{C}_{\mathbf{energy}} + \mathbf{C}_{\mathbf{maintenance}}$$

Where  $C_{\text{capital}}$  is the initial purchase and installation cost,  $C_{\text{energy}}$  is the cost of energy expenditures, and  $C_{\text{maintenance}}$  is the cost of replacing and maintaining lighting. While capital, energy, and replacement lamp costs (and therefore savings) are straightforward to calculate, the cost of maintenance is not. For example, if the requirement to replace lamps suddenly did not exist, would the building manager actually save expenditures on labor? The answer is “probably not;” as the work performed by a maintenance person or crew is

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<sup>46</sup> EPRI report (TR-106196).



probably on the margin. The hours saved could be redeployed to other requirements where some costs might be save, although difficult to quantify.

**Energy Cost Maximum Value.** The Energy Information Administration (EIA), created by Congress in 1977, is a statistical agency of the U.S. Department of Energy. The EIA provides policy-independent data, forecasts, and analyses to promote sound policy making, efficient markets, and public understanding regarding energy and its interaction with the economy and the environment. Based on the most recent survey data from 1999, average commercial building size using fluorescent and incandescent lamps was 16,000 and 17,400 square feet respectively, although buildings range in size to over 50,000 square.<sup>47</sup>

For the following analysis, a slightly-larger-than-average size of 20,000 will be used. For reference, an office building of this size would house approximately 50 workers. On a per year basis, organizations spent between 2.1 and 6.4 kilowatt-hours (kWh) per square foot (ft<sup>2</sup>) to light workspaces. Based upon estimates by the EIA, prices per kWh are expected to remain between \$0.073 and \$0.06 per kWh over the next 25 years. Using 4 kWh/ft<sup>2</sup> and \$0.07/kWh, the use per building equates to 500,000 kWh/yr or \$5,600/yr on average. Including the costs to cool current lighting technologies increases this yearly cost to about \$6,500.

Then, assuming a lifetime between remodeling and retrofits of 20 years, the maximum energy savings possible *if lighting were energy-free and did not require cooling*, discounted at 10%, would be about \$55,000.

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<sup>47</sup> Energy Information Administration, Commercial Buildings Energy Consumption Survey 1999.

**Maintenance Cost Maximum Value.** Fluorescent bulbs last between 10,000 and 20,000 hours.<sup>48</sup> Assuming 15,000 hours and a conservative on-time of 100 hours per week, the lamps require replacement approximately every three years. A commercial office building of 20,000 ft<sup>2</sup> would require 1 to 2 luminaries per 100 ft<sup>2</sup> to provide 40-50 foot candles of light, each luminary containing four bulbs, for a total of 800 to 1600 bulbs.<sup>49</sup> Additionally, because most fluorescent lamps contain mercury, businesses must pay \$2 to \$4 per lamp to have them disposed of properly.<sup>50</sup> Lamp prices range from \$3 to \$8 depending upon color temperature, energy usage, mercury content and other factors. Using the discounted cash flow method at 10% per year, the following table shows the costs of maintenance due to bulb replacement only to be on the order of \$50,000.

	Year 3	Year 6	Year 9	Year 12	Year 15	Year 18	Year 21
Fluorescent Bulbs Replaced - high	1600	1600	1600	1600	1600	1600	1600
Fluorescent Bulbs Replaced - low	800	800	800	800	800	800	800
Disposal costs - high (\$4 per lamp)	\$ 6,400	\$ 6,400	\$ 6,400	\$ 6,400	\$ 6,400	\$ 6,400	\$ 6,400
Disposal costs - low (\$2 per lamp)	\$ 1,600	\$ 1,600	\$ 1,600	\$ 1,600	\$ 1,600	\$ 1,600	\$ 1,600
New Bulbs (\$8) - high	\$ 12,800	\$ 12,800	\$ 12,800	\$ 12,800	\$ 12,800	\$ 12,800	\$ 12,800
New Bulbs (\$3) - low	\$ 2,400	\$ 2,400	\$ 2,400	\$ 2,400	\$ 2,400	\$ 2,400	\$ 2,400
Total - high case	\$ 19,200	\$ 19,200	\$ 19,200	\$ 19,200	\$ 19,200	\$ 19,200	\$ 19,200
Total - low case	\$ 4,000	\$ 4,000	\$ 4,000	\$ 4,000	\$ 4,000	\$ 4,000	\$ 4,000
DCF - high	\$75,867.34						
DCF - low	\$15,805.70						

**Figure 42.** Maximum spend on lighting maintenance for a 20,000 ft<sup>2</sup> commercial building is about \$50,000 over 20 years.

