A 20-YEAR INDUSTRY PLAN FOR LIGHTING TECHNOLOGY

Vision 2020

THE LIGHTING TECHNOLOGY ROADMAP

OFFICE OF BUILDING TECHNOLOGY, STATE AND COMMUNITY PROGRAMS
ENERGY EFFICIENCY AND RENEWABLE ENERGY • U.S. DEPARTMENT OF ENERGY
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CO-SPONSORS

The following associations have taken a lead role in developing the *Lighting Technology Roadmap* and are committed to its implementation.

- Illuminating Engineering Society of North America (IESNA)
- International Association of Lighting Designers (IALD)
- InterNational Association of Lighting Management Companies (NALMCO)
- National Association of Electrical Distributors (NAED)
- National Electrical Manufacturers Association (NEMA)
- National Electrical Manufacturers Representatives Association (NEMRA)
- National Electrical Contractors Association (NECA)
- National Association of Independent Lighting Distributors (NAILD)
- U.S. Department of Energy, Office of Building Technology, State and Community Programs

Opening New Frontiers for Lighting

It is impossible to imagine modern life without electric lighting. With the wide availability and affordability of today's lighting, people throughout much of the world are free to work, play, and learn virtually anywhere, anytime.

The flexibility of our waking hours, the richness of our information environments, the complexity of our visual tasks, and the range of our movement exceed anything our ancestors could have envisioned just over 120 years ago, in the days before Thomas Edison's carbon-filament lamp changed the world.

Continued innovation in lamps and other system components, as well as in design practices, have made lighting progressively more effective, efficient, and economical since Edison's time. Yet the *Lighting Technology Roadmap* anticipates developments in the *next* 20 years that may well dwarf the accomplishments of the past century.

A NEW INITIATIVE

The U.S. Department of Energy's Office of Building Technology, State and Community Programs (BTS) is facilitating a new industry-led initiative to develop a series of technology roadmaps. The roadmaps identify key goals and strategies for different areas of the building and equipment industry. The *Lighting Technology Roadmap,* focusing on opportunities in commercial lighting, is one of the first sponsored by BTS.

This roadmapping initiative is a fundamental component of the BTS strategic plan and will help to align government resources with the high-priority needs identified by industry. The roadmap will guide cooperation among public and private researchers, lighting companies, and other State and Federal offices to help the lighting industry achieve its long-term vision.

EXECUTIVE SUMMARY

STRATEGIES FOR ACHIEVING THE LIGHTING VISION

Market Transformation Strategies

- Develop clear definitions and standards for lighting quality.
- Increase demand for high-quality lighting solutions by quantifying, demonstrating, and promoting life-cycle benefits to broad audiences.
- Strengthen industry education and credential lighting professionals.
- Accelerate the market penetration of advanced lighting technologies. and systems, by providing incentives for R&D and reducing barriers inherent in today's specification and distribution methods.

Technology Development Strategies

- Develop advanced source and ballast technologies that enhance quality, efficiency, and cost effectiveness.
- Develop lighting controls with high levels of intelligence, interface capabilities, multiple levels of control, and ease of configuration.
- Develop luminaires and systems that enhance the quality and flexibility of light delivery.

SHAPING OUR BUILT ENVIRONMENTS

A remarkable confluence of emerging technologies can spell great improvements in our ability to harness light efficiently and effectively, to extend the reach and power of human vision, and to dynamically monitor and shape our built environments to suit specific purposes and preferences. Advances on diverse technology fronts promise to drive down the costs and multiply the capabilities of microchips, lasers, and photovoltaics, opening the way to entirely new levels of performance in sensors and controls. Also on the horizon are innovative materials, high-efficiency light sources, breakthroughs in biotechnologies and chemical sciences, and ever more powerful methods of system modeling and integration.

Advanced technologies will, in turn, enable advanced design and engineering approaches. Starting in the commercial building sector, but later moving into the residential sector as well, we will see growing sophistication in the design of lighting and other building systems within an integrated, "whole buildings" framework. The "whole buildings" approach will optimally use both human-made and natural systems to provide efficient, high-quality lighting, heating, cooling, ventilation, and information exchange.

The result? Tomorrow's buildings will provide unprecedented levels of comfort, productivity, flexibility, and well-being for occupants, while reducing energy use and other impacts on the natural environment.

VISION STATEMENT

In 2020, lighting systems in buildings and other applications will:

- Enhance the performance and well-being of people
- Adapt easily to the changing needs of any user
- Use all sources of light efficiently and effectively
- Function as true systems, fully integrated with other systems (rather than as collections of independent components)
- Create minimal impacts on the environment during their manufacturing, installation, maintenance, operations, and disposal

As a result, people will understand, value, and utilize the tangible, personal benefits provided by these lighting systems.

DETERMINING PRIORITIES

Vision 2020: The Lighting Technology Roadmap describes an exciting future for lighting in the coming decades. It represents nearly two years of work by 180 organizations representing a broad range of lighting manufacturers and professionals, as well as members of the academic, government, and research communities. Nearly 100 participants contributed to brainstorming workshops, reaching general consensus on a vision for the future of lighting and identifying possible activities for achieving it. Another 201 individuals cast their votes on which strategies and activities should receive the highest priority. (High-priority strategies and activities are presented on pages 12 to 17 of this document.) Votes were solicited and collated by the Department of Energy, Office of Building Technology, State and Community Programs (BTS), which has facilitated the development of the Lighting Vision and the Technology Roadmap.

