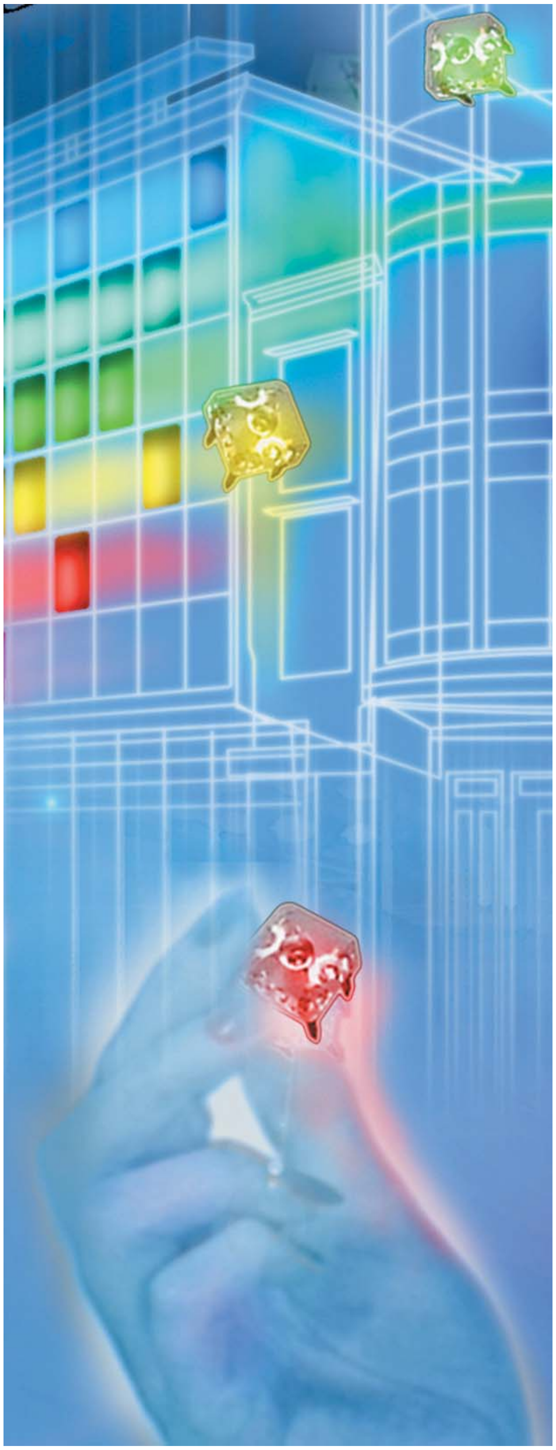

Solid-State Lighting Program Planning Workshop Report

February 3-4, 2005
San Diego, California

Prepared for:

Lighting Research and Development
Building Technologies Program
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

and

National Renewable Energy Laboratory

Prepared by:

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COMMENTS

The Department of Energy is interested in feedback or comments on the materials presented in this Workshop Report. Please write directly to James Brodrick, Lighting R&D Manager:

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EXECUTIVE SUMMARY

The Department of Energy (DOE) held its Second Annual Solid-State Lighting (SSL) Workshop on February 3-4, 2005 to provide a forum for participants to refine and re-prioritize DOE's SSL R&D activities. One hundred seventy participants gathered in San Diego, California to participate in this successful and productive Workshop.

The Workshop had four primary goals: to educate the R&D community on DOE's vision for SSL technology; to update the R&D community on broad-based government funding opportunities related to SSL; to communicate current successes and challenges for SSL from an industry perspective; and to prioritize the SSL R&D tasks to ensure a focused, quality research agenda.

Day 1 of the Workshop included brief presentations from the Department, industry representatives, academics and researchers. Topics covered included a review of the structure of the Department's program and a series of brief presentations on all the projects supported by the DOE. On day 2 of the Workshop, participants split into three sessions, (1) Inorganic Core Technology Research, (2) Inorganic Product Development, and a combined (3) Organic SSL Session looking at both Core Technology Research and Product Development. Each breakout session was asked to evaluate and prioritize their respective research tasks and subtasks. The day consisted of a round of discussion on the structure of the research agenda, followed by a participant voting process to prioritize DOE's R&D activities. Each participant distributed a number of votes among the task and subtasks to identify critical activities for the next one to two years of DOE solicitations. The goal of the overarching task/subtask framework is to identify the R&D agenda over the next ten years.

Table ES-1 lists the five subtasks that received the highest number of votes in the light-emitting diode (LED) Core Technology Research and Product Development Sessions.

Table ES-1: Top Five Priorities- LED Core Technology Research and Product Development

Core Technology Research	Product Development
Subtask 1.1.2 High-efficiency semiconductor materials	Subtask 2.3.1 Optical coupling and modeling
Subtask 1.2.1 Device approaches, structures and systems	Subtask 2.2.1 Manufactured materials
Subtask 1.3.1 Phosphors and conversion materials	Subtask 2.2.2 LED packages and packaging materials
Subtask 1.1.1 Large-area substrates, buffer layers, and wafer research	Subtask 2.3.3 Electronics development
Subtask 1.2.2 Strategies for improved light extraction and manipulation	Subtask 2.3.4 Thermal design

Table ES-2 lists the five subtasks that received the highest number of votes in the organic light-emitting diodes[1] (OLED) Core Technology Research and Product Development Session.

Table ES-2: Top Five Priorities- OLED Core Technology Research and Product Development

Core Technology Research	Product Development
Subtask 3.1.2 High-efficiency, low-voltage, stable materials	Subtask 4.1.2 Between electrodes high-efficiency, low-voltage stable materials
Subtask 3.3.2 Low-cost encapsulation and packaging technology	Subtask 4.2.2 Develop architectures that improve device robustness, increase lifetime and increase efficiency
Subtask 3.2.2 Approaches to OLED structures between the electrodes for improved-performance low-cost white-light devices	Subtask 4.3.1 OLED encapsulation packaging for lighting applications
Subtask 3.2.3 Research on low-cost transparent electrodes	Subtask 4.2.1 Implementing strategies for improved light extraction and manipulation
Subtask 3.4.3 Investigation (theoretical and experimental) of low-cost fabrication and patterning techniques and tools	Subtask 4.1.1 Substrates for electro-active organic materials

For a complete list of voting results and a summary of the discussion in each Session, see Chapter 4.

[1] The Department recognizes that not all organic light-emitting devices are diodes. However, for consistency with industry nomenclature and historical precedent, this report uses the term diode.

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ABBREVIATIONS and ACRONYMS

ALA	American Lighting Association
BT	Building Technologies Program (DOE)
CIE	Commission Internationale de l'Eclairage
CCT	Correlated Color Temperature
CRI	Color Rendering Index
DOE	Department of Energy
EQE	External Quantum Efficiency
IQE	Internal Quantum Efficiency
LED	Light-Emitting Diode
MOA	Memorandum of Agreement
NEMA	National Electrical Manufacturers Association
NGLIA	Next Generation Lighting Industry Alliance
NIST	National Institute of Standards and Technology
OLED	Organic Light-Emitting Diodes
R&D	Research and Development
SSL	Solid-State Lighting

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1. Introduction

On February 3rd and 4th, 2005, the Department of Energy (DOE) held its Second Annual Workshop to shape and prioritize its solid-state lighting (SSL) research activities for the next one to two years. This report provides an overview of the discussion, findings, and outcomes from this consultative Workshop. Held in San Diego, CA the Workshop included 170 technology leaders from industry, universities, trade associations, research institutions, and national laboratories. These participants reviewed and discussed research topics, clarified technological research needs and objectives, and prioritized tasks and subtasks that will form the basis of future DOE solicitations.

In recent decades, U.S. researchers have made significant progress in improving the performance and lowering the cost of light-emitting diodes (LEDs) and organic light-emitting diodes (OLEDs). These advances resulted in the development of niche and emerging applications for SSL technology, such as exit signs, traffic signals and airport runway edge-lights. Just as SSL has evolved to supplant lighting technologies in colored light applications, SSL technology is now positioned to lead a revolution in the general illumination (i.e., white light) market. Government support of medium to longer-term R&D, aimed at improving SSL performance and lowering costs, will accelerate performance improvements and enable energy savings from this efficient technology to be realized sooner.

Chapter 2 of this report outlines the structure of the DOE SSL Research and Development Portfolio, as presented at the workshop. Chapter 3 summarizes the SSL Workshop presentations from day 1 of the meeting. Chapter 4 summarizes the discussion in each breakout session and the results of the updates and prioritization of the SSL R&D agenda. Finally, Chapter 5 presents several upcoming activities for the SSL R&D program.

2. Structure of DOE SSL Research and Development Portfolio

This chapter outlines the structure of the DOE SSL Research and Development Portfolio. Section 2.1 provides an overview of the Department's SSL operational plan and discusses the differences between Core Technology Research and Product Development. Section 2.2 presents a summary of the Department's current SSL R&D project portfolio.

2.1. SSL Operational Plan

The Department's SSL R&D operational plan features two concurrent, interactive pathways: (1) Core Technology Research, primarily involving academia, national laboratories, and research institutions, and (2) Product Development, conducted primarily by industry. Figure 2-1 illustrates this structure, and demonstrates the symbiotic relationship between the two pillars of the operational plan.

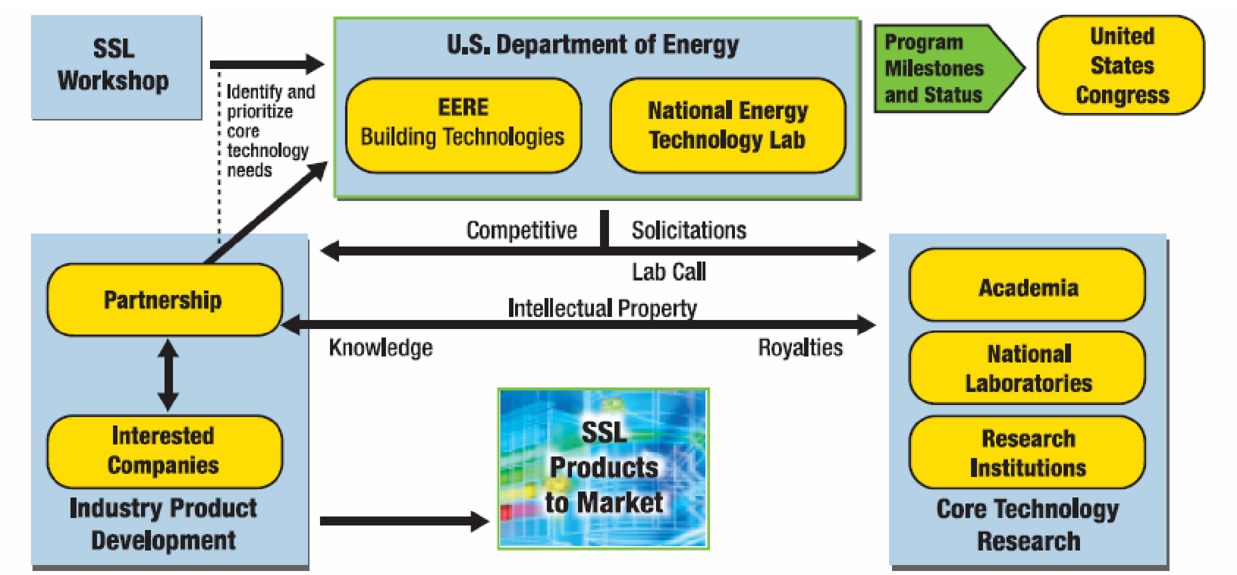

Figure 2-1: Structure of DOE SSL Operational Plan

Crossover of the technical concepts between Product Development projects and Core Technology Research projects does occur. For example, a Product Development project conducted by industry may include focused, short-term applied research, as long as its relevance to a specific product is clearly identified and the industry organization abides by the solicitation provisions. For definitions of Core Technology Research and Product Development, see Appendix C.

The operational structure also includes innovative intellectual property provisions and an SSL Partnership, composed of for-profit corporations, that provides significant input to shape the Core Technology Research priorities.

SSL Partnership — In 2004, DOE competitively selected an SSL Partnership composed of manufacturers and associated companies that are individually or collaboratively capable of manufacturing and marketing SSL products. Partnership members must comply with pertinent DOE guidelines on U.S.-based Research and Product Development. A key function of the SSL

Partnership is to provide input to shape the Core Technology Research priorities. As SSL technologies mature, any research gaps identified will be filled through Core Technology Research—allowing the SSL industry to continue its development process, while much-needed breakthrough technologies are created by the Core Technology Researchers. The Partnership members confer among themselves and communicate their individual research needs to DOE program managers who then translate these needs into the Core Technology Research solicitations.

Core Technology Research — Core Technology Research provides the focused research needed to advance SSL technology—research that is typically longer-term in nature and not the subject of sustained industry investment. DOE funds such research efforts primarily at universities, national laboratories, and other research institutions through one or more competitive solicitations. Core Technology Research supports the SSL program by providing problem solving research to overcome barriers identified by DOE with input from the Workshop and the Partnership. Participants in DOE's Core Technology Research program would conduct research subject to what is termed an "exceptional circumstance" to the Bayh-Dole Act. This means that any resultant intellectual property developed will be open, with negotiated royalties, to all Partnership members with a nonexclusive license. At DOE's discretion, Core Technology Research projects will be peer-reviewed by government personnel, independent organizations, and the SSL Partnership.

Product Development — DOE solicits proposals from interested companies (or teams of companies) for product development and demonstrations. DOE expects these proposals to include comprehensive work plans to develop a specific SSL product or product family. Since the ultimate goal is to manufacture energy-efficient, high performance SSL products, each work plan should address the abilities of each participant or manufacturer throughout the development process. These companies must not only have all the technical requirements to develop the desired SSL technology, but also must have reasonable access to manufacturing capabilities and targeted markets to quickly move their SSL products from the industry laboratory to the marketplace.

Figure 2-2 details the high-level timeline for the SSL Operational Plan. Each year, DOE expects to issue at least three competitive solicitations:

- Core Technology Research Solicitation
- Core Technology to National Labs (Lab Call)
- SSL Product Development Solicitation

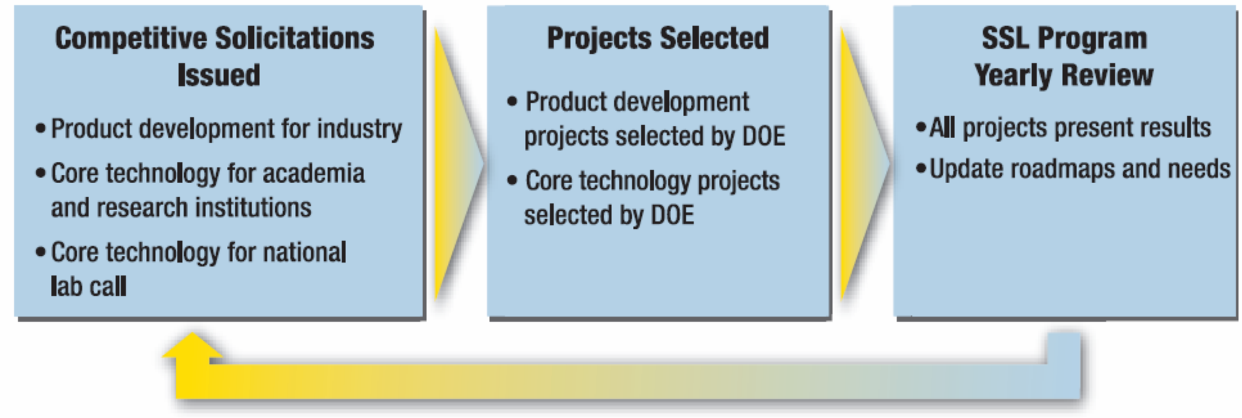

Figure 2-2: SSL Operational Plan Process

A number of annual meetings will be held to provide on-going DOE management and project progress review checks, as well as to keep all interested parties adequately informed. More specifically, these annual meetings will:

- Provide a general review of progress on the individual projects (open meeting)
- Review and update the R&D plan for upcoming "statement of needs" in future solicitations (open meeting)
- At DOE's discretion, provide a review of Core Technology Research projects
- Serve as individual project reviews for DOE on all funded projects

2.2. DOE SSL Project Portfolio

At the Workshop, the Department released its 2005 SSL R&D project portfolio.[2] The portfolio includes forty-two projects, totaling more than $63 million in cumulative government and industry investment. Figure 2-3 provides a graphical breakdown of the funding for the current SSL project portfolio; this value represents cumulative funding levels for projects awarded over the last two to three years. The Department is currently providing $46.8 million in funding for the projects, and the remaining $16.8 million is cost-shared by project awardees. Of the forty-two projects, twenty-three are associated with light-emitting diodes (LED) and nineteen are focused on organic light-emitting diodes (OLED). The OLED project partners contribute slightly more ($10.5 million) than the LED project partners ($6.3 million).