This means that the value proposition of any new lighting technique with a life of 20 years has a maximum bound of about \$100,000 for a 20,000 ft<sup>2</sup> office building, or about \$2000 per worker.

To put things into perspective, the Biotechnology Building at MIT University Park, 35 Landsdowne Street, in Cambridge is 135,000 ft<sup>2</sup> or about 7 times the average

<sup>48</sup> Thomas Drennen, Roland Haitz, Jeffrey Tsao. *A Market Diffusion and Energy Impact Model for Solid-State Lighting*. Sandia National Laboratories, August 23, 2001.

<sup>49</sup> Rae, Mark, S., ed. *The IESNA Lighting Handbook*, 11th edition. New York: IESNA, 2000

sized of a commercial building. The maximum available value of removing these lighting costs in that particular building is about \$675,000 assuming the owner/operator could consider a 20 year time horizon. Assuming new SSL technologies would require only 10% of the energy costs of fluorescent lamps, the available value would then be about \$400,000.

For any business case to hold, the payback time should be less than about 5 years. This will act to keep any upfront capital costs under about one-half of the total value available, or \$200,000. *The message is essentially “spend \$200,000 now to save \$400,000 over 20 years.”*

One business or economic model to facilitate direct replacement of all luminaries in a building such as 35 Landsdowne might have the following characteristics:

- Maximum invoice of \$200,000
- Margin of \$50,000
- Total labor and capital costs of \$150,000
- Labor costs estimate
  - 1500 luminaries (2 luminaries per 100 ft<sup>2</sup>)
  - 20 min per luminaries or 500 man-hours
  - \$10,000 labor at \$20/hr (estimate \$20,000)
- Capital costs evaluation (\$140,000 available)
  - \$93 per luminary or light source

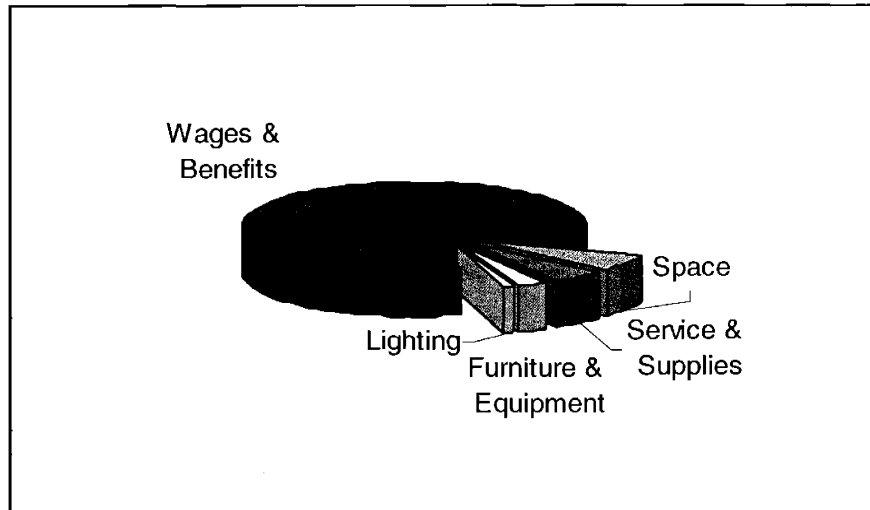
From this analysis, it seems that a business model that services or facilitates replacement of existing luminaries could exist, but on somewhat shaky ground. If the management of 35 Landsdowne could replace the luminaries with only labor costs (i.e.

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<sup>50</sup> [www.bethlehemlamprecycling.com](http://www.bethlehemlamprecycling.com)

no margin required), considered only NPV and no required payback period (i.e. spending \$400,000 to relamp the building), the available capital per luminary would be about \$266 – a result that appears very attainable. It should be noted that the foregoing simple economic analysis did not include:

- Improved performance from better CRI and color temperature control
- Improvement in directionality
- Dimming capability
- Lower glare



**Figure 43.** Lighting accounts for only 1% of spending on office spaces.<sup>51</sup>

It is also interesting to note that if the entire \$200,000 value was available to be spent on an individual basis (i.e. light would be associated with each person versus stationary luminaries) then each person could have \$500 worth of personal lighting capital.