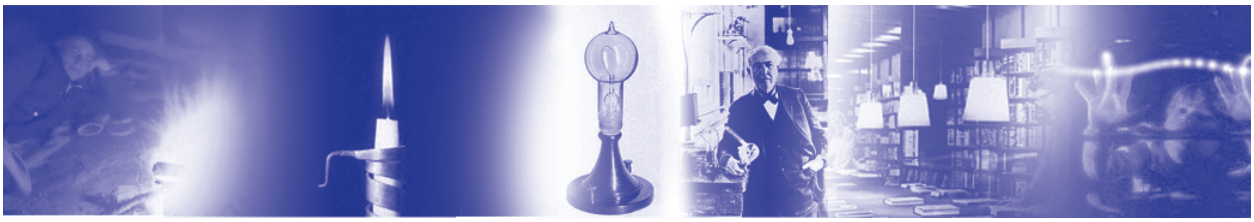
Eight lighting industry associations have sponsored the vision and roadmap process: the Illuminating Engineering Society of North America (IESNA), the International Association of Lighting Designers (IALD), the National Association of Electrical Distributors (NAED), the National Electrical Manufacturers Association (NEMA), the National Electrical Manufacturers Representatives Association (NEMRA), the National Electrical Contractors Association (NECA), the National Association of Independent Lighting Distributors (NAILD), and the InterNational Association of Lighting Management Companies (NALMCO). These associations have expressed their commitment to the ongoing effort to implement the Technology Roadmap priorities.

ADDRESSING THE BARRIERS

Both market-related and technology barriers need to be addressed to realize the Lighting Vision. One key barrier is the current weakness in the market for innovative lighting solutions. A specific challenge is to demonstrate how life-cycle benefits often make high-quality lighting systems an attractive and economical choice, even when their initial purchase costs are higher than those for other options.

The Technology Roadmap describes seven strategies for moving forward. Four strategies address the challenges of **market transformation,** with activities targeted for implementation in the short (less than three years) to medium (three to 10 years) term. The remaining three strategies relate to lighting **technology development.** These strategies target attributes that are likely to be valued in tomorrow's sources, ballasts, lighting controls, luminaires, and systems. Virtually all the desired attributes are judged to be technically achievable in the short (less than three years) to medium (three to 10 years) term.

In 20 years, the state of lighting technologies and markets may well be considerably different than that described in the Lighting Vision and the Technology Roadmap. Yet to the extent that their work inspires increased innovation, risk-taking, investment, and collaboration in the industry, the lighting manufacturers and professionals who developed this vision and roadmap will have helped to shape that future.



From the cave dwellers through much of the 19th century, humans had to rely on fire to extend the light of the day. Thomas Edison's 1879 invention of the carbon-filament lamp and its electric supply system changed everything. Steady advances in lamps, ballasts, fixtures, controls, and other lighting technologies made electric lighting progressively more affordable, available, and convenient throughout the 20th century.

INTRODUCTION

Lighting accounts for nearly one-sixth (approximately $40 billion) of the total annual electricity use in the United States.[1] Advances in lighting, particularly the use of high-efficiency lighting sources, have the potential to reduce U.S. electricity bills by billions of dollars annually and to reduce emissions of carbon dioxide and air pollutants into our environment.

[1] Energy Information Administration, Annual Energy Outlook 2000

A BROADLY REPRESENTATIVE INITIATIVE

Leaders from across the lighting industry—together with the academic and research communities—have developed *Vision 2020: The Lighting Technology Roadmap.* This industry-defined public document charts a future course for lighting that can meet the demands of tomorrow's commercial buildings and the needs of the people who design, build, own, and occupy them.

The Technology Roadmap is intended to provide clear guidance to both the government and private sector in planning future investments and initiatives. One aim: to accelerate the development of new lighting technology solutions and business practices to meet the challenges of today's and tomorrow's commercial buildings.

The roadmap will serve as a resource for government to use in appropriately aligning its activities with industry priorities and as a framework for cooperative initiatives between industry and government. Industry associations will be able to use the roadmap to develop communications materials and target key market transformation activities. Additionally, private companies may use the roadmap to identify priority funding for projects and products that will contribute to achieving the Lighting Vision.

Above all, the roadmap serves as the starting point for future-focused dialogue among lighting industry leaders, researchers, and government. Continued collaboration—including periodic updating of the vision and roadmap—will be key to realizing the Lighting Vision.

STEPS IN THE ROADMAP DEVELOPMENT PROCESS

LIGHTING EXECUTIVE FORUM (VISIONING WORKSHOP)

When and where:	September 1998 at the Robert L. Preger Intelligent Workplace, Carnegie Mellon University, Pittsburgh, Pennsylvania
Who participated:	20 top executives from all sectors of the lighting industry
Challenge:	Explore the vast possibilities for improved lighting technologies, practices, and markets in the next 20 years
Results included:	First draft of the Lighting Vision statement and "big picture" goals for the industry

ROADMAPPING WORKSHOP I

When and where:	December 1998 in Tucson, Arizona
Who participated:	More than 60 lighting industry stakeholders
Challenge:	Identify potential market and technology barriers to the Lighting Vision, and brainstorm ways to overcome the barriers
Results included:	Final version of the Lighting Vision statement and definition of 190 possible market transformation activities

ROADMAPPING WORKSHOP II

When and where:	July 1999 at the Battelle Breakthrough Center, Columbus, Ohio
Who participated:	A dozen experts representing lighting and building-related disciplines
Challenge:	Identify forms, functions, and specific technologies that extend from what is known today to the imaginable of the envisioned future (2020 timeframe)
Results included:	Specific technical attributes and capabilities that lighting systems will need over the next 20 years

VOTING ON PRIORITIES

Via the Internet, 201 stakeholders of the lighting industry voted on which of the market-transformation activities and future attributes of lighting technologies can have the greatest impact on achieving the Lighting Vision. These voters represented a broad cross-section of the lighting industry, including manufacturers (37%), lighting designers (20%), engineers (11%), government (6%), architects (4%), manufacturers' representatives (4%), nonprofits (4%), suppliers (1%), and other stakeholders (13%). Voting results formed the basis for the strategies and high-priority actions defined in this Technology Roadmap.