[2] The report, *2005 Project Portfolio: Solid State Lighting*, is available on the Department's SSL web site: http://www.netl.doe.gov/ssl/PDFs/SSL%20Portfolio%202005_2-03.pdf

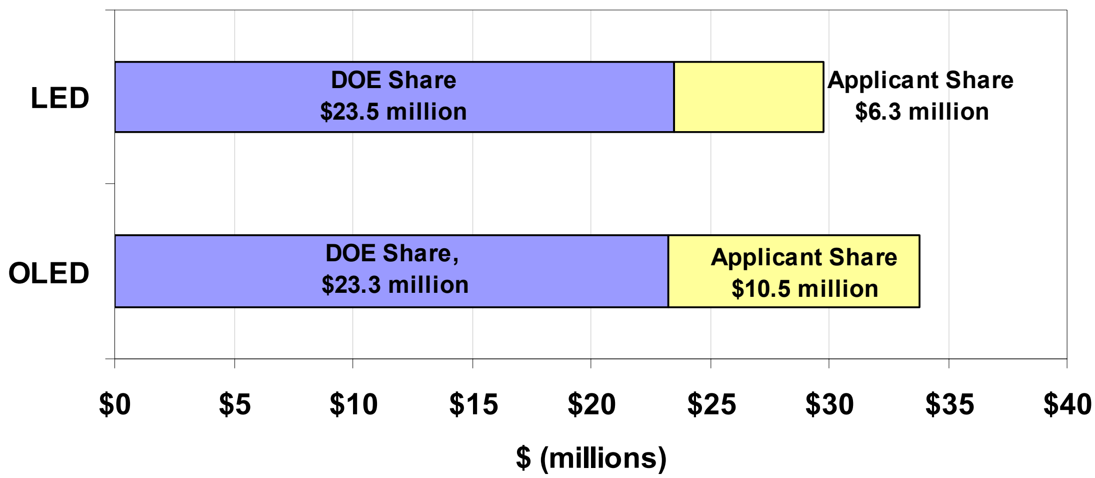

Figure 2-3: Cumulative Funding of DOE Project Portfolio[3]

Figure 2-4 shows the DOE funding sources available to support SSL tasks. As a technology matures, different funding mechanisms are available to support its development, as detailed below. SSL proposals are selected based on such factors as energy savings potential, likelihood of success, and alignment with the SSL R&D plan. The solicitations are typically conducted on an annual basis.

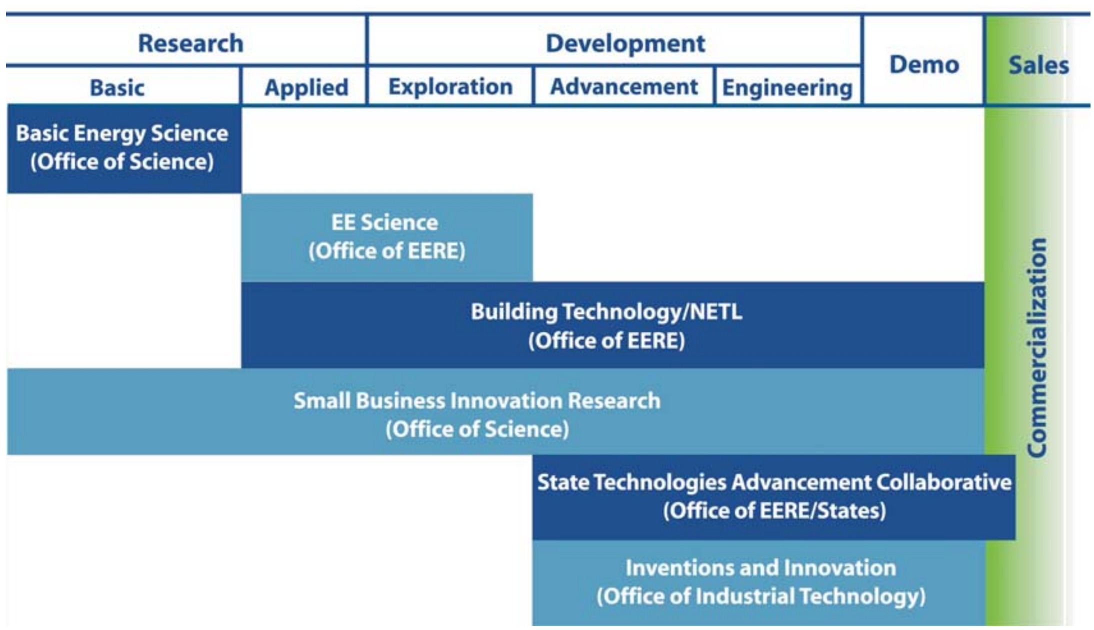

Figure 2-4: Stages of Technical Maturity Mapped to DOE Funded R&D Programs

[3] The total contract value includes DOE funding ($46.8 million) and applicant cost-share ($16.8 million).

Figure 2-5 shows the DOE funding sources and level of support contributing to the SSL project portfolio. The Building Technologies Program/NETL in the Office of Energy Efficiency and Renewable Energy (EERE) provides the majority of the funding; twenty-one projects receive $36.8 million in funding from this source. Approximately 60 percent ($22.2 million) is directed to fund Core Technology Research projects and the remaining 40 percent ($14.6 million) is dedicated to Product Development projects. The Small Business Innovation Research (SBIR) program in the Office of Science funds seventeen projects for a total of $5.5 million. The EE Science program in the Office of EERE provides $4.4 million in funding for four projects.

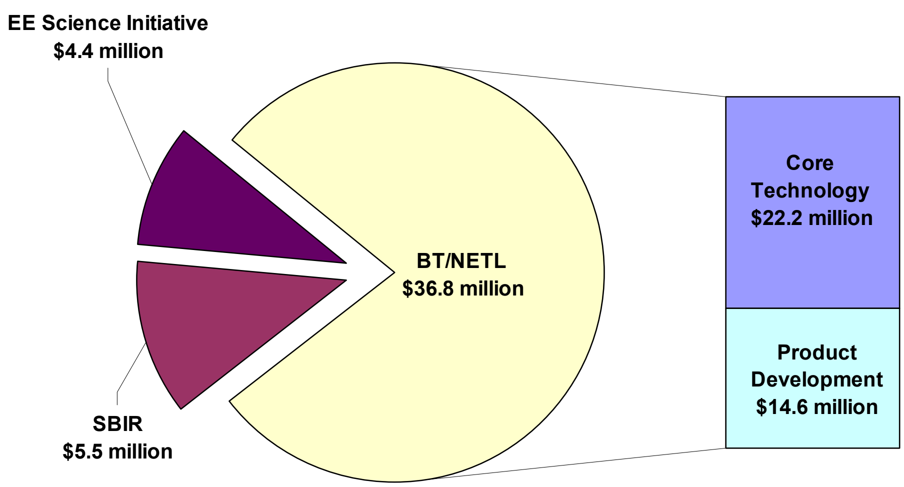

Figure 2-5: Cumulative SSL R&D Project Portfolio: Funding Sources Breakdown

The Department funds SSL R&D in partnership with industry, small business, academia, and national laboratories. Figure 2-6 provides the approximate level of R&D funding contained in the current SSL portfolio among the four general groups of SSL R&D partners. Industry participants receive just over 52% of portfolio funding, with $24.5 million in R&D activities. Academia comprise the next largest category with 22%, or $10.3 million, in research funds. Finally, national laboratories and small businesses comprise 14% and 12% of the R&D portfolio, respectively.

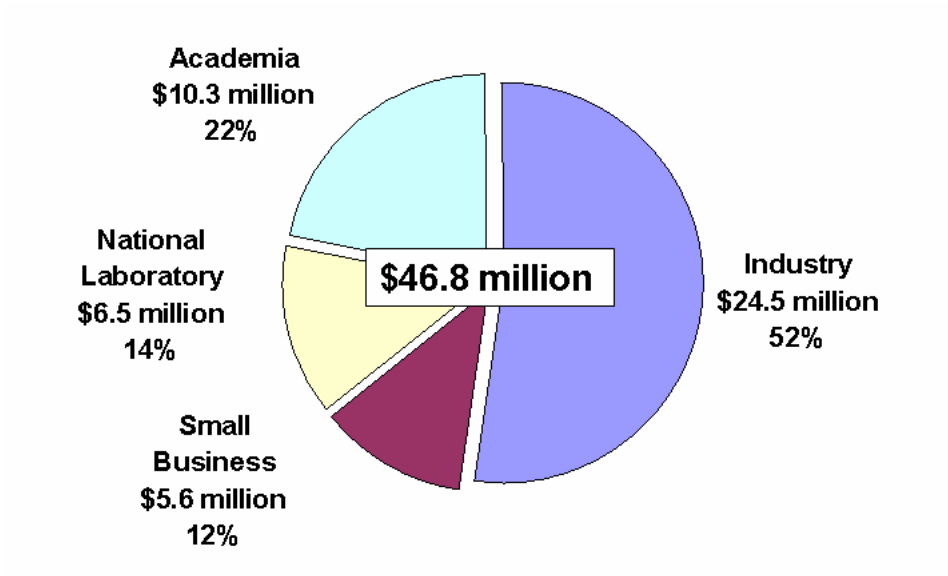

Figure 2-6: 2005 SSL R&D Project Portfolio: Recipients of DOE Funding

Table 2-1 and Table 2-2 show the total number of projects and total-project funding from DOE by research area for the FY04 solicitations. During the first SSL Workshop (November 2003), participants voted these research areas as high priority areas that needed to be developed in order to advance SSL technology toward the goal of general illumination. Table 2-1 shows the projects that received funding under the Core Technology Research solicitations. In the area of LEDs, the six project awardees focused on materials research and phosphor development. In the area of OLEDs, the five project awardees focused on materials research and creating novel design structures to improve performance and lower manufacturing costs.

Table 2-1: SSL R&D Portfolio: Core Technology Awards in FY04

	Number of Projects	Funding ($)
Light-Emitting Diode		
High efficiency visible and near UV (<380nm) semiconductor technology materials for LED-based general illumination technology	5	$4.4 million
Advanced architectures and high power conversion efficiency emitters	0	0
High temperature, efficient, long-life phosphors, luminescent materials for wavelength conversion and encapsulants	1	$2.5 million
Total LED	***6***	***$6.9 million***
Organic Light-Emitting Diodes		
High efficiency, low voltage, stable materials for OLED-based general illumination technology (hosts, dopants, and transport layers)	4	$7.0 million
Strategies for improved light extraction and manipulation	0	0
Novel device structures for improved performance and low cost	1	$2.0 million
Total OLED	***5***	***$9.0 million***
TOTAL	**11**	**$15.9 million**

Table 2-2 shows the projects that received funding under the FY04 Product Development solicitations. In the area of LEDs, the three project awardees focused on luminaire design, materials research and the development of intelligent electronics for SSL. In the area of OLEDs, the two project awardees focused on the development of novel designs and materials.

Table 2-2: SSL R&D Portfolio: Product Development Awards in FY04

	Number of Projects	Funding ($)
Light-Emitting Diode		
SSL luminaire design and materials	2	$2.8 million
High efficiency, reliable, intelligent electronics for SSL	1	$1.6 million
Total LED	***3***	***$4.4 million***
Organic Light-Emitting Diodes		
SSL luminaire design and materials	2	$5.3 million
High efficiency, reliable, intelligent electronics for SSL	0	
Total OLED	***2***	***$5.3 million***
TOTAL	**5**	**$9.7 million**

3. SSL Workshop Presentations

The Workshop had four primary goals: to educate the R&D community on DOE's vision for SSL technology; to update the R&D community on broad-based government funding opportunities related to SSL; to communicate current successes and challenges for SSL from an industry perspective; and to prioritize the SSL R&D tasks to ensure a focused, quality research agenda. All the presentations given at the Workshop are available on the Department's SSL website: http://www.netl.doe.gov/ssl/materials_2005.html

Michael J. McCabe, DOE's Program Manager for Building Technologies, launched the Workshop by welcoming 170 participants to San Diego and emphasizing the significant energy-savings potential of solid-state lighting. His welcome address highlighted the importance of SSL technology in achieving the following mission of DOE's Building Technologies Program:

> *To create technologies and design approaches that enable net zero energy buildings at low incremental cost by 2025. A net zero energy building is a residential or commercial building with greatly reduced needs for energy through efficiency gains, with the balance of energy needs supplied by renewable technologies. These efficiency gains will have application to buildings constructed before 2025 resulting in a substantial reduction in energy use throughout the sector.*

Mr. McCabe commented that "solid-state lighting fits perfectly into the goal statement of the Building Technologies Program." The commercialized efficacy goal of SSL is to reach 160 lumens per watt, which would represent an order of magnitude increase in efficacy over incandescent lamps and a two-fold improvement over fluorescent lamps. He noted that advances in the efficiency of SSL will affect the number of power plants being constructed and the reliability of the grid.

At the end of his address, Mr. McCabe reminded participants of the importance of their role at the Workshop, as the Department will use the participants' input to frame and adjust its priorities and accelerate the focus of its research in the proper direction.

Dr. James R. Brodrick, DOE SSL Program Manager, supported these remarks and presented the Department's mission statement for the SSL R&D portfolio:

> *Guided by a Government-industry partnership, the mission is to create a new, U.S.-led market for high-efficiency, general illumination products through the advancement of semiconductor technologies, to save energy, reduce costs, and enhance the quality of the lighted environment*.

During the first morning, representatives from DOE offices and industry spoke about their involvement in or relationship to DOE's overall SSL R&D portfolio. Summaries of these presentations follow, and web-links to these programs are included in Appendix B of this report.

3.1. DOE Solid-State Lighting Status and Overview, Dr. James Brodrick, Department of Energy

Dr. James Brodrick, provided an overview of the SSL program and the status of current R&D activities.

Dr. Brodrick reminded the audience that one of the Department's main missions is one of energy efficiency. The Department is looking for results and correspondingly will make awards "to those who want to move up the efficiency curve." He presented projections, shown in Figure 3-1, for improvements in the efficacy of SSL lighting for laboratory devices and commercial products.

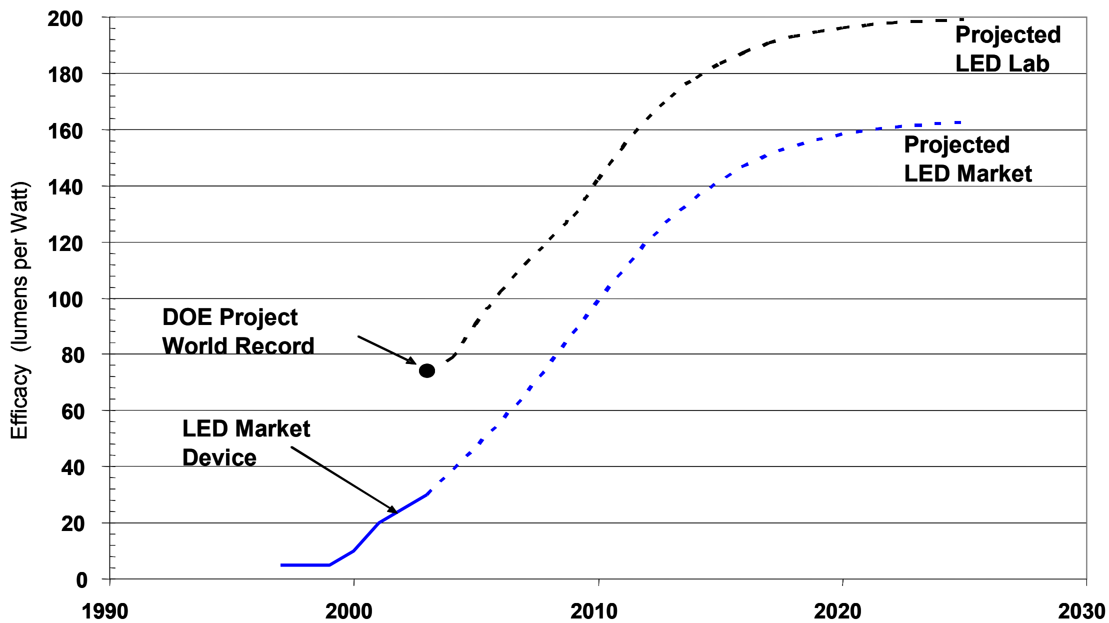

Figure 3-1: White Light Efficacy Targets, Laboratory and Market

In the area of budget and investment, Dr. Brodrick presented the current funding levels for the 2005 SSL R&D Project Portfolio. The portfolio includes forty-two projects, totaling more than $63 million in cumulative government and industry investment. Figure 2-3 provides a graphical breakdown of the funding for the current SSL project portfolio. The Department is currently providing $46.8 million in funding for the projects. Of the forty-two projects, twenty-three are associated with LED R&D and nineteen are focused on OLED R&D. For information on the current SSL R&D portfolio, see Section 2.2 of this report as well as the *2005 Project Portfolio: Solid State Lighting*.[4]

To conclude, Dr. Brodrick provided a sense of upcoming DOE commercialization support activities that will ensure that energy-efficient products reach the marketplace. In conjunction with energy organizations, such as the Next Generation Lighting Industry Alliance (NGLIA), National Electrical Manufacturers Association (NEMA), and American Lighting Association

[4] The report, *2005 Project Portfolio: Solid State Lighting*, is available on the Department's SSL web site: http://www.netl.doe.gov/ssl/PDFs/SSL%20Portfolio%202005_2-03.pdf

(ALA), the Department will use a range of tools at its disposal, including implementing an ENERGY STAR® program for SSL, initiating a design competition for SSL fixtures, encouraging utility promotion programs, and disseminating information to consumers through other marketing activities.