<sup>51</sup> Craig DiLouie, *The Lighting Management Handbook*. Fairmont Pr; 1st edition (1994)

Only 1 percent (see Figure 39) of office building spending goes to lighting. As lighting becomes more important to productivity, and as SSL is more able to deliver it, a dramatic increase in spending on lighting solutions should be seen.

## **6.5 Value Proposition Selling as a Consulting Business**

From the roadmaps presented in Chapter 3, the following likely events are evident:

- SSL will provide lower direct cost energy solutions (tangible)
- SSL will place a smaller load on building cooling systems (tangible)
- SSL will provide lower lifetime costs (tangible)
- SSL will provide increased productivity via better ergonomics (quasi-tangible)
- SSL will increase worker comfort resulting in increased retention (intangible)
- SSL technologies are fluid and require effort to understand value (intangible)

As a starting point, one business model might be a consultancy business that performed the following functions:

- Project scope: determine needs, functionality, next generation installations
- Project value: NPV and payback calculations
- Sourcing: absorb installation risk from known suppliers
- Contract maintenance: provide, via contracts, on going support

There is a distinct void of SSL experts to help guide commercial businesses through future re-lamping decisions. An organization skilled in lighting design, estimating costs and costs savings, acting as a contractor, and providing ongoing maintenance could be highly valued. In addition to the issue of establishing an economic value proposition (from above), some other immediate issues would be scalability and retention of expertise. These types of functions can be provided by many engineering consulting firms and talent will tend to drift out during high growth periods. For the right products and the right markets, this model appears favorable and warrants further investigation.

#### **6.6 Lighting Design with SSL Specialization**

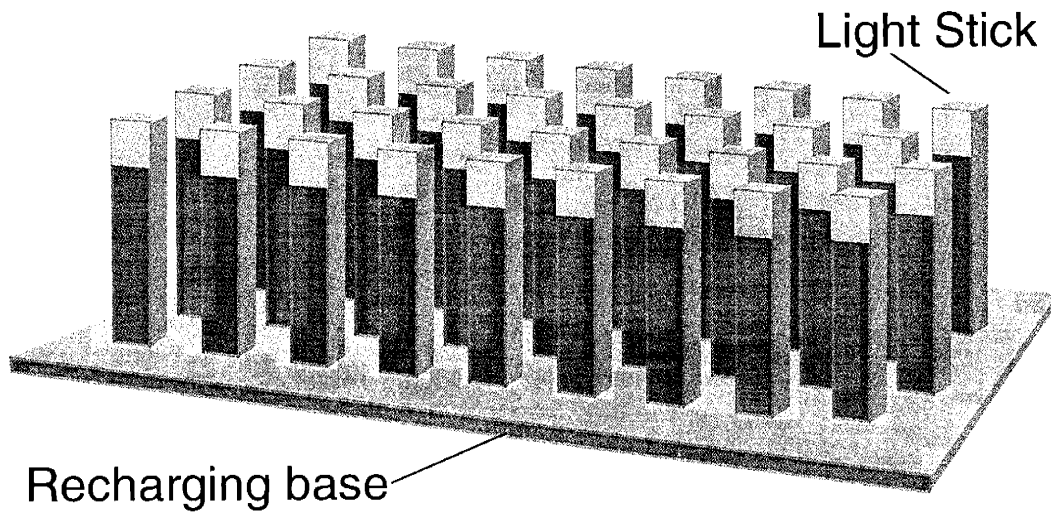
Existing lighting design firms draw upon a number of technologies to deliver products and services to their customers. Some specialize in areas such as theater lighting, retail display lighting and designer lighting. A business that is focused purely on SSL (first LEDs then OLEDs) would be at a disadvantage since expertise would not exist for HID, fluorescent, and other lighting technologies. There would be little flexibility to engage in opportunities where a mix of lighting type would be required. While lighting design is certainly a service, it tends to be niche businesses inside closely guarded communities. For this reason, lighting design is not a favorable model for a new entrant.

#### **6.7 Designer and Supplier of Portable SSL Task Lighting Solutions**

SSL, through its extreme energy efficiency, can support cordless much easier than traditional lighting. Many large rooms (such as those in libraries and classrooms) do not

provide sufficient overhead lighting for tasks such as reading. To validate that point, it is now possible to check out a CFL at Dewey Library at MIT for reading and studying purposes. Although many students do this, they still must find a location in the library with a 110v outlet. SSL could free the student from the cord, the way wi-fi has freed the laptop.