VISION AND DRIVERS

"This Roadmap will create a common point of clarity and direction, and through this effort we can, by example, become the agents of change for the entire construction industry."

— Dennis W. Clough
Team Leader
Vision 2020: The Lighting Technology Roadmap

VISION 2020: THE LIGHTING INDUSTRY VISION

While the future of lighting depends, in large part, on developments no one can predict, significant market and technology trends are already in evidence. The developers of the Lighting Vision explored these trends and their implications for lighting, and crafted a vision that can create new opportunities for lighting based on these trends.

On the **marketplace** side, developers of the Lighting Vision foresee growing demand for advanced lighting systems by **businesses, building owners and managers, and end users:**

- In **businesses,** advanced lighting will support **the relentless drive to increase productivity and value-creation, and to reduce costs.** Tomorrow's lighting will respond to the significant changes now under way in the nature of work and, in turn, in commercial building design and management. For example, lighting of the future will enable more effective use of space for multitasking, so businesses can adapt workplaces currently designed for individualized, manual, and paper-based operations into an environment that promotes teamwork, shared resources, and electronic processes. In the future, high-quality lighting systems increasingly will be valued for their ability to improve employee productivity, employee retention, and quality control, particularly as work becomes ever-more dependent on information access and interconnectivity. Businesses and individuals also will gain greater understanding of how advanced lighting solutions can improve health, safety, and security in the workplace, as well as yield significant bottom-line savings by reducing energy consumption.
- Advances in lighting will help answer the needs of **building owners and managers for the highest possible return on capital investments.** Efficient, intelligent lighting systems—especially those networked in a "whole buildings" context with other building systems—will enable managers to exercise greater levels of control over building functions, minimizing operations, maintenance, and energy costs. More important, advanced lighting

VISION STATEMENT

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- Use all sources of light efficiently and effectively
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- Create minimal impacts on the environment during their manufacturing, installation, maintenance, operations, and disposal

As a result, people will understand, value, and utilize the tangible, personal benefits provided by these lighting systems.

will provide the high-performance, aesthetically pleasing environments that increasingly will be demanded by tenants, and will help owners manage properties to their greatest economic potential.

- In the **consumer market,** advanced lighting will help fulfill our **appetite for comfort, convenience, and instant information and connectivity.** Whether at work or at play, as consumers we will demand an increased level of personalized control over the function and aesthetics of our lighting. Sensors and controls in future lighting systems will provide us with new levels of information about our environment, and will allow us to shape that environment to enhance our creativity and productivity.

On the **technology** side, the developers of the Lighting Vision anticipate a flood of scientific and technology developments that will make lighting **an increasingly more effective, efficient, and dynamically responsive contributor to our built environments.** Advanced lighting systems will exploit the capabilities of more powerful and cost-effective sensors and controls, wireless connectivity, high-efficiency light sources, breakthroughs in biotechnology and chemistry, innovative high-performance materials, sophisticated systems integration and modeling capabilities, and many other new and emerging technologies. Lighting design will increasingly be done in an integrated, "whole buildings" context that optimizes human-made and natural systems (such as daylight) to provide efficient, high-quality lighting, heating, cooling, ventilation, and information exchange. Greater emphasis on ongoing education for lighting professionals, as well as outreach to consumers, will be needed to maximize the value and opportunities afforded by fast-changing technologies.

Good lighting contributes to the productivity of businesses, the health and well-being of individuals, and the energy efficiency of buildings.

"The results of this effort will offer major benefits to both our industry and the workplace."
— William J. McCarron
Vice President of Marketing
Siemens Energy & Automation, Inc.