The Department also distributed a handout at the Workshop, titled "Solid State Lighting Program Commercialization Support Pathway" detailing the full range of commercialization support strategies planned by DOE, including (1) partnerships with industry associations, (2) ENERGY STAR® for SSL Technologies, (3) Technology Procurement, (4) Design Competitions, (5) Demonstration and Performance Verification, (6) Technology Tracking and Information Services, (7) Consumer Awareness Programs, (8) Retailer Training Programs, (9) Builder Programs, (10) Designer Programs, (11) Education Programs, (12) Utility Promotion and Incentive Programs, and (13) Federal Programs. For more information on each of these strategies and a copy of this handout, please see Appendix G.

For additional information, contact: Dr. James Brodrick, DOE SSL Program Manager, DOE.SSL.Updates@ee.doe.gov.

3.2. Solid-State Lighting Program: Organization, C. Edward Christy, National Energy Technology Laboratory

Mr. C. Edward Christy from the National Energy Technology Laboratory discussed how the SSL program is organized. As he describes it, the Department's SSL R&D program is structured around two concurrent, interactive pathways: (1) Core Technology Research, conducted primarily by academia, national laboratories, and research institutions, and (2) Product Development, conducted primarily by SSL industry partners. Figure 3-2 illustrates the operational plan structure.

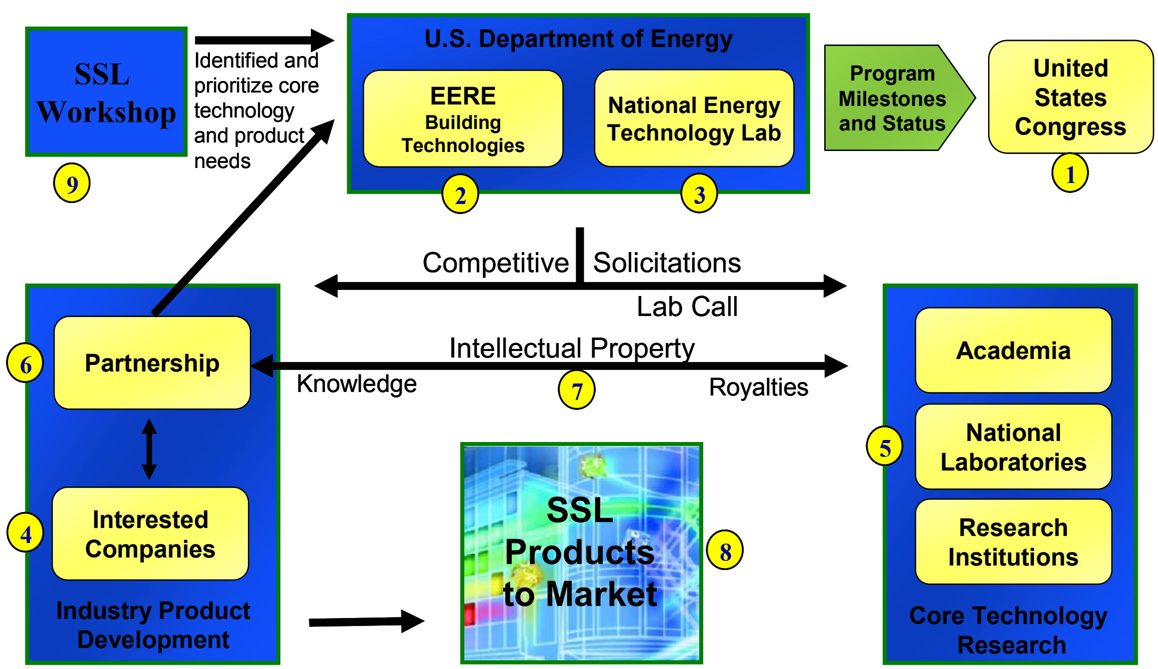

Figure 3-2: Structure of DOE SSL Operational Plan

Mr. Christy outlined the following nine components of the SSL operational plan:

1. United States Congress – Issues appropriations and language that "authorizes" the DOE to perform research and development, and requires reporting on program developments.
2. EERE/Building Technologies – Serves as program lead for activities, performs strategic planning, defines program, and interfaces with Congress.
3. National Energy Technology Laboratory – Develops and issues solicitations, manages selected projects, and reports on project status to DOE HQ.
4. Interested Companies – Submit applications that require a plan describing the development of a marketable SSL product.
5. Core Technology Research – Collection of projects performed by national laboratories (Lab Call) and academic and research institutions. This research focuses on the earlier stages of SSL development (barrier issues).
6. SSL Partnership – Provides input to and prioritization of the Core Technology Research Program's needs (in addition to prioritization that occurs at the annual workshops); provides administrative expertise and staffing to organize and conduct technical meetings and workshops; supports demonstrations of SSL; provides, at DOE's discretion, technical reviews of Core Technology Research projects; and encourages efforts to develop SSL metrics and standards.
7. Intellectual Property – This component ensures energy-efficient technologies are introduced to the market quickly to maximize energy savings benefits to the nation.
8. SSL Products to Market – This component leverages programs that can help raise awareness, improve accessibility, and encourage acceptance of new SSL products introduced into the market.
9. SSL Workshop – The annual stakeholder workshop identifies and prioritizes Core Technology Research and Product Development tasks for the next one to two years. The SSL workshop also provides an opportunity for stakeholders to better understand the Department's SSL program.

For more information on the components of the SSL Operational plan, see Section 2.1.

Mr. Christy concluded by announcing that DOE plans to issue the Lab Call, the solicitation for Core Technology Research, and the solicitation for Product Development during 3Q FY05.

3.3. Solid-State Lighting: Intellectual Property, Paul Gottlieb, Department of Energy

Paul Gottlieb, DOE Assistant General Counsel for Technology Transfer and Intellectual Property, discussed intellectual property issues as they apply to SSL. He outlined DOE's efforts to ensure technology transfer from Core Technology Researchers to Product Developers so that efficient SSL products reach the marketplace.

Mr. Gottlieb reviewed the Bayh-Dole Act, 35 USC 201*,* which established patent rights in new inventions to protect small businesses. The Bayh-Dole Act requires that universities and small businesses operating with federal funding agreements may retain title to new inventions for the purpose of further development and commercialization. The universities and small businesses are then permitted to exclusively license the inventions to other parties. Under Bayh-Dole, new inventions owned by awardees are subject to Government Purpose License, March-in, and US Preference requirements.

The DOE is currently proposing an "exceptional circumstance" to the Bayh-Dole Act. This proposed exceptional circumstance would apply to patented inventions made under government awards in the Core Technology Research Program. Awardees will retain title to their new inventions but must make offers of a nonexclusive license in the field of SSL only to members of the Next Generation Lighting Industry Alliance (NGLIA) for a one-year period after a patent is issued. This exceptional circumstance is to be carried out on reasonable terms of royalty bearing and business plans. It also holds that any entity, including the awardees, licensees, and assignees, having the right to use or sell a new invention worldwide, agree to substantial manufacture in the US of products embodying new inventions, unless substantial manufacture is waived by DOE. The exceptional circumstance to the Bayh-Dole Act is supported by Congress. Further information can be obtained at http://www.gc.doe.gov/gcmain.html

Mr. Gottlieb provided his contact information to attendees and encouraged anyone with questions to contact the Department. Questions should be directed to:

Lisa Jarr, National Energy Technology Laboratory, Intellectual Property Counsel, 304-285-4555
Paul Gottlieb, Department of Energy, Assistant General Counsel for Technology Transfer and Intellectual Property, 202-586-3439 (fax 2805), Paul.Gottlieb@HQ.DOE.GOV

3.4. Next Generation Lighting Industry Alliance, Todd Graves, Next Generation Lighting Industry Alliance

Todd Graves, Vice Chair of the Next Generation Lighting Industry Alliance (NGLIA), provided an overview of the group's origins, membership, purpose, and objectives. The NGLIA is an alliance of for-profit corporations, established to accelerate SSL development and commercialization through government-industry partnership. The NGLIA is currently made up of ten corporations — 3M, GELcore LLC, Eastman Kodak Company, OSRAM Opto Semiconductors Inc., Corning Inc., Cree, Inc., General Electric Company, Philips Electronics North America Corporation, LumiLeds Lighting LLC, and Dow Corning — though they are actively seeking to extend membership to any firms active in SSL R&D. To join the NGLIA or for more information, see the contact information for Kyle Pistor provided at the end of this section.

The NGLIA is administered by NEMA, a national trade association of 400 electrical manufacturers representing $100 billion in domestic shipments. Mr. Graves outlined the NGLIA's purpose, which is to create a forum for communication and collaboration among SSL for-profit corporations. The NGLIA's mission involves public advocacy on issues related to SSL, promotion and support of SSL technology and DOE's research program in SSL, and facilitation of communications among members and other organizations with substantial interest in the NGLIA activities.

Mr. Graves also described the Memorandum of Agreement (MOA) that was signed on February 2, 2005 between DOE and the NGLIA.

Mr. Graves stated that the industry as a whole needs commercially viable access to pre-competitive intellectual property (IP) generated under DOE funding. However, the NGLIA also recognizes the need to give non-profit entities an incentive to develop high impact IP. The NGLIA supports an approach to IP for SSL R&D in which inventors would retain the rights to IP, and the NGLIA members active in SSL would receive priority to negotiate non-exclusive licenses and royalty payments.

To join the NGLIA or for more information, contact: Kyle Pitsor, NEMA, (703) 841-3247, kyl_pistor@nema.org.

3.5. Keynote Presentation: 2nd Annual DOE SSL Workshop, Kevin Dowling, Color Kinetics, and Sheila Kennedy, Kennedy and Violich Architecture

In the keynote address, Kevin Dowling from Color Kinetics and Sheila Kennedy from Kennedy & Violich Architecture highlighted the challenges and opportunities facing SSL researchers and developers, noting that the potential forms and functions for SSL technology are not yet fully known.

Sheila Kennedy examined the history of lighting and the electrical infrastructure, noting how the form factors of light sources have changed over time. She explained that the challenge of how to implement a novel lighting technology is not a new one (e.g. gas lighting, Edison's electric lamp), noting that "history doesn't repeat itself, but it does rhyme." For instance, Thomas Edison not only pioneered commercialization of the incandescent lamp, but he also created a market for electric lighting. Similar to SSL researchers and developers today, Edison was fighting against technologies that were cheaper and brighter (e.g., arc lamp, gas lamp), with the additional burden of a higher cost of electricity (for the 1880's and 1890's). Throughout the history of lighting, innovators have faced issues similar to ones SSL developers face today. Perhaps, through the example of these former lessons, SSL researchers and developers may navigate these challenges with greater ease, Kennedy noted.

Kevin Dowling emphasized the impact that SSL could have on the lighting industry. Designers can have electronic control over the source and the ability to tailor the lighting spectrum automatically. SSL sources may be scaled in size so that they are practically invisible. This type of technology enables designers to have temporal and spatial control and to create imagery that is not obvious. Kennedy and Dowling suggested appropriate near term applications for SSL, including the exterior of buildings or bridges. Eventually, this technology will move to the interior of buildings to provide general illumination.

They also emphasized the danger of allowing previous technologies to set future expectations. The speakers cautioned against the promulgation of interim SSL solutions that are meant as replacements for conventional technologies. These products, such as LED replacements for the A-19 lamp, have poor thermal properties, light output and light quality. The keynote speakers concluded by asking the audience to rethink SSL as a novel light source and not just as a replacement form.

3.6. Complexities of Color, Dr. Wendy Davis, National Institute of Standards and Technology

During lunchtime on Day 1 of the Workshop, Dr. Wendy Davis from NIST presented the "Complexities of Color," exploring the impact of human factors.

Dr. Davis explained that people see the same objects differently, due to differences across the population caused by age or genetics. Situational variables, such as hue, luminance, chromatic saturation, and chromatic adaptation also affect how people perceive colors.

SSL developers currently assess color rendering quality using the Color Rendering Index (CRI). CRI indicates how well a test source renders eight standard colors of intermediate saturation, when compared to a reference lamp of the same color temperature. However, there are several problems with this metric. Dr. Davis explained that the CRI uses an outdated color space and chromatic adaptation correction formulas, and negates the effect of color temperature.

Dr. Davis presented the results of her work focused on improving the CRI index. Together with Dr. Yoshi Ohno of NIST, she is updating the reflective samples used to calculate CRI. Currently, CRI is calculated using eight Munsell samples; however, these sample colors are low to moderately saturated. NIST is proposing to replace these samples with fifteen new samples of highly saturated colors. These reference samples result in a calculated CRI value that is postulated to be a much better indicator of color quality.

Other work underway at NIST in this area includes: using the updated color space (CIELAB), using the updated chromatic adaptation correction formula (probably Bradford transform), calculating differences so that increases in saturation do not lower CRI scores, and addressing the use of referents matched in CCT.

For additional information, contact: Dr. Wendy Davis, wendy.davis@nist.gov or Dr. Yoshi Ohno, ohno@nist.gov.

3.7. Presentations on SSL Projects in the DOE R&D Portfolio

Day 1 of the Workshop also included brief presentations on current DOE-funded SSL projects. Presenters for each of the current projects provided an overview of the project team, R&D objectives, project elements, and technology. These presentations provided attendees with a snapshot of DOE's current project portfolio and provided a useful reference point for the Day 2 discussion and prioritization for future R&D task areas. The presentations were run in two concurrent sessions – one consisting of all the LED Project Reports (23 projects) and another for OLED Project Reports (19 projects).

To see an overview of all currently DOE-funded R&D projects related to solid-state lighting including a brief description, partners, the funding level, and the proposed timeframe, see the *2005 Project Portfolio: Solid-State Lighting*.[5]

[5] The report, *2005 Project Portfolio: Solid State Lighting*, is available on the Department's SSL web site: http://www.netl.doe.gov/ssl/PDFs/SSL%20Portfolio%202005_2-03.pdf

4. SSL Workshop Day Two – Breakout Group Discussions

The balance of the Workshop focused on defining the individual R&D program tasks and establishing priorities. The Department's approach for engaging participants in the prioritization process proceeded as follows:

Figure 4-1: Linear Representation of SSL R&D Tasks Discussion and Prioritization

The Department distributed an initial list of research topics, tasks and subtasks based on the output from the November 2003 Workshop and road-mapping activities (see Appendix D for the original list). Prior to the Workshop, the Department invited review and comment on the SSL R&D agenda tasks and subtasks. The Department asked participants to review these task and subtasks, and to consider the following questions:

> <u>Question 1</u>: Do you agree with each task and subtask as written? If not, provide a proposed rewording, using the same outline format.
>
> <u>Question 2</u>: Which, if any, subtask(s) require detailed discussion at the Workshop? Please identify which one(s) and provide an explanation.
>
> <u>Question 3</u>: Is this list complete? If not, please identify any task or subtask that is missing, using the same outline form, and provide an explanation.

The Department then prepared an updated version of its Solid-State Lighting R&D Agenda based on comments from stakeholders and researchers from industry, academia, and the national labs. This version of the R&D agenda is presented in Appendix E.

On Day 2 of the Workshop, participants were split into three Sessions – Inorganic Core Technology Research (~45 participants), Inorganic Product Development (~40 participants), and a combined Organic SSL Session (~50 participants). Each group was asked to evaluate and prioritize their respective research tasks and subtasks. The goal of the final task/subtask structure is to addresses the research needs of the Department for the next ten years. The prioritization process will guide the agenda for the next one to two years. In the morning, participants discussed the task/subtask structure and made necessary changes to the language. Through this process, some of the original tasks and subtasks were re-shuffled, dropped or amended. Following the structural changes, each group discussed and voted to recommend which subtask areas should be prioritized in the next one to two years. After the discussion on the relative importance of each subtask, the participants voted for the subtasks that they felt were most important for the Department to fund. Each participant had five votes to distribute in any pattern he/she wished. Following the voting, each group discussed the implications of the results. The final task/subtask structure that resulted from this process appears in the following sections, but also as one complete R&D agenda in Appendix F. The discussion from each session is detailed below in Sections 4.1, 4.2, 4.3, and 4.4. The comments made by stakeholders during these Sessions were suggestions and observations and do not necessarily constitute the opinions or observations of the Department.

4.1. Group # 1: Inorganic Core Technology Research

4.1.1. Discussion of Typology and Subtasks

The group discussed the typology of the tasks and subtasks under the Inorganic LED Core Technology Research Group to identify and organize the priority topics of research. Although cost is not mentioned explicitly in any task or subtask area, the group paid special attention to cost drivers, as cost is an important factor when results transfer from Core Technology Research to Product Development. If a specific cost driver requires substantial science, it needs to be identified and addressed as a specific research subtask (e.g., ammonia impacts on manufacturing cost).