The types of educational places where students might appreciate portable task orientated lighting solutions are libraries, study rooms, dormitories, classrooms, and student centers. For commercial solutions, a worker could have a very portable lamp at all times – potentially becoming part of a laptop or palmtop. Control of the lamps could be via ID card checkout, RFID technologies or several other solutions. While many form factors and configurations are possible, one option might be a “checkout table” that serves as a recharger and payment system (if required) as well a system for tracking lamps and users. Although the market size for this application might be limited at first, it could conceivable grow very rapidly to schools, universities and businesses world wide.



**Figure 44.** A delivery system for portable SSL light-sticks might act as a recharger, a tracking mechanism, and also provide a means of payment.

This product/service model would be highly specialized at first, being limited to colleges and universities. But, as the idea of using portable illumination increases, the model could expand to offices and other work spaces.

Money would be made through the following ways:

- Initial setup and equipment installation
- On-going replacement of lamps lost or broken
- Additional lamps as required

## **6.8 A New Paradigm in Personal Lighting**

Although the analysis in Chapter 5 pointed to a service model as the most successful, the final model presented is a product model. If a product could be developed with the following characteristics, powerful economics could support a product model:

- Light that travels with the user



- Light on demand, when and where the user needs it
- A product that is bought once a lifetime (unless lost)
- A product that can change the lives of those in developing countries, providing light to read and work by
- A comfortable, ergonomically designed hands-free product
- A rugged, sturdy product that is waterproof and floats
- No batteries, bulbs or other consumables (ever)
- A product that was never possible until now

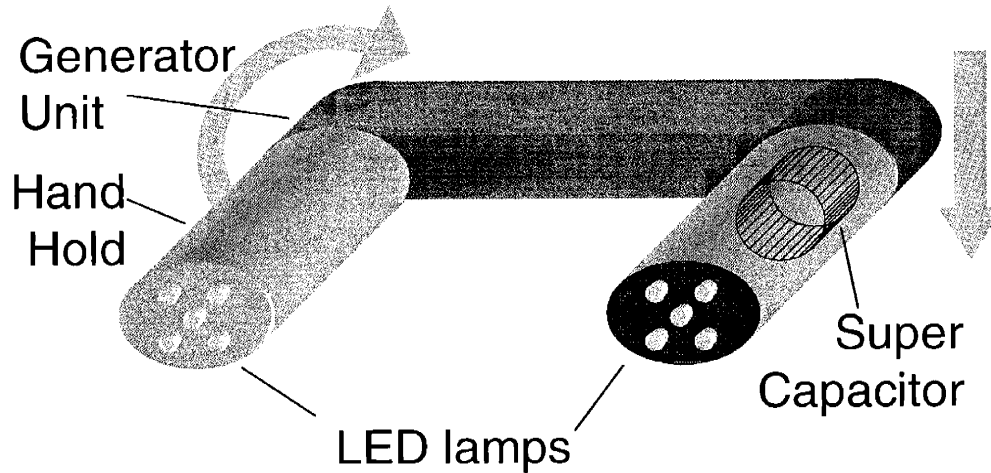
**Introducing the U-Light™.** By combining new technologies from SSL, new super capacitors and new polycarbonate materials, this personal lighting device could change the way people work and use light.

The light is composed of the following simple, easy to assemble parts:

- Solid polycarbonate plastic housing (3 parts)
- 10 Lumileds Luxeon 1 W White LEDs or
- 2 Lumileds Luxeon 5 W white LEDs
- Highly geared DC generator, 5V, 1A
- Maxwell BoostCap 450F UltraCapacitor

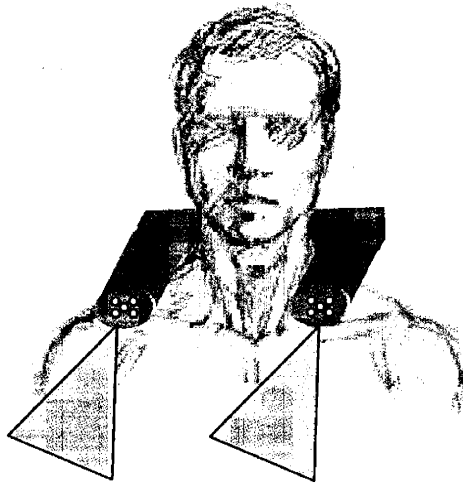
Operation of the light would be very simple and intuitive. By grasping the light on the generator tube and spinning the device, the opposite tube would spin about the hand, in turn spinning the generator and charging the super-capacitor. There would be no need for an on/off switch since the light can be “extinguished” by standing the U-Light on the ends. Also, it is not necessary to save the energy in the capacitor as it would be

come natural to spin the U-Light each time it is picked up. The following image shows the form factor of the light.