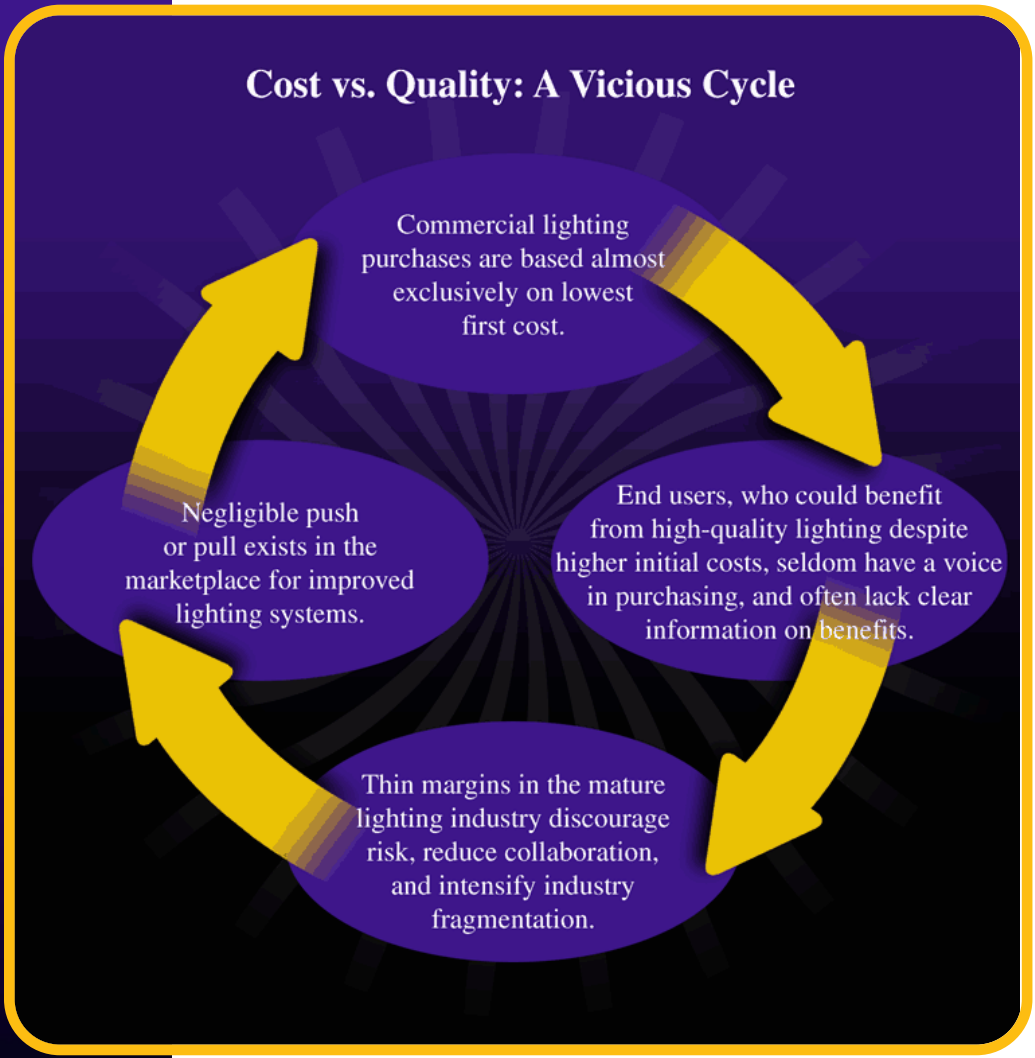
BARRIERS

The speed of technology development and product innovation in lighting is exceptionally slow when compared with that in other industries. Emphasis on low-first-cost in lighting purchases, and in commercial construction purchases in general, contributes to a "vicious cycle" that slows the development and adoption of improved lighting solutions.

MARKET-RELATED AND TECHNOLOGY BARRIERS

In the Lighting Vision, lighting professionals have articulated a bold view of their industry's future over the next 20 years. Significant challenges lie ahead in making this vision a reality.

One set of challenges will require **market transformation,** to build demand for advanced lighting products and systems and to gain a deeper understanding of how consumers and purchasers will value new lighting capabilities. Another set of challenges are technical, requiring increased levels of **investment in science and technology,** including basic and applied research, product development, and demonstrations.



MARKET TRANSFORMATION CHALLENGES

A major factor threatening timely realization of the Lighting Vision is the traditionally low rate of technology development and product innovation in the lighting and building industries.

In any industry, new products gain market acceptance over time by demonstrating a value superior to that of competing products. Yet product cycles have been exceptionally long in the lighting industry. The commercial building marketplace, in particular, has been slow to accept new lighting products and technologies, and the building industry has invested considerably less than most other industries in research, development, and demonstration. A study done in 1994, for example, found that U.S. private investment in construction research and development was only 0.5 percent of sales, while the rate of private investment for U.S. industry as a whole was 3.5 percent.

One result of these long product cycles can be seen in the catalogs of today's lamp manufacturers. A typical manufacturer's catalog may carry 3,000 products, many of which have been available for decades.

Today, there is negligible demand for innovation in commercial lighting, a situation that is worsened by the unusually complex distribution channel serving the construction industry (see illustration, page 11).

Lighting systems are often purchased by a general or electrical contractor on behalf of the building owner or manager. While their purchases may be influenced by the recommendations of an architect or lighting specifier, most contractors put an overriding focus on **low-first-cost lighting.** Indeed, contractors may often "value-engineer" lighting, finding lower-cost options to substitute for the equipment selected by the architect or lighting specifier. The end user typically has little or no voice in lighting selection and often lacks awareness of the options available. In fact, an end user who seeks out information is likely to get conflicting recommendations from advisors in different parts of the distribution channel.

Because of the market focus on low-first-cost solutions, lighting equipment manufacturers are often pitted against each other to supply the least expensive system that will pass standards set by the installer, rather than the end user. As a result, lighting profit margins are increasingly constrained, limiting the industry's ability to invest in technology and product development. Further, since new products are accepted very slowly, production volumes of high-quality lighting solutions often remain below the critical mass needed to achieve economies of scale. As a result, high-quality lighting products stay pegged in high-priced niches, even though their market benefits and applications are potentially very broad.

In short, innovation in the commercial lighting marketplace is being neither strongly pulled by customer demand nor strongly pushed by industry investment. Transforming the dynamics of this marketplace—moving away from low-first-cost decisions to valuations based on life-cycle benefits—will be critical to achieving the Lighting Vision.

The overriding market-related barrier to the Lighting Vision is the **lack of a strong business case for advanced lighting** that can drive end-user demand. Many case studies point to the advantages of high-quality lighting in improving productivity, employee retention, error-reduction, and workplace safety; in attracting retail customers and improving retail sales; and in reducing energy consumption and other operating and maintenance costs. Yet these benefits have not yet been adequately documented, measured, and communicated to make a compelling case to tenants and building owners. Tenants and building owners will be key in driving demand for higher-quality lighting, where life-cycle returns justify the greater initial cost of their purchase and installation. Architects, lighting specifiers, lighting manufacturers, and industry trade associations all will have pivotal roles in demonstrating and communicating these life-cycle benefits, and many will require ongoing education on advanced lighting technologies and design standards to perform these roles effectively.