The group first discussed the typology at the task level. The group then moved to a discussion of subtasks under each task area. Although there was a suggestion to create another task area dealing with next generation materials, the group decided to maintain the existing typology. The following sections summarize the key points from the discussion, organized by task area.

Task 1.1 – Inorganic Materials Research
During the discussion at the task level, the group agreed to broaden the scope of Task 1.1 to include conversion materials. Conversion materials were originally covered under Task 1.3, "inorganic technology integration," but proponents of this change argued that conversion materials (i.e., phosphors, polymers, nanoparticles and quantum dots) are an issue of materials research, not integration. In addition, the group agreed that lifetime measurement and quantum dot efficiency should also be included in Task 1.1.

When the task level discussion ended, the group considered research activities at the subtask level. At this level, the group showed little opposition to the typology. However, at this point, the group continued its discussion of conversion materials. Proponents argued that fundamental research of conversion materials (i.e., phosphors) should be included as a stand-alone subtask in Task 1 and removed as part of Subtask 1.3.1, "phosphors and conversion materials," to ensure its equal footing with other materials research. Although a show of hands demonstrated that ¾ of participants did not feel a need to add this Subtask under materials research, they agreed to include conversion materials as Subtask 1.1.4 for voting purposes. A participant also commented that subtasks were "chip heavy" and did not include enough opportunities for research in device measurement (e.g., spectroscopy).

The group made two other small changes under this Task. Participants added alloy phenomena as a bullet under Subtask 1.1.2, although it should be noted that bulleted items are descriptive examples and do not represent an exhaustive list of the priority areas of research. Next, the word "emitter" replaced "LED" in Subtask 1.1.3 to be inclusive of all emitter technologies (e.g., lasers).

Task 1.2 – Inorganic Device Architecture Research and Modeling
Discussion arose regarding the goal statement for Task 1.2, *"increase external quantum efficiency."* Some participants argued that external quantum efficiency (EQE) is not distinct

from internal quantum efficiency (IQE) because EQE is a function of IQE and extraction. However, the group decided that work to increase IQE results in increased EQE and presents an element of continuity from Task 1.1 to Task 1.2, which should not be lost in this categorization as it may be a useful bridge. In addition, the group asserted that this Task area should consider issues of heat management.

The group had no issues with the Subtasks in this Task area.

Task 1.3 – Inorganic Integration Technology Research
In Task 1.3, the group felt that the need for further investigation is split equally between chip (die) and post-chip (post-die) at this stage of research. Some participants suggested replacing the word "technology" with "science," or to rename Task 1.3 to "laboratory research technology" and add the word "lamp" to explicitly describe activity that results in a complete light source. In the end, the group modified the descriptor of Task 1.3 from "inorganic technology integration" to "inorganic integration technology research" to better convey the focus on Core Technology Research.

The group questioned why Subtask 1.3.4, "measurement metrics and human factors," is part of Task 1.3. Participants believe it is the responsibility of NIST to fund this type of research. However, NIST only funds basic research generic to all applications, i.e., candela, color, lumen, and specialized measurement and services are not covered (e.g., flashing lights in aircraft). NIST, therefore, does not fund LED research. Although Subtask 1.3.4 is the type of research NIST is equipped to perform, participants felt that DOE support of NIST work would be an appropriate use of funds. The research encompassed in this Task will help identify SSL targets and set the parameters for maximum effectiveness.

One participant questioned where researchers would submit work regarding submounts, the interface between chip and board. The group decided that if research demonstrates that submounts improve efficiency, the work belongs in this Task area under Subtask 1.2.2, "strategies for improved light extraction and manipulation."

The group made two other changes to the Subtasks in this Task area. The word "high-efficiency" was added to the descriptor of Subtask 1.3.1 to highlight the efficiency aspect. Next, they added "higher performance converter research" as a bullet to Subtask 1.3.1 to emphasize inclusion of all research resulting in higher performance converters.

Task 1.4 – Inorganic Growth and Fabrication Processes and Manufacturing Research
The group modified the descriptor of Task 1.4, from "inorganic growth and fabrication processes and manufacturing issues" to "inorganic growth and fabrication processes and manufacturing research" to better convey its research focus. The group decided that Task 1.4 deals with manufacturing issues, not manufacturing processes, and research is not directed at any specific material or technology. Any work that leads to improvements in an existing process or product belongs under Product Development activities.

In addition, the group expanded the scope of Task 1.4 to include device fabrication of both wafer research (i.e., large-area substrate manufacturing and processing) and thin-film growth and epitaxy. The group also discussed technology transfer to product and interaction with the OLED group on some common issues. Although no changes were made to address these issues, the group believed that this bridging activity is vital to the success of the SSL program.

Subtasks 1.4.1 and 1.4.2 should include wafer research, participants said. Therefore, "substrate" was added to the descriptors of those Subtasks. In addition, modeling includes other activities than numerical modeling. Therefore, "modeling" was replaced with "measurement and experimentation" in Subtask 1.4.1.

Some participants felt that the Subtasks under Task 1.4 were much more specific and at a different level than the other task areas. Participants noted that all subtasks should have the same level of descriptiveness, and they discussed whether to add processes to Task 1.1. In this case, Subtask 1.4.1 would subsume 1.4.2 and the resultant Subtask would be added to Task 1.1. However, these suggestions were dropped in favor of the existing typology.

4.1.2. Revised Typology

Based on the discussion of the typology, the group made revisions to the existing tasks and subtasks. The revised typology is outlined below.

Task 1.1: Inorganic Materials Research
Goal: increase internal quantum efficiency

Subtask 1.1.1: Large-area substrates, buffer layers, and wafer research

- Low defect density
- Existing and alternate low-cost substrates

Subtask 1.1.2: High-efficiency semiconductor materials

- Efficient broadband materials (including orange, yellow, green, and UV (360nm to 410nm))
- Existing and alternate low-cost materials (e.g. nitride materials)
- p-doping and charge mobility studies
- alloy phenomena

Subtask 1.1.3: Reliability and defect physics for improved emitter lifetime and efficiency

- Dopant and defect physics, device characterization and modeling
- Droop (reduced efficiency at high temperature and current density)

Subtask 1.1.4: Conversion Materials

Task 1.2: Inorganic Device Architecture Research and Modeling
Goal: increase external quantum efficiency

Subtask 1.2.1: Device approaches, structures and systems

- Lasers, resonant cavities
- Nanocomposite sources (e.g., photonic crystals & microcavity effects)
- Surface plasmons

Subtask 1.2.2: Strategies for improved light extraction and manipulation

- Optical and device modeling for general illumination

Task 1.3: Inorganic Integration Technology Research
Goal: research technology for high performance LED lamps and luminaires

Subtask 1.3.1: High-efficiency phosphors and conversion materials

- Deposition methods and technology, layer packing
- Long-life, heat tolerant (e.g., nanophosphors)
- Higher performance converter research

Subtask 1.3.2: Encapsulants and packaging materials

- High temperature, long-life, UV-tolerant, improved optical extraction (e.g., nanocomposites)
- Thermal management strategies and modeling

Subtask 1.3.3: Electrodes and interconnects

- Ultra-low resistance
- Piezoelectric contacts

Subtask 1.3.4: Measurement metrics and human factors

- Productivity, preference, and demonstrations
- Use-dependent metrics for white light
- Standards for electrical and photometric measurement
- Binning strategies

Task 1.4: Inorganic Growth and Fabrication Processes and Manufacturing Research
Goal: cross-cutting improvements to growth and fabrication processes and manufacturing

Subtask 1.4.1: Physical, chemical, optical modeling, measurement, and experimentation for substrate and epitaxial processes

Subtask 1.4.2: Design and development of in-situ diagnostic tools for the substrate and epitaxial process

Subtask 1.4.3: Research into low-cost, high-efficiency reactor designs and manufacturing methods

Subtask 1.4.4: Investigation (theoretical and experimental) of die separation, chip shaping, and wafer bonding techniques

4.1.3. Results of Prioritization

In the voting process, DOE asked participants to prioritize areas of research for the next one to two year period. Although the group considered issues of technology transfer from Core Technology Research to Product Development when organizing the task and subtask structure, members focused their efforts at prioritizing Core Technology Research issues. For instance, they decided that broader integration factors (i.e., electronics) have applications in Product Development and belong in that Group.

During the voting process, participants decided they should also consider if the research topic has broad-based applicability. In addition, participants agreed that prioritization should address areas where the US is weak because international competitiveness should be an important factor for DOE. Participants also reminded each other to consider the balance of funding between LED and OLED technology. One participant noted that DOE splits its resources evenly while the rest of the world devotes 90% of its funding to LED and 10% to OLED, but he also noted that this international ratio is changing.

The group used these principles as a guide to prioritization. The following section presents the results, by task area, of the voting and comments from participants regarding the merits of each subtask.

Task 1.1: Inorganic Materials Research
Table 4-1, below, shows the number of votes received by each Subtask in this Task area. Each participant had five votes to distribute in whatever manner he/she decided (e.g. all five votes on one subtask, five votes spread over several subtasks). Following the tables are comments from session participants regarding the merits of the Subtasks in this Task area.

Table 4-1: Prioritization of Group 1, Task 1.1

Subtask	Number of Votes
1.1.1: Large-area substrates, buffer layers, and wafer research	24
1.1.2: High-efficiency semiconductor materials	51
1.1.3: Reliability and defect physics for improved emitter lifetime and efficiency	11
1.1.4: Conversion Materials	0

Subtask 1.1.2, "high-efficiency semiconductor materials," received the highest number of votes in Group 1: Inorganic Core Technology Research. Subtask 1.1.1, "large-area substrates, buffer layers, and wafer research" also received a large number of votes.

Subtask 1.1.2 is broad in scope and includes many important research topics such as the impact of doping on performance. There are additional issues (e.g., cracking is not understood) that make this Subtask a research priority. In addition, participants noted that for DOE to achieve its SSL goals, it is critical to improve the efficiency of color-mixing. However, one component of a color-mixing device, the green LED, has a low efficiency. Therefore, participants felt that efficient reproduction of green is the biggest hurdle. Although some participants stated that they would prefer to see this activity as a discrete subtask, its inclusion in Subtask 1.1.2 makes it a compelling case for top priority.

Subtask 1.1.1 also received a large number of votes. Participants felt that Sapphire and Silicon Carbide (SiC) may not be the correct substrate to achieve DOE's SSL efficiency targets. They noted that researchers should develop lower defect density materials, and that substrate materials (i.e., GaN, ZnO) are the key to reducing defect density. In discussion of Subtask 1.1.1, participants felt that the United States views substrates as a commodity. Therefore, foreign manufacturers dominate the market, led by Japan, with China gaining market share. Because of the difficulty of getting lattice-matched substrates, substrate manufacturers may limit the availability of good substrates. For example, while investigating growth of II-VII materials, Rockwell experienced a tremendous amount of difficulty because they could not obtain enough sapphire substrates to conduct their research. One participant noted that SiC went through 50 years of investment, and sapphire had a 70-year cycle. The group felt it was important that the US not lose any strategic advantage. Therefore, DOE should try to keep substrate research in the US, and should also do what it can (e.g., consider making bulk substrate purchases) to make it available for research.

Participants also felt that these two Subtasks could be more detailed, and perhaps broken out into several Subtasks. Participants noted that there is much more granularity than what is presently described by the language. For instance, participants questioned, how much of Subtask 1.1.1 deals with substrates and how much of Subtask 1.1.2 is concerned with developing a viable green emitter?

Task 1.2: Inorganic Device Architecture Research and Modeling
Table 4-2, below, shows the number of votes received by each Subtask for this Task area. Following the table are comments by session participants regarding the merits of the related subtasks.

Table 4-2: Prioritization of Group 1, Task 1.2

Subtask	Number of Votes
1.2.1: Device approaches, structures and systems	39
1.2.2: Strategies for improved light extraction and manipulation	18

Subtask 1.2.1 received the second highest number of votes in Group 1. Participants noted that this Subtask is important because there is a huge cost differential to overcome to achieve high performance. Getting the maximum lumens out of the smallest chip possible will impact price. In addition, this Subtask contains much more activity than its descriptor implies (i.e., development of concepts). For example, a participant noted that from an applications perspective, optical quality (direction and light density) is currently insufficient for projectors.

In the group's discussion of Subtask 1.2.2, "strategies for improved light extraction and manipulation," one participant noted that the LED is simply a light engine and is highly suboptimal. Because light is best manipulated closest to the source, optics should be fully integrated into the chip. Full system optimization is crucial and would require organizing a major modeling and analytical effort. This participant felt funding in this Subtask should be increased because work with optical research should be conducted parallel with materials research.

Subtask 1.2.2 touches on this relationship, but participants felt that the relationship should be more explicit. In this Subtask, another participant felt that surface modifications should be a high priority. Research in transport structures, device configuration, and reflector design also falls under Subtask 1.2.2.

Task 1.3: Inorganic Integration Technology Research

Table 4-3, below, shows the number of votes received by each Subtask for this Task area. Following the table are comments by session participants regarding the merits of the subtasks.

Table 4-3: Prioritization of Group 1, Task 1.3

Subtask	Number of Votes
1.3.1: High-Efficiency Phosphors and conversion materials	33
1.3.2: Encapsulants and packaging materials	11
1.3.3: Electrodes and interconnects	1
1.3.4: Measurement metrics and human factors	16

The group listed several research tasks that would fall under Subtask 1.3.1. The group felt that it was necessary to develop high-efficiency phosphors suitable for LEDs, because none currently exist. The group also decided that lumen maintenance research could be completed under Subtasks 1.3.1 and 1.3.2 because phosphors and packaging must last as long as the chip technology. In the area of nanoparticles, a participant noted that most of the current research is in biotechnology, not lighting, and that research should focus on size and surface (surface defects) because lifetime is actually a function of surface state, and not temperature.

Participants commented that research under Subtask 1.3.1 should include nanophospor research. Research under Subtask 1.3.2 should determine how to embed (integrate) nanophosphors into the LED package while considering temperature dependence. Nanophosphors have the potential to be highly efficient because extraction using nanophosphors has no self-absorption. However, they degrade rapidly under high temperature exposure. Participants agreed that quantum dots are not nanophosphors because they are self-absorbing.

While discussing Subtask 1.3.4, "measurement metrics and human factors," participants expressed why research in this area is important. Developers optimize to a given metric, and if the metric is flawed, the optimization will be wrong. Because LEDs can reproduce virtually any spectrum, it raises a lot of questions regarding what spectrum should be considered optimum. Do we need broad spectrum? Is 3-color, 4-color enough? How do color rendering index (CRI) and correlated color temperature (CCT) impact performance? Is CRI an appropriate metric for light quality? The spectrum issue is relevant to all technologies and participants felt that it is urgent to address these issues now. However, the Commission Internationale de l'Eclairage (CIE) is already doing the activities mentioned in this Subtask. Therefore, it may not be necessary for DOE to duplicate the effort. The group felt that this Subtask would not require a lot of funding to make a significant impact.

The group questioned if modeling and software would be useful to examine under this Task (e.g., new design tools to predict light extraction). However, the group decided that these topics are already covered under Subtask 1.2.2.

Task 1.4: Inorganic Growth and Fabrication Processes and Manufacturing Research

Table 4-4, below, shows the number of votes received by each Subtask for this Task area. Following the table are comments by session participants regarding the merits of the subtasks

Table 4-4: Prioritization of Group 1, Task 1.4

Subtask	Number of Votes
1.4.1: Physical, chemical, optical modeling, measurement, and experimentation for substrate and epitaxial processes	8
1.4.2: Design and development of in-situ diagnostic tools for the substrate and epitaxial process	8
1.4.3: Research into low-cost, high-efficiency reactor designs and manufacturing methods	0
1.4.4: Investigation (theoretical and experimental) of die separation, chip shaping, and wafer bonding techniques	0

The group felt that this Task received a relatively fewer number of votes than other groups because the SSL community is happy with existing tools. The group noted that toolmakers are not experts in semiconductors and they depend on semiconductor manufacturers to tell them what is needed.

When discussing the voting results, the group noted that industry already handles activities that would fall under Subtask 1.4.4 very well, and may not need additional support from DOE. One activity that could be completed under Subtask 1.4.4 would be to research how to shape the chip before considering methods of creating them.

In total, Task 1.1 received 86 votes, Task 1.2 received 57 votes, Task 1.3 received 61 votes, and Task 1.4 received 16 votes. Figure 4-2 presents a histogram of the votes.