**Figure 45.** Introducing the **U-Light™**, a new way to think of personal lighting. By combining the emerging technologies from SSL, polycarbonate materials, and super capacitors, a never before possible lighting device is within reach.

While the technologies involved are interesting, the most significant part of the design is that the user can *wear* it. Similar to the flexible flashlights from the early 1990's, the U-Light is worn around the user's neck to enable the hands to be free for tasks like working or reading.



**Figure 46.** The U-Light in its natural position, leaving the users hands free for other tasks.

**Future Roadmap.** As improvements in LED lights, materials, power supplies and other technologies are made, improvements in the U-Light might include the following:

- **Thermal Power.** By placing highly efficient electro-thermal transition plates near the surface of the light that touches the wearer, the U-Light can be powered by energy from the user.
- **Kinetic Power.** Much like kinetic powered watches, electro-kinetic devices inside the lamp could generate the power needed from the movement of the lamp itself.
- **Clothing Integration.** Personal lighting could become as natural as wearing a jacket. The U-Light technology could be integrated into the collars of coats so that it is always available.
- **OLED Integration.** As OLED technologies progress, it will be possible to *simplify* the light, possibly with *light panels* versus point source LEDs.

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## **7.0 Recommended Policies for Managers**

### **7.1 How to Stay on Top of Technology**

It is impossible to fully understand the movement of technologies by reading the popular technology reviews such as in the New York Times, Nature, the Economist, etc. Technology is much like the stock market in that as soon as the information is known, the market reflects the associated value of that information. More importantly, the transactional cost of sorting out new and unique information from that which has been known for months is very high. It is best to find sources of concentrated aggregation of emerging technologies. Some specific examples of sources that are often publicly available include government commissioned reports, patent databases, national laboratories, and, of course, universities.

From an institutional perspective, the culture should be one of always asking, always investigating, always being curious. From this inquisitive team, an ordered process of road-mapping, understanding trends and developing scenarios must exist. Unlike the stock market, trends in innovation are not a random walk – it is possible to perform some amount of prediction. The manager's role is to ensure that the processes are in place to help figure out what the next disruption will be, but also to ensure that the blinkers are not on the organization. For the margins of the organization, there should be a sense of *patient understanding* that people can spend some precious resources to mine the hills of innovation.

The use of models and frameworks like those presented in Chapter 1 and 4 will be useful for interpreting data and resolving it to useful information. Scenarios, like the two presented in Chapter 3, will provide the organization a useful language with which to converse and further understanding about specific technologies.

Visual interpretation and presentation of data is also extremely underutilized. Engineers and managers have a long way to go before the full value is realized from new techniques of visualization. As was seen in the post-accident investigation of the Space Shuttle Columbia, the simple expansion of a graph to include (or exclude) data can make all the difference.

## **7.2 Why Analogies Sometimes Fail**

While analogies give us a warm, fuzzy sense of well being when they seem to fit our circumstance, they can also lead us down a dangerous path of misunderstanding. Like scenarios, they allow us to assume that the next step will be something familiar. But instead of providing a vision of the future specific to current circumstances, analogies supplant thinking and ingenuity with a seemingly easy answer. The often cited example of competition and diffusion in the VCR industry was unique to that intellectual property, customer utility, and country-based competition situation. Different technologies and industries require new mental maps, partnerships, and real options. While thinking about historical examples of innovation can help develop frameworks to be applied to new situations, the analogies cannot be applied without modification.

There is also a propensity to liken technology progression to that of ecologies and evolution. While these again can get us into trouble, the randomness of evolution provides a broader backdrop onto which technical innovations can be projected. In fact, the very act of humans choosing a technology is part of the ongoing process of our own evolution. Additionally, the elegance and simplicity of Nature's solutions can provide inspiration for new technologies.