BARRIERS

TECHNOLOGY BARRIERS TO OVERCOME

- Lack of standardization in current lighting control technologies and systems
- Need for more sophisticated control capabilities
- Need for better metrics to evaluate the quality and performance of products and technologies
- Lack of effective design tools and practices for integrating lighting into whole building design
- Need for higher-efficiency lighting sources, including reduced-mercury sources
- Need for new ballasts to support advanced lamp technologies
- Need for increased portability and flexibility in luminaires

"Educated and informed end users will drive demand for lighting products that deliver desired features and benefits. Only then will lighting function take precedence over price. Effective use of the Internet and other information channels will be key in this transformation."

— Henry P. Bergson
President
NEMRA

TECHNOLOGY CHALLENGES

The industry participants who crafted the Lighting Vision and Technology Roadmap identified several key trends that will affect commercial activities and buildings and, in turn, impose new demands on lighting technologies.

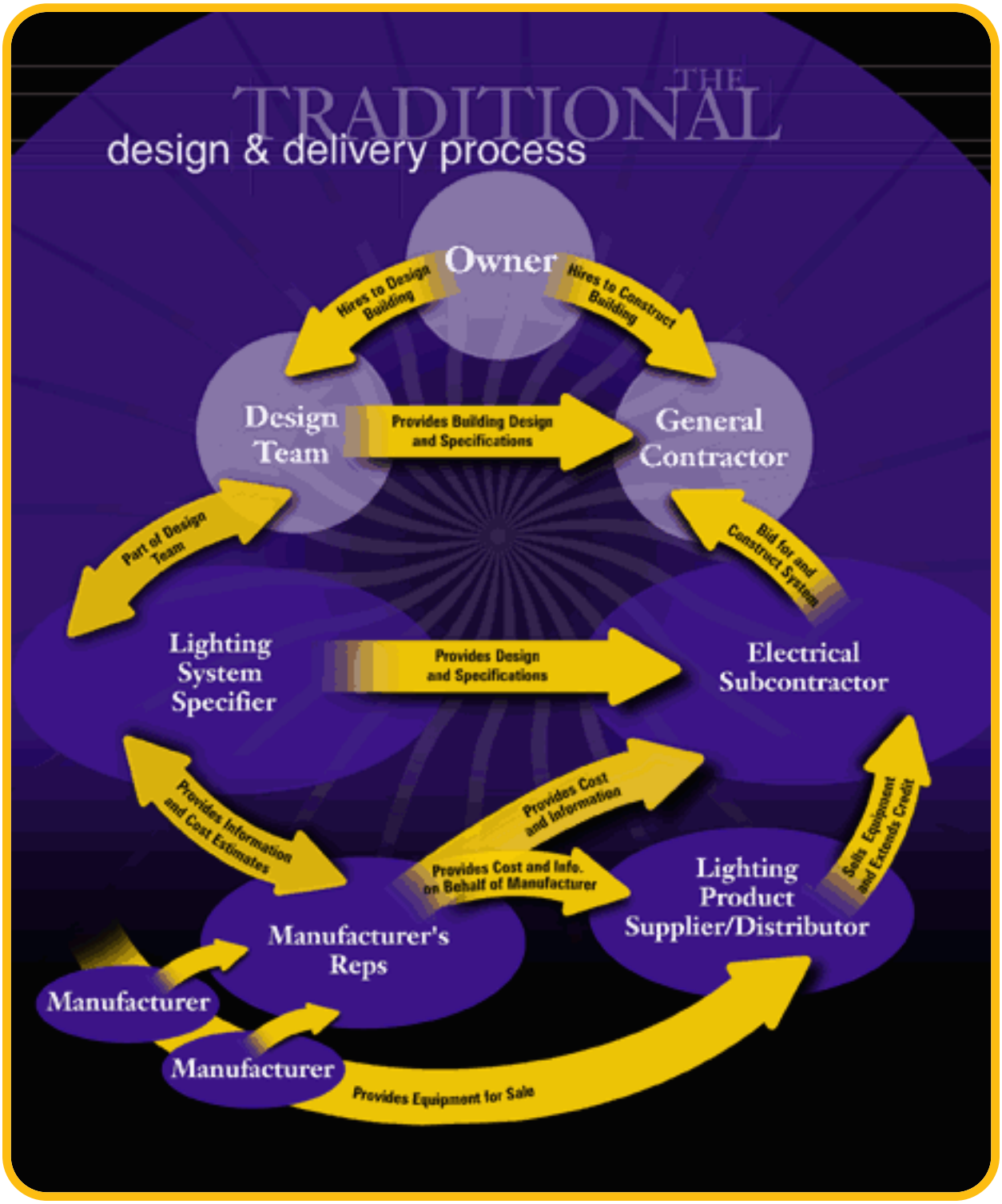
Commercial lighting systems will be challenged to adapt to the changing nature of work, including the increase in paperless, electronic-based tasks; the growing prevalence of team-based activities; and the ongoing reorganization and reconfiguration of many business functions.

Another trend affecting lighting will be the continued drive to enhance human productivity, creativity, and well-being. High-quality lighting that can measurably contribute to workplace productivity is expected to be in growing demand. In addition, there will be increased requirements for lighting systems to function as a fully integrated part of the total commercial building, raising the need for more sophisticated lighting control capabilities and for building design approaches that make optimal use of both natural and human-made systems.

The Technology Roadmap strategies define the attributes of future lighting components and systems that can respond effectively to these trends. Specifically, the strategies identify features and functions of tomorrow's sources and ballasts, lighting controls, and luminaires and systems.