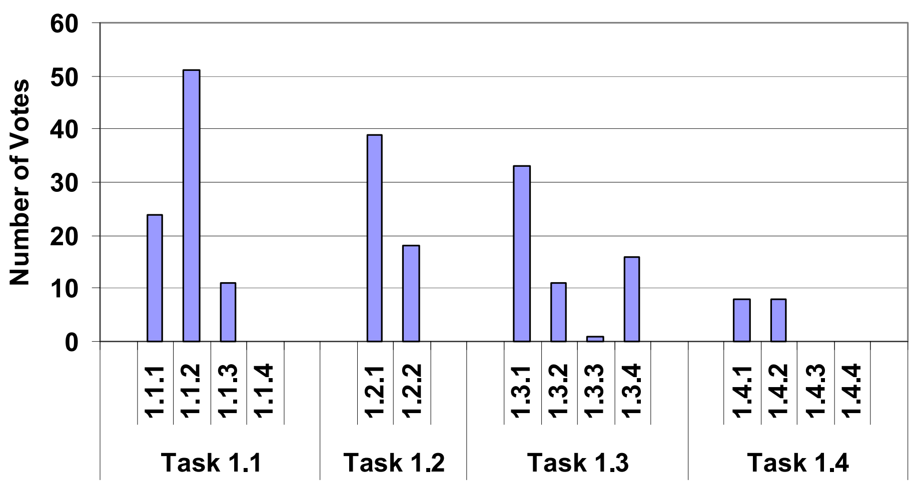

Figure 4-2: Inorganic Core Technology Research Distribution of High Priority Votes

There were several subtasks that received more than twenty-five votes.

Table 4-5 presents the five subtasks that received the most votes.

Table 4-5: Prioritization of Group 1, Top Five Subtasks

Subtask	Number of Votes
1.1.2 High-efficiency semiconductor materials	51
1.2.1 Device approaches, structures and systems	39
1.3.1 Phosphors and conversion materials	33
1.1.1 Large-area substrates, buffer layers, and wafer research	24
1.2.2. Strategies for improved light extraction and manipulation	18

The highest priority area of research was Task 1.1, "inorganic materials research". The lowest priority area was Task 1.4, "growth and fabrication processes and manufacturing research." The group believes that some of Task 1.4 will be picked up by industry without DOE support.

4.1.4. Post Voting Remarks and General Comments

After the prioritization and discussion, the group was given the opportunity to share any final comments with DOE.

In terms of prioritization, the group suggested that DOE consider that the Product Development Session added human factors and metrics as a discrete Subtask. On another note, several participants agreed that DOE should not draw the line and cut off the subtasks with low votes. DOE should calibrate these results with its current investment and use this to reprioritize its portfolio. In addition, the group wanted DOE to balance its portfolio between LED and OLED technology. There should be some formalized process to look at cross fertilization opportunities between LED and OLED. Participants felt that DOE could benefit from open dialogue with stakeholders on these issues.

As a general comment, participants felt that DOE should clarify terminology. For example, what is meant by device, chip, die, and lamp? Are device and lamp equivalent? Are chip and die equivalent? What is the difference between lamp and device, if there is one? The group wanted DOE to develop nomenclature and definitions (i.e., a glossary). One participant noted that DOE could develop a glossary of terms based on definitions used by NEMA, and publish it with DOE's definition of Core Research and Product Development. The NEMA definitions can be found on their website and in addition, NEMA also describes different levels of research (e.g., Task 1.3 corresponds to NEMA level 1).

Other participants noted that, as technology moves from Core Technology to Product Development, lumens-per-dollar may become more important than lumens-per-watt. However, cost was not mentioned in any of the tasks or subtasks. Participants agreed that now may not be the best time to make cost such a big factor. The group also suggested that DOE consider forming a committee to figure out how to effectively transfer Core Technology Research to the Product Development side.

4.2. Group # 2: Inorganic Product Development

4.2.1. Discussion of Typology

The SSL Product Development group demonstrated some resistance to the proposed task/subtask structure. The majority of the participants felt that the proposed structure did not reflect the needs of product developers.

The original Task 2.1, “inorganic materials development,” and 2.2, “inorganic device architecture development” were combined into the new Task 2.1, entitled “inorganic materials and device architecture.” This Task now has four Subtasks aimed at improving the external quantum efficiency of LEDs through improvements in internal and external quantum efficiency. Participants noted that this Task should focus on technology transfer, and not replicate work done in Core Technology Research.

The major structural change occurred in the original Task 2.3, “inorganic technology integration.” The group felt that the proposed structure of this Task did not accurately reflect the needs of product developers. The first three Subtasks in Task 2.3 were moved to the new Task 2.2, entitled “LED component technical integration.” The group also voted to add another Subtask, “evaluate component lifetime and performance characteristics,” to Task 2.2.

Group consensus determined that the original Subtask 2.3.4, “design, engineered applications, field tests and demonstrations,” was too broad, and needed to be elevated to the task level. The new Task 2.3 is titled “system technology integration and novel luminaire design.” The word “novel” was added at the request of a stakeholder who wanted the structure to allow for projects that propose a completely original luminaire design. The group voted to break Task 2.3 down into subtasks based on the “building blocks” of system integration (i.e., optical design, thermal, mechanical, electrical). Participants also added two Subtasks, “evaluate human factors and metrics” and “evaluate systems lifetime and performance characteristics.” Originally, these two Subtasks were not in the Product Development section because they were considered a better fit in the Core Technology Research framework. Several participants asserted that robustness and repeatability should be assumed throughout the entire Product Development framework; however, others felt it was necessary to add subtasks to Task 2.3 that apply specifically to luminaire design. Ultimately, the group agreed to add these subtasks and allow the prioritization process to determine their importance.

The original Task 2.4 was not altered.

4.2.2. Revised Typology

Based on the discussion of the typology, the group made revisions to the existing Tasks and Subtasks. The revised typology is below.

Task 2.1. Inorganic Materials and Device Architecture
Goal: increase internal and external quantum efficiency

Subtask 2.1.1. Substrate, buffer layer and wafer engineering and development

Subtask 2.1.2. High-efficiency semiconductor materials
- Efficient broadband light emitting materials (including yellow-green, orange, and UV (360nm to 410nm))
- Existing and alternate low-cost materials (e.g., nitride materials)

Subtask 2.1.3. Implementing strategies for improved light extraction and manipulation
- High refractive index encapsulants for improved light extraction
- Large-area light extraction and current injection

Subtask 2.1.4. Device architectures with high power-conversion efficiencies
- Chip scaling and micro-arrays
- Multi-color chips, arrays on a single substrate

Task 2.2. LED Component Technical Integration
Goal: develop cost-effective LED lamps and luminaires

Subtask 2.2.1. Manufactured materials
- Phosphors and luminescent materials
- High temperature encapsulants and mounting materials

Subtask 2.2.2. LED packages and packaging materials
- Ultra-low resistance contacts, tunnel contacts
- Heat dissipation techniques

Subtask 2.2.3. Modeling, distribution, and coupling issues
- Secondary optics design
- Computer modeling and analysis tools

Subtask 2.2.4. Evaluate component lifetime and performance characteristics

Task 2.3. System Technology Integration and Novel Luminaire Design

Subtask 2.3.1. Optical coupling and modeling

Subtask 2.3.2. Mechanical design

Subtask 2.3.3. Electronics development
- Size, voltage, standardization, color control
- Light engine versus luminaire electronics

Subtask 2.3.4. Thermal design

Subtask 2.3.5. Evaluate human factors and metrics

Subtask 2.3.6. Evaluate systems lifetime and performance characteristics

Task 2.4. Inorganic Growth and Fabrication Processes and Manufacturing Issues
Goal: develop equipment and tools for low-cost, high-yield manufacturing and scaling to larger wafers

Subtask 2.4.1. Incorporate proven in-situ diagnostic tools into existing equipment

Subtask 2.4.2. Develop low-cost, high-efficiency reactor designs

Subtask 2.4.3. Develop techniques for die separation, chip shaping, and wafer bonding

4.2.3. Discussion of Subtasks

After the participants settled on the framework, they discussed which subtasks should be funded in the next one to two years.

Task 2.1. Inorganic Materials and Device Architecture
The group discussed the importance of funding the subtasks in Task 2.1. Specifically, one stakeholder noted that development in this area is critical to the Department's goal of saving energy.

Task 2.2. LED Component Technical Integration
Several participants elucidated the importance of the activities incorporated in Task 2.2. For example, Subtask 2.2.1, "manufactured materials," is important because material development is not just a Core Technology Research issue. Better encapsulants need to be developed for high temperature applications. Similarly, participants felt that additional work is necessary in Subtask 2.2.2, "LED packages and packaging materials." This research is still in its infancy, especially with respect to removing heat from the chip, delivering high-lumen output, and getting electricity into the chip. Participants also deemed Subtask 2.3.6, "evaluate component lifetime and performance characteristics," important because manufacturers of LED systems need reliable, computable information on lamp performance characteristics (e.g., lamp life, UV emission, radio frequency).

Task 2.3. System Technology Integration and Novel Luminaire Design
The majority of the discussion focused on the importance of Task 2.3, "system technology integration and novel luminaire design." Most stakeholders in the session felt that manufacturers had reached the stage where it was necessary to address luminaire design and this Task provides product manufacturers the opportunity to address critical design issues. For example, the participants felt that the first four Subtasks, or "building blocks," of luminaire design were of critical importance. One stakeholder pointed out that research in the electronics Subtask, such as a project focused on lighting controls, could result in huge energy savings. Another participant, however, cautioned the group from committing a "tyranny of the majority" during the prioritization process, and only voting for the Subtasks under this Task. He maintained that critical work is still necessary under the first two Tasks, and that participants should be careful to spread their votes to these areas. Another stakeholder said that research under Subtask 2.3.5, "evaluate human factors and metrics," was necessary so that designers may gain an understanding of consumer preference and demand at an early stage in order to address how light should be put into buildings.

Task 2.4. Inorganic Growth and Fabrication Processes and Manufacturing Issues
No comments were put forth about the importance of Task 2.4.

The group intended to discuss the type of work that should be performed in each subtask, but ran out of time.

4.2.4. Results of Prioritization

Table 4-6 presents the number of votes that each Subtask received.

Table 4-6: Prioritization of Group 2: Inorganic SSL Product Development

Task 2.1. Inorganic Materials and Device Architecture	Number of Votes
2.1.1. Substrate, buffer layer and wafer engineering and development	15
2.1.2. High-efficiency semiconductor materials	12
2.1.3. Implementing strategies for improved light extraction and manipulation	15
2.1.4. Device architectures with high power-conversion efficiencies	13
Task 2.2. LED Component Technical Integration	
2.2.1. Manufactured materials	28
2.2.2. LED packages and packaging materials	28
2.2.3. Modeling, distribution, and coupling issues	7
2.2.4. Evaluate component lifetime and performance characteristics	9
Task 2.3. System Technology Integration and Novel Luminaire Design	
2.3.1. Optical coupling and modeling	30
2.3.2. Mechanical design	2
2.3.3. Electronics development	25
2.3.4. Thermal design	23
2.3.5. Evaluate human factors and metrics	11
2.3.6. Evaluate systems lifetime and performance characteristics	17
Task 2.4. Inorganic Growth and Fabrication Processes and Manufacturing Issues	
2.4.1. Incorporate proven in-situ diagnostic tools into existing equipment	0
2.4.2. Develop low-cost, high-efficiency reactor designs	1
2.4.3. Develop techniques for die separation, chip shaping, and wafer bonding	2

In total, Task 2.1 received 55 votes, Task 2.2 received 72 votes, Task 2.3 received 108 votes, and Task 2.4 received 3 votes. Figure 4-3 presents a histogram of the votes.

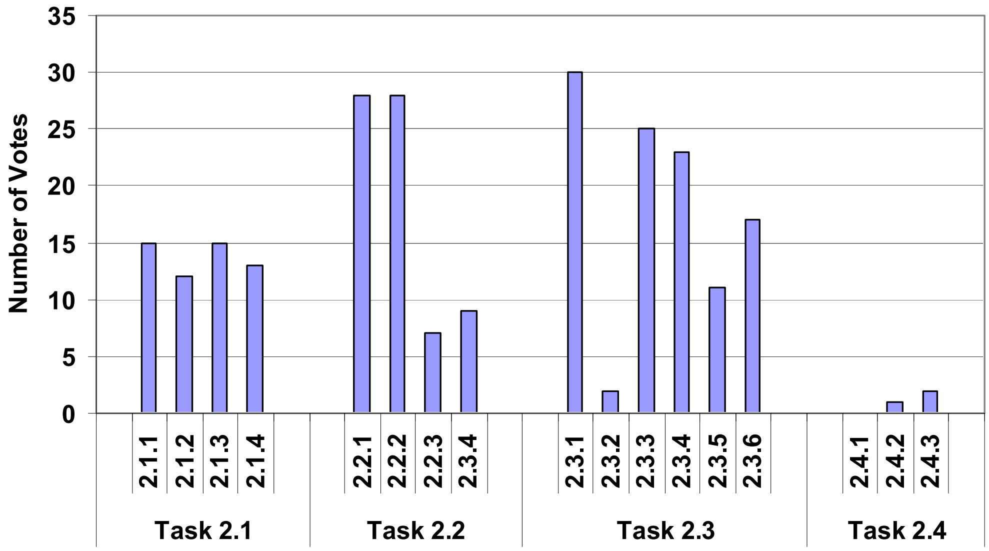

Figure 4-3: Prioritization of Group 2: Distribution of High Priority Votes

There were several subtasks that received between twenty-five and thirty votes. Comparatively, Task 2.4 did not receive many votes (3 of 248 votes).

Table 4-7 presents the five subtasks that received the most votes.

Table 4-7: Prioritization of Group 2: Top Five Subtasks

Subtask	Number of Votes
2.3.1. Optical coupling and modeling	30
2.2.1. Manufactured materials	28
2.2.2. LED packages and packaging materials	28
2.3.3. Electronics development	25
2.3.4. Thermal design	23

The subtasks with the highest votes were concentrated in Tasks 2.2, “LED component technical integration” and 2.3, “technology integration and novel luminaire design.” Three of the five top subtasks came from Task 2.3, the Task created by the group during the restructuring of the task/ subtask format in the morning discussion.

4.2.5. Post Voting Remarks and General Comments

Following the voting, the facilitator and technical expert presented the results of the prioritization to the group. They requested that the group discuss the outcome of the prioritization, identify any patterns, and comment on the implications of the results. The facilitator also encouraged stakeholders to make any general comment or suggestions that they would like the Department to consider.

The Subtasks in Task 2.1 received substantial votes during the prioritization process. The participants realized that there are still problems to solve with materials and substrates before industry can begin manufacturing high efficiency devices.

Tasks 2.2 and 2.3 received the majority of the votes. The participants were not surprised by this trend. They felt that DOE should start to increase funding on SSL lighting integration at the luminaire level. One stakeholder noted that if the goal is to have products in the marketplace in six years, it isn't premature to begin working on the development of codes and standards for these products.

The participants felt that while it is still important for the Core Technology Research Group to focus on the basic science and material development, the Product Development Group should start to look past basic material properties and examine how these materials will be integrated into the component level device. In addition, the Product Development group felt it should be considering ways to overcome new obstacles, such as market and behavioral forces and the influence of human factors. Participants felt that it is important to develop strategies to encourage the use of SSL products, and to convince the design community to use SSL products to create livable spaces.

Although Task 2.4 received only three votes, the participants still felt it should remain in the structure for the R&D agenda for the next ten years. The lack of votes for this Task reflected participant attendance in the room (i.e., no equipment manufacturers). One participant expressed the hope that the low prioritization of this Task would not hurt the development of SSL sources in the future. Although it is not a high priority Task for the next two years, it will likely demand attention in the future, he said. One stakeholder suggested that equipment manufacturers are likely waiting for the materials and systems developers to advance the technology before they can design the best way to manufacture it. The group felt that when a need emerges, equipment manufacturers should be funded.

The main theme that emerged from the group discussion was the apparent transformation from basic research to deployment, which one participant called a "system shift." One stakeholder commented that this phenomenon was due to the success of the Department's program to date. The success of the program enables industry to see the broader picture, and to see that SSL products can be developed for successful commercialization. Several participants commented that it was a positive sign that more there was increased industry attendance at this Workshop compared with the November 2003 Workshop. The Workshop is no longer just a meeting of materials researchers, but now attracts attendees from large scale system integration and lighting companies. Participants felt that this should be viewed as a testament to the success of the technology.

Stakeholders had several final suggestions for the Department, including:

- The Department should map the Core Technology Research results onto the Product Development structure to show how DOE links up the parts of its program.
- The Department should be aware of how the Subtasks were split in Task 2.3, and not all combined together.

- The Department should support the development of a detailed definition to measure lighting "quality" in a quantitative way (e.g., metrics). This is a difficult issue, but a critical one to resolve to achieve energy efficiency goals.
- The Department should provide an impetus to create efficient manufacturing techniques and help U.S. companies contend with competition from abroad.
- The Department should accept "hybrid proposals," which would allow an organization to submit a proposal that relates to more than one subtask.

4.3. Group #3: Organic Core Technology Research

The OLED breakout group combined the discussion on Core Technology Research and Product Development into one breakout Session. The LED breakout groups had separate discussions on Core Technology Research and Product Development, due to the larger number of LED participants. The OLED group found it advantageous to have representatives from both the research and the development side of industry in the same room to exchange ideas and enhance the discussion.