### **7.3 Three Guiding Principles**

While much of the discussion in Chapters 1 through 6 has focused on products and the innovation of technology, simply concentrating on making better products is not enough.

The first principle is to create value. Managers must consider the bigger picture of how not only to make a profit, but rather to create value – an entirely different result. A product centric mentality may create value for a short period of time, but in time competition will cause a reversion to average and in turn create a commodity mentality. Firms and product teams must stay above the mean by finding ways to create total customer satisfaction and eventually customer lock-in. Risks must be taken to find solutions to problems – when solutions are found, long-term value creation is suddenly possible. It is not the product that creates solutions, it is the whole package for which customers pay.

The second principle is to continually create strategies for risk mitigation. There are a number of ways to hedge: financial options, currency options, land options and real options to name a few. A portion of the management team must be expert at constructing vehicles for hedging risks that are taken to create value. In order to measure the effect of decisions, granular metrics must be available. Measuring averages is paramount to disaster.

Finally, a culture must be established. One of the keys to long lived companies as reported in the aforementioned Royal Dutch Shell study of 200 long lived companies was a core culture to which employees could adhere. It is fine that different companies create different, diverse communities. The key aspect of company community is that it is

consistent, well communicated, and most importantly, visible to insiders and outsiders alike. The ability of a company to project its culture makes an impression on customers and suppliers that no amount of advertising and public relations money can equal.

<b>Create Value</b>	<b>Hedge Risk</b>	<b>Establish Culture</b>
<ul style="list-style-type: none"> <li>• Beware the product centric mentality: products revert to commodities</li> <li>• Allow employees to take risks to solve customer's problems</li> <li>• Pursue and remove costs religiously</li> <li>• Understand where and how value is being created, and communicate it</li> <li>• Search for network effects and complementors</li> <li>• At the margins, preempt the market</li> <li>• Grow</li> </ul>	<ul style="list-style-type: none"> <li>• Be expert at financial intelligence</li> <li>• Trade off fixed and current assets</li> <li>• Establish and track granular metrics</li> <li>• Balance risk inherently in the portfolio of products</li> <li>• Establish policies for make vs. buy decisions</li> <li>• Understand the value chain, and protect the firm's position in it</li> </ul>	<ul style="list-style-type: none"> <li>• Creating value with a hedged position is not enough: the culture must offer a guiding light</li> <li>• Communicate corporate purpose and reason for business, focus on scope of markets and products</li> <li>• Value employees openly</li> <li>• Establish policies for and communicate frequently</li> <li>• Create a community centered at the firm's value add</li> </ul>

#### **7.4 The Future of the Lighting Industry**

The ultimate question is whether existing lighting firms will be able to continue to create value from lighting products and services; or, if as has been seen in other industries disrupted by emerging technologies, newer firms will sweep the incumbents from the stage. The spin-off organizations of the major players exist with separate technology bases but often use shared channels to customers. If SSL is really going to diffuse into



the market via new applications and never before practical products, then using traditional channels is probably a non-starter. Additionally, the ability of transforming these organizations into service organizations will be a huge challenge.

That said, the ultimate “holy grail” continues to be the displacement of existing lighting in one way or another. If companies remain open to diffusion modes, take risks to push the envelope of technology, mitigate the risks taken, and stay true to their culture, the future of how our lives are lit will be brilliant for all of us.