A central challenge for future lighting systems is to allow end-user control of light intensity, color, color temperature, quality, and distribution within the space. Enabling control technologies need to be easy, intuitive, robust, and simple, and must be integrated with interoperable building-level controls.

Commercial lighting purchases are usually made by the general or electrical contractor on a low-first-cost basis, on behalf of the building owner or operator. End users are unaware of the benefits of high-quality lighting solutions, and they have little impact on purchasing decisions. Further, since lighting is one of the last systems to be installed in a building, it may be "value engineered" to help meet total construction budget constraints, even when a higher-quality system is initially specified.


THE TRADITIONAL
design & delivery process
Owner
Hires to Design Building
Hires to Construct Building
Design Team
Provides Building Design and Specifications
General Contractor
Part of Design Team
Bid for and Construct System
Lighting System Specifier
Provides Design and Specifications
Electrical Subcontractor
Provides Information and Cost Estimates
Provides Cost and Information
Provides Cost and Info. on Behalf of Manufacturer
Sells Equipment and Extends Credit
Lighting Product Supplier/Distributor
Manufacturer's Reps
Manufacturer
Manufacturer
Provides Equipment for Sale

STRATEGIES

VOTING PROFILE

A total of 201 lighting stakeholders cast their votes to select the high-priority activities identified in this Technology Roadmap. Voters included:

- Manufacturers (37%)
- Lighting designers (20%)
- Engineers (11%)
- Government (6%)
- Architects (4%)
- Manufacturers' representatives (4%)
- Nonprofits (4%)
- Suppliers (1%)
- Other stakeholders (13%)

Detailed voting results are posted on the *Lighting Technology Roadmap* Web site: www.eren.doe.gov/buildings/vision2020

Achieving the Lighting Vision will require strategies to transform the lighting marketplace, encouraging more purchasers to consider life-cycle benefits as well as low first-cost. Such a change in purchasing decisions will, in turn, create demand for innovative lighting solutions and drive higher levels of investment in lighting research and development.

Specifically, four market transformation strategies and three technology development strategies emerged from the vision and roadmapping process. These strategies are supported by a series of high-priority activities that will directly lead to their fulfillment. Virtually all of these activities and technology capabilities were judged to be achievable in the short (less than three years) to medium (three to 10 years) term.

MARKET TRANSFORMATION STRATEGIES

S Short—Less than 3 years
M Medium—3 to 10 years
L Long—More than 10 years

MARKET TRANSFORMATION

STRATEGY 1—Develop clear definitions and standards for lighting quality

Activity	Timeframe
✔ Develop a uniform set of performance specifications for lighting systems.	S M
✔ Create industry-standard formats for energy and economics data for use across the many available software packages.	M
• Increase enforcement of ASHRAE/IESNA Standard 90.1-1989 and adoption of ASHRAE/IESNA Standard 90.1-1999.	S
• Determine objective definitions and metrics of lighting quality.	S M
• Support and conduct third-party evaluation of integrated lighting system design and application.	S M
• Incorporate requirements for environmental sensitivity for lighting systems (such as daylight use) into the existing code structure.	M

Note: Checkmarks indicate the activities that ranked #1 in their respective category from the internet voting. For detailed voting results for all categories, visit the Lighting Roadmap Web site.

MARKET TRANSFORMATION

STRATEGY 2—Increase demand for high-quality lighting solutions by quantifying, demonstrating, and promoting life-cycle benefits to broad audiences

Activity	Timeframe
✔ Increase scientific knowledge of how lighting parameters impact human psychology, health, and productivity.	M
✔ Maintain nonpartisan lighting centers and laboratories around the country where innovative lighting technologies can be demonstrated.	M
✔ Conduct educational forums for end users about the effects of lighting on people and their activities.	S
• Identify real customer needs through needs assessments and focus groups.	S
• Determine unique lighting characteristics and needs for specific environments (e.g., hospital, retail, office, restaurant).	M
• Use work performance research to help make the marketing of quality lighting more effective, as with ergonomic furniture.	M
• Conduct regional light fairs/expositions to showcase innovative lighting technologies.	S
• Develop a marketing campaign promoting quality lighting to the general public.	S
• Increase use of government buildings to demonstrate innovative technologies.	S M
• Increase publicity on the results of collaborative design and construction projects.	S M

MARKET TRANSFORMATION

STRATEGY 3—Strengthen industry education and credential lighting professionals

Activity	Timeframe
✔ Create educational programs on the design, installation, and use of lighting controls.	S
✔ Improved education on daylighting, including simple rules of thumb for architects.	S
• Provide training to product sales and distribution professionals about life-cycle cost analysis and the effects of lighting on people.	S
• Increase incorporation of NCQLP and CLMC certification requirements into Request for Proposal and Request for Quote language for building construction projects and energy-saving performance contracts.	S
• Establish design assistance teams to teach others how to better integrate lighting into overall building design and how to maximize daylighting.	S M
• Increase use of the Internet to provide information on research, demonstration, and regulatory activities.	S

S Short—Less than 3 years
M Medium—3 to 10 years
L Long—More than 10 years

MARKET TRANSFORMATION

STRATEGY 4—Accelerate the market penetration of advanced lighting technologies and systems, by providing incentives for R&D and reducing barriers inherent in today's specification and distribution methods

Activity	Timeframe
✔ Continue to develop rebate programs, coupled with public information programs, to transform the market for energy-efficient technologies.	S
• Encourage manufacturers to develop new innovative and energy-efficient technologies through public/private programs.	S M
• Create new Federal and State tax investment credits that encourage manufacturers and others to increase funding for lighting research.	M
• Create supplemental construction project funding for the purchase of innovative lighting products (through government or manufacturer efforts).	S M
• Lobby Congress to allow longer-term funding commitments, rather than annual funding, for fundamental research programs.	M
• Host stakeholder roundtables, focusing on distribution channels and other issues affecting technology market penetration.	S M

Note: Checkmarks indicate the activities that ranked #1 in their respective category from the internet voting. For detailed voting results for all categories, visit the Lighting Roadmap Web site.