The participants were tasked with discussing, refining and prioritizing the research agenda for OLED Core Technology Research and Product Development. The discussion started by identifying the five most important cross-cutting issues that need resolution before OLEDs are able to compete in and service general illumination applications. These five issues are truly cross-cutting, and impact research and development activities throughout the agenda. The group stated that resolving these priority issues would be critical to ensuring the commercial viability of OLED devices for general illumination:

1) Develop a highly efficient, long-lived blue OLED emitter
2) Develop low-cost manufacturing – maximizing lumens while minimizing cost
3) Establish industry standards for general illumination devices
4) Research the OLED white-light system overall, including materials stability and device stability over its service life
5) Address research at the fundamental science level, including understanding and controlling singlet to triplet ratios to achieve 100% IQE and understanding degradation mechanisms to maximize lifetime.

4.3.1. Discussion of Typology and Subtasks

With these five cross-cutting priorities identified, the group proceeded to discuss and prioritize the research agenda. The following sections summarize the key points from the discussion organized by task area.

Task 3.1. OLED Materials Research

The goal of this research Task is to increase internal quantum efficiency through enabling physics and chemistry. These activities are meant to stimulate "out-of-the-box" thinking for developing new and better avenues for manufacturing. The group recognizes that only one or two approaches will be followed through to Product Development, however if the OLED industry is to achieve efficacies beyond 100 lumens per watt, some innovative ideas and approaches are necessary.

The group proceeded to briefly discuss each of the Subtasks within this Task area, starting with Subtask 3.1.1. "electro-active organic materials substrate research." Discussion centered on the fact that all of today's OLED demonstrations are on display quality glass, which is expensive and inflexible. The group described the need in this Subtask as developing new substrate materials, such as plastics, metal foils or something totally new and innovative that could replace glass. The title of this Subtask was modified to emphasize substrates, so it reads, "substrates for electro-active organic materials research."

The group discussed the differences between Task 3.1, "electro-active organic materials substrate research," and Task 3.4, "manufacturing growth and fabrication processes." The group believed that substrates are pertinent to both areas, and felt that having substrates in both Task areas was appropriate. One participant expressed concern that once the right blue emitter is developed, there may not be a good substrate to grow it on.

Under Subtask 3.1.2, "high-efficiency, low-voltage, stable materials," the group felt that the parenthetical description in the Subtask title "(host, dopant, and transport layers)" could be deleted as it was restrictive and may constrain innovative research in this area. This Subtask was seen as encompassing stable hole and electron blocking layers and single and multilayered devices. The discussion re-enforced the importance of allowing "out-of-the-box" thinking and totally new systems. The expectation is that some of the activities in this Subtask would include work on technologies that will not require expensive, slow encapsulation processes. It was also suggested that this might be the appropriate area to consider for hybrid organic/inorganic device research.

The group understood that Subtask 3.1.3, "improved contact materials and surface modification techniques to improve charge injection," would include n- and p-doped polymers and molecular dopants. With emphasis on new systems and approaches to this research area, the group discussed the expectation that this Subtask would focus on new techniques to get the charge into the device at the lowest possible voltage.

Finally, the group discussed and added a new Subtask for fundamental science research. The group felt that the progress to date has been somewhat incremental, and further understanding of the structure-property relationships and mechanisms would enable the rational design of improved materials. This Subtask would enable scientists to evaluate a number of different solutions to a problem and choose those that would be most effective from a cost and performance perspective.

Task 3.2. Organic Device Architecture Research and Modeling

The goal of this Task is to increase external quantum efficiency. The group understood that the difference between Task 3.2 and Task 3.1 is that latter is focused on substrates and materials chemistry while Task 3.2 is focused on device engineering. Within this Task, there are several subtasks which address the device engineering aspects of OLEDs in general illumination applications.

Subtask 3.2.1, "strategies for improved light extraction and manipulation" was discussed as encompassing completely new approaches for extracting light. This Subtask would look at optical and device modeling for general illumination. There is some overlap with 3.1.1, since substrate modification could be used to improve lighting extraction.

Subtask 3.2.2, "approaches, structures and systems for improved-performance, low-cost white-light devices" was thought to be too vague. This Subtask could encompass any activity or approach for improving white-light OLED systems. The group decided to modify the title by inserting the term "OLED" and removing the phrase "and systems," so it reads "approaches and OLED structures for improved-performance low-cost white-light devices." This Subtask is looking at engineering between the electrodes (as opposed to chemistry), including the layering of the device for optimal efficiency. And as with other subtasks in Core Technology Research, the emphasis is on new approaches that promise to move OLED technology in general illumination applications from a concept to reality.

The last Subtask for the device architecture research and modeling was Subtask 3.2.3, "transparent electrode research." Here, the group felt that the research activities should emphasize something other than ITO. A transparent electrode is needed if OLEDs are to achieve their goal, but the group felt that something better than ITO would be required due to its cost and deposition rate. This Task was recognized as one critical interface between the Core Technology Research and Product Development sides of the Department's R&D agenda. Research into better transparent electrode technology will be necessary before OLEDs can become a viable, commercialized product. The group decided to amend the title of this Subtask, inserting the phrase "low-cost" to emphasize the importance of this aspect of the research.

Task 3.3. OLED Technology Integration

The goal of this Task is to research technology for high performance OLED lamps and luminaires. Looking outside the device, the emphasis in this area is on technologies outside the electrodes, in other words, non-active layer material devices.

The group discussed the first Subtask, 3.3.1, "phosphors and conversion materials." Concern was expressed over the explicit mention of phosphors in this context and it was agreed to change the title to simply "down-conversion materials." This Subtask area was understood to encompass packaging issues as they relate to OLEDs, including both organic and inorganic downconversion materials.

The title of Subtask 3.3.2, "encapsulation and packaging materials" was modified by the group to shift the emphasis onto low-cost approaches and technologies. The group understood that this Subtask included work on new ways to seal the edges of a device and finding ways to protect an organic system from the environment. This Subtask stood-out from the others as critical for OLEDs in general illumination applications. Encapsulation techniques are one of the most expensive parts of white OLED manufacturing today, both from a cost and a processing time perspective. For example, present encapsulation rates are approximately 30 minutes per square foot, but this will have to be reduced to seconds per square foot. The operating lives of today's OLEDs are limited to a few thousand hours – this will have to increase to at least 20,000 hours and be considerably less expensive if OLEDs are to compete with fluorescent lamps. Many felt this was the number one priority for OLEDs. Some were critical that the industry was still thinking in terms of displays rather than general illumination applications.

Subtask 3.3.3, "electrodes and interconnects" was understood not to include the electrode in contact with the organic material, but rather how all the system will be wired together. Participants commented that this was a relatively mature technology, with some research needs, but nothing too critical.

The group discussed Subtask 3.3.4, "measurement metrics and human factors," which is understood to include productivity, preference and demonstrations, as well as standards for electrical and photometric measurement. Given the current status of the OLED devices, the group felt that this Subtask was premature, and there is a lot of work that needs to be done before this Subtask can be addressed. Some felt that this was not an area that the Department should focus its efforts, indicating that there is a built-in responsibility for companies to fund this activity, and it will happen without the Department's involvement.

Task 3.4. OLED Growth and Fabrication Processes and Manufacturing Issues
The goal of this Task is the development of equipment and tools for low-cost, high-yield manufacturing. Within this Task area, in the context of Core Technology Research, scientists would address pre-competitive issues.

The group discussed Subtask 3.4.1, "physical, chemical and optical modeling for fabrication of OLED devices." While the group recognized that there are computer models that simulate the growth of an LED, there is no computational model that tracks the growth of an OLED, and there would be value in modeling this process. However, the group also felt that device modeling was already part of Task 3.2, and so this Subtask was perhaps unnecessary. A recommendation was made to interpret the scope of Subtask 3.4.3 to include these activities.

Subtask 3.4.2, "tools and methods for manufacturing," was discussed by the group as including in-situ diagnostic tools and organic material purity. The group agreed that this Task did not really belong in Core Technology, and therefore moved the Subtask to Task 4.4 within OLED Product Development. The group also decided to modify the title of Subtask 3.4.3 to include the phrase "and tools," so some aspects of research items within this Task would be retained in 3.4.3.

Subtask 3.4.3, "investigation (theoretical and experimental) of low-cost fabrication and patterning techniques and tools" was discussed by the group. The group agreed that there may be a timing difference between when you look at tools and methods for manufacturing and low-cost fabrication and patterning techniques, but it was felt that these were all part of the same research area, and should be grouped together under one Subtask. In the broader context, the group recognizes that it is important to model and understand the OLED fabrication process; however, as one participant put it, "you can't model your way out of this problem – at some point, someone will have to develop a new technique."

4.3.2. Revised Typology

Based on the discussion of the typology, the Group made revisions to the existing tasks and subtasks. The revised typology is presented below.

3.1. OLED Materials Research

Goal: increase internal quantum efficiency through enabling physics and chemistry

Subtask 3.1.1. Substrate materials for electro-active organic devices

Subtask 3.1.2. High-efficiency, low-voltage, stable materials
- Stable hole and electron blocking layers
- Single and multilayered devices

Subtask 3.1.3. Improved contact materials and surface modification techniques to improve charge injection
- n and p doped organics
- Molecular dopants

Subtask 3.1.4. Fundamental Science

3.2. OLED Device Architecture Research and Modeling

Goal: increase external quantum efficiency

Subtask 3.2.1. Strategies for improved light extraction and manipulation
- Optical and device modeling for general illumination

Subtask 3.2.2. Approaches to OLED structures between the electrodes for improved-performance low-cost white-light devices

Subtask 3.2.3. Research on low-cost transparent electrodes

3.3. OLED Technology Integration

Goal: research technology for high performance OLED lamps and luminaires

Subtask 3.3.1. Down conversion materials

Subtask 3.3.2. Low-cost encapsulation and packaging technology

Subtask 3.3.3. Electrodes and interconnects

Subtask 3.3.4. Measurement metrics and human factors
- Productivity, preference, and demonstrations
- Standards for electrical and photometric measurement

3.4. Organic Growth and Fabrication Processes and Manufacturing Issues
Goal: develop equipment and tools for low-cost, high-yield manufacturing

Subtask 3.4.1. Physical, chemical and optical modeling for fabrication of OLED devices

Subtask 3.4.2. Investigation (theoretical and experimental) of low-cost fabrication and patterning techniques and tools

4.3.3. Results of Prioritization

The following table provides the number of votes that were recorded for each of the subtasks. In this way, the participants provided a recommendation to the Department on where it should be concentrating its R&D resources over the next one to two years.

Table 4-8: Prioritization of Group 3: Organic SSL Core Technology Research

Task 3.1. OLED Materials Research	Number of Votes
3.1.1. Substrate materials for electro-active organic devices	4
3.1.2. High-efficiency, low-voltage, stable materials	38
3.1.3. Improved contact materials and surface modification techniques to improve charge injection	15
3.1.4 Fundamental Physics	11
Task 3.2. OLED Device Architecture Research and Modeling	
3.2.1. Strategies for improved light extraction and manipulation	8
3.2.2. Approaches to OLED structures between the electrodes for improved-performance low-cost white-light devices	25
3.2.3. Research on low-cost transparent electrodes	18
Task 3.3. OLED Technology Integration	
3.3.1. Down conversion materials	3
3.3.2. Low-cost encapsulation and packaging technology	28
3.3.3. Electrodes and interconnects	0
3.3.4. Measurement metrics and human factors	0
Task 3.4. OLED Growth and Fabrication Processes and Manufacturing Issues	
3.4.1. Physical, chemical and optical modeling for fabrication of OLED devices	0
3.4.2. Investigation (theoretical and experimental) of low-cost fabrication and patterning techniques and tools	18

In total, Task 3.1 received 68 votes, Task 3.2 received 51 votes, Task 3.3 received 31 votes, and Task 3.4 received 18 votes. Figure 4-4 presents a histogram of the votes.

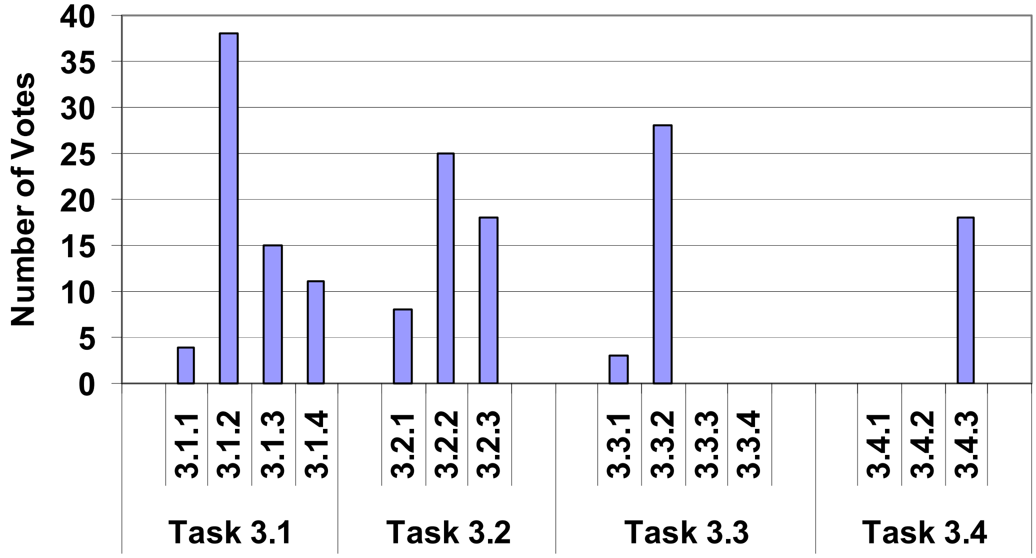

Figure 4-4: Prioritization of Group 3: Distribution of High Priority Votes

Table 4-9 presents the five subtasks that received the most votes.

Table 4-9: Prioritization of Group 3: Top Five Subtasks

Subtask	Number of Votes
3.1.2 High-efficiency, low-voltage, stable materials	38
3.3.2 Low-cost encapsulation and packaging technology	28
3.2.2 Approaches to OLED structures between the electrodes for improved-performance low-cost white-light devices	25
3.2.3 Research on low-cost transparent electrodes	18
3.4.3 Investigation (theoretical and experimental) of low-cost fabrication and patterning techniques and tools	18

4.3.4. Post Voting Remarks and General Comments

The OLED group was satisfied with the results of the voting. They recognize the limitations of resources, and felt that the votes reflected all the immediate/urgent issues that need to be studied in the next one to two years. The five cross-cutting themes were not forgotten, and participants could identify tasks and subtasks that were prioritized and encompassed each of these.

4.4. Group #4: Organic Product Development

4.4.1. Discussion of Typology and Subtasks

Task 4.1. OLED Materials Development
The goal of this Task is to develop devices with increased internal quantum efficiency. Within this Task there are three Subtasks that cover OLED materials related issues from a product development perspective.

The group decided to change the title of Subtask 4.1.1 in the same way it changed Task 3.1.1 to increase the emphasis on substrates, so it now reads "substrates for electro-active organic materials." The group understands that this Subtask includes the critical issue of the ability of OLED manufacturers to get quality materials for production. The over-arching problem of developing a blue-emitting OLED was discussed in this context, as well as the $30 to $50 cost per square meter of display quality glass. Until the substrate issue is addressed, OLEDs cannot be cost competitive in general illumination applications. The group also discussed the fact that general illumination white light will not be the first market for OLEDs. Rather, niche applications will be identified first, which will generate revenue for further research and accelerate the process. Ultimately general illumination is the target, but niche applications must come first.

The group changed the title of Subtask 4.1.2 to differentiate it from Subtask 3.1.2 and to be more specific about what parts of the OLED device are included in this Subtask. The original title was 'high-efficiency, low-voltage, stable materials (host, dopant and transport layers)" and the group modified it to read "between electrodes, the advancement of known material systems." Among other development areas, the group understood this Subtask to include stability of light production in lighting applications, organic/inorganic hybrid devices, and materials for lighting including thermal considerations. Given that this Subtask falls under Product Development, the focus should be on optimizing existing and current material systems, not necessarily developing new technologies or approaches. The activities under this Subtask would be directed more at short to intermediate-term deliverables and technologies. As niche markets start to develop, anything developed under this Subtask must demonstrate mass production potential.

The group briefly discussed Subtask 4.1.3, "improved contact materials and surface modification techniques to improve charge injection." Activities under this Subtask include the refinement of currently available technologies, and investigates problems with the supply chain - i.e., improving the quality of the material inputs for manufacturing.

Task 4.2. Organic Device Architecture Development
The goal of this Task is to develop devices with increased external quantum efficiency. The group discussed the difficulty associated with this Task; they felt that more work is necessary in order to develop new devices. The Department's focus is on the needs of the market, and what devices may be necessary to satisfy those needs based on developing more efficient white-light OLED devices.