## BIBLIOGRAPHY

- Adner, Ron and Levinthal, Dan. *The Emergence of Emerging Technologies*. California Management Review, vol 45, number 1, Fall 2002.
- Arthur D. Little, Inc. Energy Savings Potential of Solid State Lighting in General Lighting Applications. Final Report Prepared by for the U.S. Department of Energy
- Aykaç, Ahmet and Brumat, Carlo et al, *New Developments in the Applications of Bayesian Methods*. North-Holland Publishing Company, Amsterdam, New York, Oxford , 1977.
- Bardsley, J. Norman. *International OLED Technology Roadmap: 2001-2010* U. S. Display Consortium.
- Bright, James R., *Practical technology forecasting, concepts and exercises, with notes on anticipating sociopolitical interactions with technology*, Austin, Industrial Management Center, 1978.
- Campbell, C.J. *Perceptions of Compact Fluorescent Lamps in the Residential Market: Update 1994*. Palo Alto, CA: Electric Power Research Institute, 1994.
- Christensen, Clayton. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Harper Business, New York, 2000.
- Collins, James and Porras, Jerry. *Built to Last: Successful Habits of Visionary Companies*. Harper Collins, New York, 1994.
- Collins, James C. Letters to the Editor. Harvard Business Review, May/June 1997, Volume 75 Issue 3
- Cunningham, Ralph, *LED Inventor Fights for Ownership, Managing Intellectual Property*, London, Oct 2002.
- de Geus, Arie. *The Living Company*. Harvard Business School Press, Boston, Massachusetts, 1997.
- Diebold, Francis and Rudebusch, Glenn. *Business Cycles: Durations, Dynamics, and Forecasting*. Princeton University Press, Princeton, New Jersey, 1999.
- DiLouie, Craig. *The Lighting Management Handbook*. Fairmont Pr; 1st edition (1994).
- Drennen, Thomas; Haitz, Roland and Tsao, Jeffrey. *A Market Diffusion and Energy Impact Model for Solid-State Lighting*. Sandia National Laboratories, August 23, 2001.
- Forrest, Stephen and Burrows, Paul. *The dawn of organic electronics*. IEEE Spectrum, August 2000.
- Gardner, Carl. *Sources for courses*. Light, November, December 2002.
- Goldfisher, Ken. *Modified Delphi: A concept for new product forecasting*. The Journal of Business Forecasting Methods & Systems; Flushing; Winter 1992-1993.
- Harvey, Andrew C. *Time Series Models*. MIT Press, Cambridge, MA, 1993.
- Hax, Arnaldo and Majluf, Nicolas. *The Strategy Concept and Process: A Pragmatic Approach*. Prentice Hall, New Jersey, 1996.
- Hax, Arnaldo and Wilde, Dean. *The Delta Project*. Palgrave, Hampshire and New York, 2001.
- Holonyak, Nick, Jr. From *Transistors to Light Emitters*, IEEE Journal of Selected Topics in Quantum Electronics, vol. 6, no. 6, November/December 2000.
- Kennedy, Sheila. *bugs, fish, floor & ceilings: luminous bodies and the contemporary problem of material presence*. Harvard University Graduate School of Design. President and Fellows of Harvard College, 2000.

- Keyes, R. J. and Quist, T. M. "Recombination radiation emitted by gallium arsenide," in IRE Solid-State Device Research Conf., Durham, NH, 1962.
- Kialka, John. *How to Build a Better Light Bulb: Use the Original*. The Wall Street Journal. New York, N.Y.; May 2, 2002
- Moore, Geoffrey A. *Crossing the chasm: marketing and selling technology products to mainstream customers*. New York, N.Y. Harper Business, 1991.
- Pistorius, C.W.I. and Utterback J.M. *Multi-mode interaction among technologies*. Research Policy 26 (1997). pp. 67-84.
- Rae, Mark, S., ed. *The IESNA Lighting Handbook*, 11th edition. New York: IESNA, 2000.
- Robertson, Ken et al, *Light Up The World - Update (2001 – 2002)*. www.lutw.org
- Schwartz, Peter. *The Art of the Long View*. Doubleday, New York, NY, May 1991.
- Sze, S.M. *Semiconductor Devices: Pioneering Papers*, World Scientific Publishing, 1991.
- Tang, C.W. and VanSlyke, S.A. *Organic electroluminescent diodes*. Applied Physics Letters 1987.
- Tsao, Jeff. *LEDs for General Illumination Update 2002 – Tutorial*. Optoelectronics Industry Development Association, Washington DC.
- Utterback, James. *Mastering the Dynamics of Innovation*. Harvard Business School Press, Cambridge, MA, 1994.
- Weber, Marvin J. *Selected papers on phosphors, light emitting diodes, and scintillators: Applications of photoluminescence, cathodoluminescence, electroluminescence, and radioluminescence*. Bellingham, Wash.; SPIE Optical Engineering Press, c1998.
- Welty, Gordon A. *The Selection and Deflection of Expertise in Delphi Exercises*, presented at the 1972 Joint National Meetings of the Operations Research Society of America and the Institute of Management Sciences, Atlantic City, New Jersey, November 8, 1972.
- Wessner, Charles W. *Partnership for Solid-State Lighting: Report of a Workshop*. Washington DC, March 2001. National Academy Press.
- Utterback, J. M. and Brown, J. W. *Profiles of the Future: Monitoring for Technological Opportunities*, Business Horizons, Vol 15, Oct 1972.