"Like fresh air and clean water, good lighting adds much to the quality of life but is taken for granted. The Vision 2020 program will help to raise awareness of the importance of good lighting."

— Ron Lewis
Director of Information Resources
Lighting Corporation of America
Chairman, NEMA Lighting Systems Division

TECHNOLOGY DEVELOPMENT

STRATEGY 5—Develop advanced source and ballast technologies that enhance quality, efficiency, and cost effectiveness

Attribute/Capability	Timeframe
✔ Achieve dimmability that still maintains energy efficiency, color, and lamp life.	S M
✔ Extend lamp life (less turnover).	M
✔ Develop low-cost electronic ballasts for compact fluorescent lamps (CFLs).	S
✔ Develop point source for optical fibers and pipes (high efficiency).	S M
✔ Create advanced solid-state structures such as LEDs, LEPs, and ceramics.	M
• Maintain color throughout lamp life and from lamp to lamp.	M
• Increase efficacy: greater than 100 lumens per watt at high CRI (*80 CRI).	M
• For fluorescent lamps, develop two-photon phosphor technologies with efficiencies approaching 200 lumens per watt with CRI greater than 90.	M L
• For incandescent lamps, improve IR films to increase efficiency (50 to 100+ lumens per watt).	M
• For incandescent lamps, improve efficiency of incandescing filaments by increasing the emissivity in the visible range (+10% to 15% efficacy) and increasing the temperature capabilities of these new materials (+25% to 30% efficacy).	M
• For incandescent lamps, develop low-cost coatings to increase efficiencies from the current level of 20 lumens per watt to 30 lumens per watt.	M
• Develop improved design tools that incorporate daylighting concepts.	S M
• Develop toxic-free lamps and ballasts.	M
• Develop electrodeless metal halide technology, replacing mercury with xenon.	M
• Develop new geometrical optics, efficient packaging, and efficient light distribution systems.	M
• Create area sources (thin, flat panels).	M
• Redesign ballasts and conduct materials research to solve the lumen depreciation/color shift problem that accompanies electrode degradation.	M
• Develop new phosphor materials, electrode materials, and advanced ballast designs to produce gas discharges with quantum efficiencies greater than 1.5.	M
• Develop universal ballasts.	S M

S Short—Less than 3 years
M Medium—3 to 10 years
L Long—More than 10 years

TECHNOLOGY DEVELOPMENT

STRATEGY 6—Develop lighting controls with high levels of intelligence, interface capabilities, multiple levels of control, and ease of configuration

Attribute/Capability	Timeframe
✔ Enable easy installation (e.g., self-configuring and friendly to non-experts).	S
✔ Develop controls that are self-teaching, intuitive, easy to use.	S
✔ Develop universal control and communication protocols for component interconnection (such as BACnet or Echelon).	M
• Create a dialogue with energy management companies and lighting control industry in an effort to develop simple, easy-to-use controls.	S M
• Incorporate anticipatory logic so systems learn and adapt to user preference.	M
• Sense multiple inputs to configure and define lighting environments to user (color, room temperature, user temperature, user mood, eyesight of user, occupancy of room, motion, activity type, time of day, daylight levels).	M L
• Allow ease of programming by time of day and date.	S
• Improve robustness (e.g., non-volatile memory).	S M
• Establish interactive linkage between the lighting, HVAC, and other system controls.	M
• Provide some control at building level (range of levels, override).	S
• Develop a universal building interface (remote control and monitoring) for load shedding, optimization of lighting/heat, preventive maintenance.	M
• For public spaces, develop control systems that accommodate multiple uses of the space.	S
• Develop control systems that serve emergency-response needs.	S
• Develop control systems that monitor status of settings.	S

Note: Checkmarks indicate the activities that ranked #1 in their respective category from the internet voting. For detailed voting results for all categories, visit the Lighting Roadmap Web site.

TECHNOLOGY DEVELOPMENT

STRATEGY 7—Develop luminaires and systems that enhance the quality and flexibility of light delivery

Attribute/Capability	Timeframe
✔ Develop and utilize compatibility protocol to support "plug and play" (software and hardware).	M
✔ Utilize positioning and control to allow more effective task lighting.	S
✔ Develop combined light source/reflector panel.	M
• Achieve increased/variable reflectivity.	M
• Develop materials that support multiple functions (e.g., reflect light and absorb sound).	M
• Develop configurable reflectors.	M
• Enable users to easily adjust quantity and direction of light from set location (e.g., adjustable louvers, configurable reflector/diffuser).	M
• Develop smart fixtures that communicate with the control system, have intuitive learning capabilities, and perform diagnostics to enable preventive maintenance.	M
• Develop expressive lighting that enhances psychological well-being.	S M
• Achieve foolproof installation and simplified operations.	S M
• Develop systems that capture daylight for later transmission and distribution.	M
• Support easy movement of fixtures within a space.	S

NEXT STEPS

A GLIMPSE OF THE (TECHNICALLY POSSIBLE) FUTURE

By 2003… Lighting systems will exhibit increased flexibility, using a single universal protocol for component interconnection. System controls will learn and adapt to user preferences, ultimately becoming capable of anticipating user needs. Controls will be robust, easily upgradable, and easily commissioned. Lighting sources will have increased dimming abilities, and a specialized reduced-mercury metal halide source will come to the market. Luminaires will be easy to relocate in the workspace through "plug-and-play" technology.