The group briefly discussed Subtask 4.2.1, "implementing strategies for improved light extraction and manipulation." The focus of activities in this Subtask is on improving known approaches for extracting light. There was some disagreement among the group as to whether this area was well represented in the program review presentations given on the previous day of the Workshop.

Subtask 4.2.2 focuses on "developing architectures that improve device robustness, increase lifetime and increase efficiency." By focusing on these issues when developing OLED products, better quality devices will be produced.

Subtask 4.2.3 considers the "development and demonstration of device architectures: e.g., white-light engines (multi-color versus single emission)." The goal is to demonstrate something that is scalable, for instance, a device architecture that enables you to scale it up in size so you can make something really big. Whether the work is directed at a down-converter blue, an RGB mix or some other approach, the problems are known, and the focus is trying to improve it.

Task 4.3. OLED Technology Integration

The goal of this Task is to develop efficient and reliable OLED lamps and luminaires. The title previously included the term "organic," but the group felt that throughout the R&D framework for OLEDs, it would be better to use the term OLED rather than organic.

Subtask 4.3.1 concentrates on "OLED encapsulation packaging for lighting applications." Contained within this Subtask are activities such as heat management and dissipation techniques, encapsulants to create robust devices, and down-conversion materials for maximizing high-quality lumen output. The group felt that this Subtask was one of the most important for the DOE, and one participant noted that "you can't sell devices if you don't solve the encapsulation problem."

Subtask 4.3.2 evaluates "simulation tools for modeling OLED devices." The scope of this Subtask was broadened to include all simulation tools associated with OLED devices. For example, a program similar to SPICE, a program used to model inorganic semiconductor (LED) circuits, could be developed to model the response of an OLED driver circuit under this subtask.

Subtask 4.3.3 considers topics such as "voltage conversion, current density, power distribution and driver electronics." This Subtask is clearly a system integration activity, encompassing a number of development challenges that will need to be addressed before mass production can be engaged. There are many opportunities here for cost-savings, and identifying techniques and approaches that will reduce production costs.

Subtask 4.3.4 includes the "development of luminaire designs, engineered applications, field tests and demonstrations." The group explained that this Subtask should focus on developing products that people want, and standardizing approaches, metrics and components (e.g., NIST research work). Generally, looking at the next one to two year timeframe, it was felt that the technology needs further development before this will become a priority.

Task 4.4. OLED Growth and Fabrication Processes and Manufacturing Issues
The goal of this Task is to develop equipment and tools for low-cost, high-yield manufacturing of OLED devices. There are three subtasks included in this Task that relate to growth and fabrication processes as well as manufacturing issues associated with OLED products.

Subtask 4.4.1 focuses on "module process optimization and manufacturing." The group discussed that this Subtask concentrates on "know-how" associated with scaled-up production of OLED devices. Some activities included in this Subtask include large-area coating and deposition, roll-to-roll manufacturing on flexible substrates, and optimization techniques associated with manufacturing.

Subtask 4.4.2 is associated with the "scale-up of active OLED materials for manufacturing and production." This involves developing and improving methods of depositing film and then being able to scale devices to production volumes where they could compete with general illumination devices. This Subtask also includes investigating impurities in the feedstock of the processes and other quality control issues associated with the chemicals used in manufacturing. Some participants in the group felt that the issue of the degree of purity of chemicals for production was not a critical issue for the next one to two years, but rather a five to ten year timeframe. The group considered moving this Subtask into Task 4.1, as it relates to research into production materials that operate in between the electrodes. However, others felt that this Subtask encompassed this issue more broadly, including all the components of the supply chain – the tools, the process and the supply chemicals.

Subtask 4.4.3 is a new Subtask that was added by the group to this Task. This Subtask was previously 3.4.2, called "tools and methods for manufacturing." The title of this new Subtask was modified to be "tools for manufacturing the lighting module." Quality control is a critical aspect of this Subtask. The group discussed the challenges encountered when determining the input quality of the materials used in manufacturing. If the chemicals do not meet the specifications, then the resulting OLED lighting modules will not meet their quality specifications. In-situ diagnostic tools, substrates and organic material purity are three critical aspects of this Subtask, which focuses on processes for scaling up manufacturing.

4.4.2. Revised Typology

Based on the discussion of the typology, the Group made revisions to the existing tasks and subtasks. The revised typology is below.

4.1. OLED Materials Development
Goal: develop devices with increased internal quantum efficiency

Subtask 4.1.1. Substrates for electro-active organic materials

Subtask 4.1.2. Between electrodes high-efficiency, low-voltage stable materials

Subtask 4.1.3. Improved contact materials and surface modification techniques to improve charge injection

4.2. OLED Device Architecture Development
Goal: develop devices with increased external quantum efficiency

Subtask 4.2.1. Implementing strategies for improved light extraction and manipulation

Subtask 4.2.2. Develop architectures that improve device robustness, increase lifetime and increase efficiency

Subtask 4.2.3. Demonstrate device architectures: e.g., white-light engines (multi-color versus single emission)

4.3. OLED Technology Integration
Goal: develop efficient and reliable OLED lamps and luminaires

Subtask 4.3.1. OLED encapsulation packaging for lighting applications
- Heat management and dissipation techniques
- Encapsulants to create robust devices
- Down-conversion materials for maximizing high-quality lumen output

Subtask 4.3.2. Simulation tools for modeling OLED devices

Subtask 4.3.3. Voltage conversion, current density and power distribution and driver electronics

Subtask 4.3.4. Luminaire design, engineered applications, field tests and demonstrations

4.4. OLED Growth and Fabrication Processes and Manufacturing Issues
Goal: develop equipment and tools for low-cost, high-yield manufacturing

Subtask 4.4.1. Module and process optimization and manufacturing
- Large-area coating and deposition
- Flexible substrates for roll-to-roll manufacturing

Subtask 4.4.2. Synthesis manufacturing scale-up of active OLED materials

Subtask 4.4.3. Tools for manufacturing the lighting module

4.4.3. Results of Prioritization

The following table provides the number of votes that were recorded for each of the subtasks. Through the voting process, the participants provided a recommendation to the Department on where it should be concentrating its R&D resources over the next one to two years.

Table 4-10: Prioritization of Group 4: Organic SSL Product Development

Task 4.1. OLED Materials Development	Number of Votes
4.1.1. Substrates for electro-active organic materials	17
4.1.2. Between electrodes high-efficiency, low-voltage stable materials	33
4.1.3. Improved contact materials and surface modification techniques to improve charge injection	4
Task 4.2. OLED Device Architecture Development	
4.2.1. Implementing strategies for improved light extraction and manipulation	25
4.2.2. Develop architectures that improve device robustness, increase lifetime and increase efficiency	28
4.2.3. Demonstrate device architectures: e.g., white-light engines (multi-color versus single emission)	2
Task 4.3. OLED Technology Integration	
4.3.1. OLED encapsulation packaging for lighting applications	27
4.3.2. Simulation tools for modeling OLED devices	0
4.3.3. Voltage conversion, current density and power distribution and driver electronics	0
4.3.4. Luminaire design, engineered applications, field tests and demonstrations	0
Task 4.4. OLED Growth and Fabrication Processes and Manufacturing Issues	
4.4.1. Module and process optimization and manufacturing	12
4.4.2. Manufacturing Scale-up of active OLED materials	3
4.4.3. Tools for manufacturing the lighting module	0

In total, Task 4.1 received 54 votes, Task 4.2 received 55 votes, Task 4.3 received 27 votes, and Task 4.4 received 15 votes. Figure 4-5 presents a histogram of the votes.

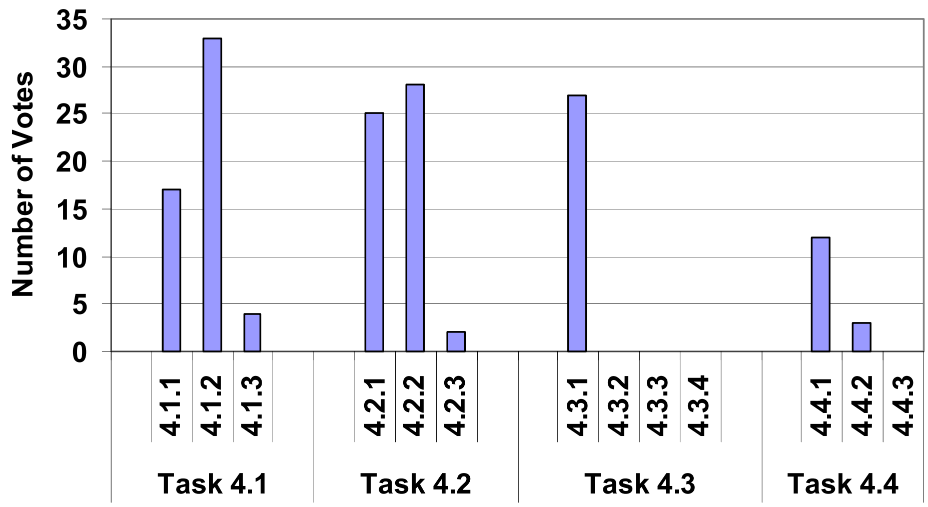

Figure 4-5: Prioritization of Group 4: Distribution of High Priority Votes

There were several subtasks that received more than twenty-five votes. Table 4-11 presents the five Subtasks that received the most votes.

Table 4-11: Prioritization of Group 4: Top Five Subtasks

Subtask	Number of Votes
4.1.2 Between electrodes high-efficiency, low-voltage stable materials	33
4.2.2 Develop architectures that improve device robustness, increase lifetime and increase efficiency	28
4.3.1 OLED encapsulation packaging for lighting applications	27
4.2.1 Implementing strategies for improved light extraction and manipulation	25
4.1.1 Substrates for electro-active organic materials	17

4.4.4. Post Voting Remarks and General Comments

The OLED group was satisfied with the results of the voting on product development. Recognizing that resources are limited, they felt that there were no surprises in the results, and that the voting reflected all the immediate/urgent issues that need to be studied in the next one to two years. The five cross-cutting themes were represented in the prioritized activities.

5. Coming Soon

The Department of Energy's Second Annual SSL Workshop in San Diego, California was successful and productive. Day 1 of the Workshop included brief presentations from the Department, industry representatives, academics and researchers. During Day 2 of the Workshop, participants reviewed, discussed, and prioritized more than 65 research and development tasks and subtasks within the DOE SSL R&D agenda. Feedback from this workshop will be one of the main sources used by the Department in the development of future SSL solicitations. The DOE intends to repeat these successful Workshops every one to two years.

DOE has a long-term vision for commercialization support of SSL technologies. Over the next 20 years (2005-2025), SSL technologies for general illumination will continue to improve and evolve, with luminous efficacy increasing and unit costs decreasing. Appropriate commercialization support strategies will be determined by the status of the technology relative to particular applications. Some commercialization support activities are already in progress. The full range of activities planned by DOE is listed in Section 3.1. Additional information is also provided in Appendix G.

In the next year, the Department and the NGLIA partnership will coordinate several activities. Refer to the DOE SSL and NGLIA websites[6] for further details on these activities.

DOE intends to issue the Core Technology Lab Call, the solicitation for Core Technology Research, and the solicitation for Product Development during 3Q FY05. More information will be posted on the SSL website soon. For information and updates on the DOE SSL R&D program, please visit http://www.netl.doe.gov/ssl

[6] The NGLIA website is hosted at: http://www.nema.org/prod/lighting/solid/

6. List of Appendices

APPENDIX A

SSL R&D Workshop Registrants List

SSL R&D Workshop Registrants List

Table A.1 Complete List of Workshop Registrants

Registrant's Name	Title	Company
Mowafak Al-Jassim	Dr.	National Renewable Energy Laboratory
Roberto Alvarez	President	Light Prescriptions Innovators, LLC
Homer Antoniadis	OLED Product Engineer	OSRAM Opto Semiconductors, Inc.
Daniel Barton	Manager	Sandia National Laboratories
Suresh Baskaran	Manager III	Pacific Northwest National Laboratory
David Bay	Manager of Research	OSRAM SYLVANIA INC.
Dietrich Bertram	Manager OLED Development	Philips Lighting
Rameshwar Bhargava	President	Nanocrystals Technology
Carl Bilgrien	Business Development Manager	Dow Corning
James Brodrick		U.S. Department of Energy
Doug Brookman		Public Solutions
Steve Brueck	Professor	University of New Mexico
Jenny Brust	Business Development Manager	AccelerOptics
Paul Budak	Partner	Advanced Electroluminescent Sciences
Paul Burrows	Laboratory Fellow	Pacific Northwest National Laboratory
Voitek Byszewski	Dr.	Consultant
Michael Callahan	Researcher	Air Force Research Lab
Henry E. Cantwell	Chief Scientist	ZN Technology
Densen Cao	President	CAO Group, Inc.
Allen Cary	Marketing and Sales Manager	Photon Inc.
Joel Chaddock	Project Manager	U.S. Department of Energy, National Energy Technology Laboratory
J.C. Chen	VP Marketing	Blue Photonics Inc.
Wei Chen	Ph.D., Senior Scientist	Nomadics, Inc.
Felipe Chibante		NanoTex Corporation
Makarand Chipalkatti	Innovation Management	OSRAM SYLVANIA INC
Thomas Choo	Vice President	ZN Technology Inc.
Louise Conroy	Consultant	Navigant Consulting, Inc.
M. George Craford	CTO	Lumileds Lighting
Randall Creighton	PMTS	Sandia National Laboratories
Eddie Christy		National Energy Technology Laboratory
Brian Crone	TSM	Los Alamos National Laboratory
Brian D'Andrade	Senior Scientist	Universal Display Corporation

Registrant's Name	Title	Company
Wendy Davis	Vision Scientist	National Institute of Standards and Technology
Lynn Davis	Senior Research Associate	RTI International
Steven DenBaars	Professor	University of California at Santa Barbara
John Dickenson	Business Development Manager	APCI
Kevin Dowling		Color Kinetics Inc.
Anil Duggal	Scientist	GE Global Research
Ralf Dunkel	Director	Display Products
Russell Dupuis	Professor	Georgia Institute of Technology
Paul Eckels	President	AccelerOptics
Ryan Egidi	Engineer	U.S. Department of Energy, National Energy Technology Laboratory
Arthur Epstein	Professor	Ohio State University
Waqidi Falicoff	Vice-President	Light Prescriptions Innovators, LLC
Zhaoyang Fan	Assistant Research Professor	Kansas State University
Ian Ferguson	Professor	Georgia Tech
Mark Fink	Director Engineering Services	Breault Research Organization, Inc.
Arthur Fischer	Research Scientist	Sandia National Laboratories
Robert Fleming	Program Manager	3M
Jelm Franse		Philips Lighting BV, BU Solid State Lighting
Michael Frate	Business Leads Coordinator	Breault Research Organization, Inc.
Doug Freitag	Consultant	Dow Corning Corporation
Jesse Froehlich	Researcher	Nitto Denko Technical
Jim Gaines	Principal Design Engineer	Philips
Scott Gaynor	Senior Research Chemist	The Dow Chemical Company
Leo Geng	Technical Solutions Manager	CAO Group, Inc.
Ken Gertz	Assistant Vice-President for Research	Rensselaer Polytechnic Institute
Kelly Gordon	Program Manager	Pacific Northwest National Laboratory
Paul A. Gottlieb	Assistant General Counsel for Technology Transfer and Intellectual Property	U.S. Department of Energy
Todd Graves	Business Program Manager	GE Global Research

Registrant's Name	Title	Company
Douglas Gyorke		U.S. Department of Energy, National Energy Technology Laboratory
Mike Hack	VP Strategic Product Development	Universal Display Corporation
Deborah Haitko	Ph.D.-Project Leader	General Electric Global Research
Jung Han	Associate Professor	Yale University
Drew Hanser	Chief Technical Officer	Kyma Technologies, Inc.
Uwe Happek	Dr.	The University of Georgia
James Harris	Research Manager	Corning Inc.
Ken Hess	Project Manager	Aixtron
Gustavo Hirata	Research Scientist	University of California at San Diego
Eugene Hong	Senior Consultant	Navigant Consulting, Inc.
William Houck	Engineer	Rohm and Haas Electronic Materials
Michelle Huang	Manager of LED Applications Engineering	OSRAM Opto Semiconductors Inc.
James Ibbetson	Manager, LED Process Development	Cree Santa Barbara Technology Center
James Intrater	Chief Engineer	Materials Modification, Inc.
Steve Johnson	Lighting Group Leader	Lawrence Berkeley National Laboratory
Bernd Keller	Vice President / General Manager	CREE, Inc.
Sheila Kennedy	Director of Design and Applied Research	Kennedy & Violich Architecture
Richard Kern	Engineering Section Manager	Lumileds Lighting
Garo Khanarian	Program Manager	Rohm and Haas
Bernard Kippelen	Professor	Georgia Institute of Technology
Klaus Kunze	Senior Materials Development Leader	Cabot Superior MicroPowders
Sandy Kushner	Contract Development Manager	Air Products 7 Chemicals, Inc.
Marc Ledbetter	Program Manager	Pacific Northwest National Laboratory
Virgil Lee	VP, Corporate Development	Maxdem Inc.
Mark Lehman	Executive Vice-President	Emissive Energy Corp.
Leslie Levine	Consultant	Les Levine Consultant
Jay Lewis	Dr.	MCNC-RDI (Research & Development Institute
Jie Liu	Assistant Professor	Duke University
Gao Liu	Scientist	Lawrence Berkeley National Laboratory
Robert Lucas	Vice-President	Onix Corporation
Samuel Mao	Staff Scientist	Lawrence Berkeley National Laboratory
Karen Marchese	Senior Writer/Project Manager	Akoya