By 2010… Lighting systems will have capabilities unlike anything before. Luminaires will become smarter and more integrated, communicating with the control system, performing self-diagnostics, and enabling preventive maintenance. New materials will make reflectors configurable and more integrated with the light source. Microelectronics will show up in smaller, more flexible ballasts, and sensors will provide multiple inputs to define the lighting environment for users. Controls will work with the larger building management system to optimize use of daylighting, thermal load management, preventive maintenance, and demand load shedding. Highly efficient long-life sources, including solid-state LEDs and organic light-emitting polymers, will become available in the market. Fluorescent sources will reach efficiencies approaching 200 lumens per watt while maintaining a high color rendition index through the use of new two-photon phosphor coatings. Universal ballasts will increase flexibility of the systems, and low-cost electronic ballasts will make compact fluorescent lamps as common in America's homes as they are in the workplace.

By 2020… Design of building systems will optimally combine both natural and human-made systems to shape the indoor climate. Technology will be available to capture daylight for later transmission and distribution. Programmable flat-panel luminaires will create theatrical effects that are currently unknown. The attributes of this light will be manipulated by advanced control systems. Highly efficient, reduced-mercury fluorescent sources will come to market, while incandescent lamps will see new life through advanced materials that will raise their efficiency to 60 lumens per watt.

Vision 2020: The Lighting Technology Roadmap outlines a view of where the lighting industry is today, a vision of where its stakeholders want to go tomorrow, and strategies on how to get there. It provides guidance to both government and industry on the direction of future activities. It offers a framework for greater collaboration across the industry in creating new market opportunities and innovative technologies, and provides guidance for the Department of Energy and other agencies in planning their activities and in forming research and development partnerships with industry.

The Technology Roadmap intentionally excludes detailed implementation approaches. These will be jointly developed between government and industry as the Technology Roadmap's strategies are analyzed and enriched. One early step in the implementation phase will be to investigate existing efforts already under way and determine how these might be leveraged to further the Lighting Vision and to avoid duplication of efforts.

Feedback on the Technology Roadmap is welcome. In particular, the sponsoring organizations would welcome inputs on which of the identified activities most directly relate to your organization's goals and needs, and whether a respresentative of your organization would want to become an active participant in implementing these activities. To become involved in the implementation process, contact the sponsoring association of which you're a member, or contact:

U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, DC 20585-0121
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ACKNOWLEDGEMENTS

A NOTE FROM…

Dennis W. Clough, Team Leader
Vision 2020: The Lighting Technology Roadmap

As the Department of Energy's Team Leader for the development of *Vision 2020: The Lighting Technology Roadmap,* I have met and worked with literally hundreds of lighting professionals. Each of them has helped me better understand the many facets and intricacies of the lighting industry. These professionals have contributed to a process whose result will serve the government and industry for many years to come.

I would like to recognize three people especially:

Norm Grimshaw, Vice President of Technical Relations for Advance Transformer Company, spent many hours with me to ensure I understood the "real world" complexities of the industry. He has also been one of the Lighting Roadmap's most vocal and active advocates, consistently encouraging his colleagues and peers to engage in this important process.

Carol Jones, Senior Research Scientist with Pacific Northwest National Laboratory, introduced me to many of the industry's key players early in the roadmapping process, which helped make our Executive Forum, and ultimately the entire process, a success.

Ron Lewis, Director of Information Resources for Lighting Corporation of America and Chair of NEMA's Lighting Systems Division, has been the model change agent for his industry. His forethought, insight, and integrative abilities moved this process to a level that would have been unattainable without him.

Thank you so much for your help and guidance.

I would like to thank **Battelle, Public Solutions, Inc.,** and **What Box? Communications** for their hard work with our Executive Forum and three roadmapping workshops, and thanks to **Energetics, Inc.,** and **Brandegee, Inc.,** for their support in the development, writing, and design of *Vision 2020: The Lighting Technology Roadmap.*

I would also like to thank the eight sponsoring professional associations, which helped us to get a wide representation of the entire industry engaged in this process. And finally, thank you to the 170 companies and organizations that actively participated in the development of the technology roadmap:

Available Light
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Advanced Lighting Technologies
Alamo Lighting
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Armstrong World Industries
Auerbach & Glasgow
AVCA Corporation
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Battelle/Pacific Northwest National Laboratory
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Belfer Lighting Company
Benya Lighting Design
Bos Lighting Design
Building Acoustics and Lighting Labs
California Energy Commission
California Lighting Sales

(continued on next page)

LIGHTING WEB SITE

For up-to-date information on implementation, refer to the Lighting Roadmap Web site at www.eren.doe.gov/buildings/vision2020

"By focusing commercial, government, and academic groups on common goals, Vision 2020 promises dramatic improvements in a market still quite reliant on the technology of Edison's first electric lamp."

— William Leaman
President
Lightly Expressed Ltd.

(continued)

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Neoray Lighting
New Buildings Institute
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Optika Lighting
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Philips Lighting Company
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DESTINATION EXCITING LIGHTING

VISION 2020

THE LIGHTING TECHNOLOGY ROADMAP

Tomorrow's lighting systems will open the way to more productive, creative, and comfortable built environments.

Find out how industry leaders are mapping the road ahead.

For more information, contact:

Office of Building Technology,
State and Community Programs
U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585-0121
202-586-1510

Call the Energy Efficiency and
Renewable Energy Clearinghouse at:
1-800-DOE-3732

Or visit the Lighting Roadmap Web site at:
www.eren.doe.gov/buildings/vision2020

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