Registrant's Name	Title	Company
Michael McCabe		U.S. Department of Energy
Fred McCormick	Senior Research Specialist	3M Display & Graphics Business Laboratory
Scott McCreary		CONCUR, Inc.
Michael Meis	Senior Research Specialist	3M
Alexander Mikhailovsky	Staff Researcher	University of California at Santa Barbara
Kailash Mishra	Dr.	OSRAM SYLVANIA Inc.
Amane Mochizuki	Chief Researcher	Nitto Denko Technical Corporation
Tim Moggridge	President	Instrument Systems
Theodore Moustakas	Professor	Boston University
Nadarajah Narendran	Director of Research Lighting Research Center	Rensselaer Polytechnic Institute
Jeff Nause	President	Cermet, Inc.
Rick Neby	Senior Laboratory Manager	3M
Hans Nikol	Dr.	Philips Lighting B.V.
Ann Norris	Associate Development Scientist	Dow Corning Corp.
David Norton	Professor	University of Florida
Arto Nurmikko	Professor	Brown University
Douglas Nutter	Vice-President of Business Development	Optical Research Associates
Yutaka Ohmori	Dr.	Nitto Denko Technical Corp.
Yoshi Ohno	Group Leader	National Institute of Standards & Technology
Jennifer Pagan	Senior Engineer	Dot Metrics Technologies
Primit Parikh	Manager, Process Development	CREE, Inc.
William Parkyn	Senior Optical Scientist	Light Prescriptions Innovators, LLC
David Pelka	President	Tailored Optical Systems Inc.
Ed Petrow		Lincoln Technical Services
Gregory Phelan	Assistant Professor	University of Washington
Roland Pitts	Optoelectronics Team Leader	National Renewable Energy Laboratory
Jeff Popielarczyk	Business Development Manager	GE Global Research
Jonathan Raab		Raab Associates
Emil Radkov	Phosphor Technology Manager	GELcore, LLC
Jeffrey Rageth	National Manager	3M

Registrant's Name	Title	Company
Ron Randall	Director of Sales and Marketing	CAO Group, Inc.
Bruce Rhodes	Director - Electronics Design Engineering	Philips Lighting Electronics
Kurt Riesenberg	Industry Director, Lighting Division	NEMA
Bernie Saffell	Manager, Building Technology Programs	Pacific Northwest National Laboratory
David Salzman	President	LightSpin Technologies, Inc.
Linda Sapochak	Staff Scientist	Pacific Northwest National Laboratory
David Schaafsma	President	Applied Optical Materials
Erik Scher	R&D Scientist	Nanosys, Inc.
Winston Schoenfeld	Assistant Professor of Optics and Photonics	University of Central Florida
Michael Scholand	Managing Consultant	Navigant Consulting, Inc.
E. Fred Schubert	Wellfleet Senior Constellation Professor	Rensselaer Polytechnic Institute
Rachel Segalman	Assistant Professor/Faculty Scientist	University of California at Berkeley / Lawrence Berkeley National Labs
Anant Setlur	Materials Scientist	GE Global Research
Sean Shaheen		
Narkis Shatz	Chief Scientist	SAIC
Jerry Simmons	Program Manager Solid State Lighting	Sandia National Laboratories
Terje Skotheim	Dr.	Intex
Darryl Smith	Dr.	Los Alamos National Laboratory
Franky So	OLED R & D	OSRAM Opto Semiconductors
William So		eLite Optoelectronics, Inc.
Sameer Sodhi	Marketing Manager	OSRAM SYLVANIA Inc.
Christopher Somogyi	CEO	AES, Inc.
Jin Joo Song	Professor	ECE Dept., University of California at San Diego
Ed Stokes	Associate Professor	University of North Carolina at Charlotte
Courtney Stout	Lighting Engineer	Independent Testing Labs, Inc.
David Strip	Senior Technical Associate	Eastman Kodak
Chris Summers	President/CEO	PhosphorTech
Mark Thompson	Professor	University of Southern California
Paul Thurk	President	InnovaLight, Inc.
Jeffrey Tsao	Member of Technical Staff	Sandia National Laboratories
Alexander Usikov	Dr.	Technologies and Devices International

Registrant's Name	Title	Company
Jud Virden	Deputy Associate Laboratory Director	Pacific Northwest National Laboratory
Brent Wagner	Senior Research Scientist	Georgia Tech Research Institute
King Wang	Principal Scientist	Agiltron Inc.
Allen Weiss P.E.	Professional Engineer	Sesco Lighting
Christian Wetzel	Professor	Rensselaer Polytechnic Institute
Grady White	Dr.	National Institute of Standards and Technology (NIST)
Darryl Williams	Senior Scientist	Cabot Corporation
Dale Work	Government Relations	Philips Electronics
Matthew Wrosch	Business Development Manager	Display Products
Henry Xin	Manager	ZN Technology Inc.
Steffen Zahn	Dr.	Air Products & Chemicals, Inc
David Zaziski	Business Development Associate	Nanosys, Inc.
Yong Zhang	Senior Scientist	National Renewable Energy Laboratory
Theodore Zhou	Principal Scientist	Universal Display Corporation

APPENDIX B

Web-Sites and Other Resources Related to SSL

Web-Sites and Other Resources Related to SSL

Department of Energy

http://www.netl.doe.gov/ssl (Building Technologies Program)
http://www.naseo.org/stac/ (State Technologies Advancement Collaborative)
http://www.oit.doe.gov/inventions/solicitations.shtml (Inventions and Innovation)
http://sbir.er.doe.gov/sbir (Small Business Innovation Research)
http://www.science.doe.gov/bes (Office of Basic Energy Sciences)
http://www.science.doe.gov/bes/dms/DMSE.htm (Division of Materials Science & Engineering)
http://www.science.doe.gov/grants/ (Sponsored Research Details)
http://www.energy.gov/scitech/index.html (Science & Technology across DOE)

Other Sources of Funding

http://www.atp.nist.gov (Advanced Technology Program)
http://www.nist.gov (National Institute of Standards and Technology)
http://www.darpa.mil/mto/ (DARPA Microsystems Technology Office)
http://www.nsf.gov/funding/research_edu_community.jsp (National Science Foundation)

Solid-State Lighting Partnership

http://www.nema.org/prod/lighting/solid/ (Next Generation Lighting Industry Alliance)

APPENDIX C

Definitions of Core Technology and Product Development

Definitions of Core Technology and Product Development

Core Technology - Core Technology research includes scientific efforts that seek to gain more comprehensive knowledge or understanding of the subject under study, with possible multiple applications or fields of use in mind. Within Core Technology research areas, scientific principles are demonstrated, and the knowledge is shown to offer price or performance advantages over previously available science/engineering. Laboratory testing and/or math modeling may be conducted to gain new knowledge, and provide the options (technical pathways) to a SSL application. Activities could include theory, fabrication, and measurement of a material to provide the detailed understanding (properties and relationships) that solve one or more of the technical challenges of the DOE SSL program. Tasks in Core Technology are truly innovative and groundbreaking, fill technology gaps, provide enabling knowledge or data, and represent a significant advancement in the SSL knowledge base. These tasks focus on gaining pre-competitive knowledge for future application to products, for use by other organizations. The desired outcome is pioneering work that would be available to the community at large, to use and benefit from as they work collectively towards attainment of the DOE's efficacy goals.

Some examples include: theoretical investigations of light generation and extraction at molecular scales; material properties of substrates, encapsulants, or polymers; software tools that capture scientific principles to expedite the decision process of design; modeling of heat transfer principles to estimate temperature profiles within a semiconductor reactor; and mapping of scientific principles that explain the interactions of dopants and hosts or metal alloys to create light of a specified spectrum.

Product Development - Product Development is the systematic use of knowledge gained from basic and applied research to develop or improve commercially viable materials, devices, or systems. Technical activities are focused on a targeted market application with fully defined price, efficacy, and other performance parameters necessary for success of the proposed product. Product development encompasses the technical activities of product concept modeling through to the development of test models and field-ready prototypes. In some cases, Product Development may include "focused-short-term" applied research, but its relevance to a specific product must be clearly identified.

Laboratory performance testing is conducted on prototypes to evaluate product utility, market, legal, health, and safety issues. Feedback from the owner/operator and technical data gathered from testing are used to improve prototype designs. Further design modifications and re-testing are performed as needed.

Along with the technical aspects of Product Development, market and fiscal studies are completed to ensure a successful transition from Product Development to demonstration and commercialization. To be positioned for success, new products must exhibit cost and/or performance advantages over commercially available technologies.

APPENDIX D

Original List of R&D Task Areas Discussed (Pre-Workshop)

Original List of R&D Task Areas Discussed (Pre-Workshop)

Group 1. Inorganic SSL "Core Technology" Research

1.1 Inorganic Materials Research: Enabling Physics and Chemistry
Goal: increase internal quantum efficiency

1.1.1 Substrates, buffer layers, and wafer research
- Large area, low defect density bulk substrates
- Low defect density buffer layers

1.1.2 High efficiency visible and near-UV semiconductor materials
- Efficient, yellow-green emitters
- Efficient near UV emitters (360 to 410 nm)
- P-doping and charge mobility studies

1.1.3 Reliability and defect physics for improved LED lifetime
- Device, dopant and defect physics and interactions
- Dopant and defect characterization
- Droop (reduced efficiency at high temperature and current density)

1.2 Inorganic Device Architecture and Conversion Materials
Goal: increase external quantum efficiency

1.2.1 Source emitters
- Lasers, resonant cavities
- Photonic crystals & microcavity effects
- Surface plasmons

1.2.2 Stable, efficient, long-life phosphors, luminescent materials for wavelength conversion.
- D65 or spectrum replacing
- High temperature (>200°C)

1.2.3 High temperature, long lived, UV-tolerant encapsulants
- Nanocomposites
- High temperature (>200°C)

1.3 Inorganic Technology Integration
Goal: develop technology that enables high performance devices

1.3.1 Physical, chemical, and optical models for the epitaxial process and the LED device

1.4 Tools and Techniques to Improve Inorganic Manufacturing
Goal: cross-cutting improvements to manufacturing

1.4.1 Invention, design and development of in-situ diagnostic tools for the epitaxial process

1.4.2 Modeling and development of low-cost, high-efficiency reactor designs for efficient source utilization

1.4.3 Investigation (theoretical and experimental) of die separation, chip shaping, and wafer bonding techniques

1.4.4 Scale to larger wafers

Total for Group 1. Inorganic SSL "Core Technology" Research: 4 tasks and 11 subtasks.

Group 2. Inorganic SSL "Product Development"

2.1 Inorganic Materials Development

Goal: increase internal quantum efficiency

2.1.1 Advanced substrate, buffer layer and wafer engineering and development

2.1.2 High efficiency, long-lived, low-cost visible and near-UV semiconductor materials systems

2.1.3 Nitride materials limitations for cost-effective HB LEDs

2.2 Advanced Inorganic Device Architecture and Conversion Materials and Encapsulants

Goal: develop device level technology

2.2.1 Advanced architectures with high power conversion efficiencies

- Chip scaling and micro arrays
- Large area light extraction and current injection
- Multi-color chips and/or RGB arrays on a single substrate

2.2.2 Manufactured materials

- Phosphors and luminescent materials
- High temperature encapsulants and mounting materials

2.3 Inorganic Technology Integration

Goal: improve components

2.3.1 Advanced packages and packaging materials

- Ohmic losses: Ultra-low resistance contacts, tunnel contacts
- Advanced heat dissipation strategies

2.3.2 Binning strategies

2.3.3 Modeling, distribution and coupling issues (chip, device and component level)

- Secondary optics design
- Computer simulators and analysis tools

2.3.4 Advanced electronics

- Size, voltage, standardization, color control
- Light engine versus luminaire electronics

2.4 Equipment and Tools for Low-Cost, High-Yield Manufacturing

Goal: cost-effective manufacturing

2.4.1 Incorporate existing or proven in-situ diagnostic tools into existing equipment

2.4.2 Implementation of demonstrated, low-maintenance, low-cost, high-efficiency reactor designs including die separation, chip shaping, and wafer bonding

2.5 Inorganic Lighting Systems

Goal: practical sources and luminaires

2.5.1 Retrofit luminaire designs, field tests and demonstrations
- Low voltage reflector (MR-16)
- Screw-In replacements (A-19)
- Integrated solutions (distributed lighting)

2.5.2 New luminaire designs, engineered applications, field tests and demonstrations

2.6 Human Factors and Visual Performance Issues

Goal: market deployment

2.6.1 Measurement metrics and standards

2.6.2 Performance, workplace environmental quality and demonstrations

Total for Group 2. Inorganic SSL “Product Development”: 6 tasks and 15 subtasks.

Group 3. Organic SSL "Core Technology" Research

3.1 Organic Materials Research: Enabling Physics and Chemistry
Goal: increase internal quantum efficiency

3.1.1 Application of basic Electro-Active Organic Materials Research to OLEDs

3.1.2 High efficiency, low-voltage, stable materials for OLED-based general illumination technology (hosts, dopants, and transport layers)

3.1.3 Improved contact materials (n and p doped polymers) and surface modification techniques to improve charge injection (electrode substrates)

3.1.4 Organic materials for large area electrodes and interconnects

3.2 Advanced Organic Device Architecture and Materials
Goal: increase external quantum efficiency

3.2.1 Novel strategies for improved light extraction and manipulation

3.2.2 Novel device approaches, structures and systems for improved performance (e.g., white light) and low cost

3.2.3 Advanced materials and designs for electrodes and interconnects

3.3 Materials and Characterization for Increased Efficiency, Performance, Long-term Stability and High-reliability
Goal: improved performance

3.3.1 Novel encapsulation and packaging materials

3.3.2 Novel and advanced electrodes, e.g., transparent

3.4 Manufacturing Equipment and Tools for OLED Lighting
Goal: cost effective manufacturing

3.4.1 Low cost fabrication substrates and technologies (roll, flexible or not)

3.4.2 Low cost, efficient patterning techniques

Total for Group 3. Organic SSL “Core Technology” Research: 4 tasks and 10 subtasks.

Group 4. Organic SSL "Product Development"

4.1 Organic Device Architectures

Goal: develop device level technology

4.1.1 Implementing light extraction and manipulation strategies whose impact on performance has been quantified and proven

4.1.2 Efficient and practical phosphors and phosphor excimers with demonstrated efficiency improvement

4.2 OLED Module Integration

Goal: develop demonstration devices

4.2.1 Reliable, robust OLED packages for lighting applications

4.2.2 Physics, chemistry, and optical design models from OLED molecule structure to bulk morphology

4.2.3 Characterization tools for device, module and process optimization and manufacturing

4.2.4 Demonstrate novel device architectures: e.g., white light engines (RGB versus single emission)

4.3 Systems Architecture Issues

Goal: address application spaces

4.3.1 Voltage conversion, current density and power distribution

4.3.2 Luminaire design, engineered applications, field tests and demonstrations

4.4 Equipment and Tools for Low-Cost, High-Yield Manufacturing

Goal: cost-effective manufacturing

4.4.1 Synthesis of active OLED materials

4.4.2 Large-area coating and deposition

4.4.3 Plastic substrates for flexibility and roll-to-roll manufacturing

4.5 Human factors and visual performance issues

Goal: market deployment

4.5.1 Measurement metrics and standards

4.5.2 Performance, workplace environmental quality and demonstrations

Total for Group 4. Organic SSL "Product Development": 5 tasks and 13 subtasks.

APPENDIX E

Revised R&D Task Areas, Incorporating Written Comments before the Workshop

Revised R&D Task Areas, Incorporating Written Comments before the Workshop

Group 1. Inorganic SSL "Core Technology" Research

The bullets are descriptive examples and do not represent an exhaustive list or priority areas of research.

1.1. Inorganic Materials Research

Goal: increase internal quantum efficiency

1.1.1. Large-area substrates, buffer layers, and wafer research
- Low defect density
- Existing and alternate low-cost substrates

1.1.2. High-efficiency semiconductor materials
- Efficient broadband materials (including orange, yellow-green, and UV (360nm to 410nm))
- Existing and alternate low-cost materials (e.g. nitride materials)
- p-doping and charge mobility studies

1.1.3. Reliability and defect physics for improved LED lifetime
- Dopant and defect physics, device characterization and modeling
- Droop (reduced efficiency at high temperature and current density)

1.2. Inorganic Device Architecture Research and Modeling

Goal: increase external quantum efficiency

1.2.1. Device approaches, structures and systems
- Lasers, resonant cavities
- Nanocomposite sources (e.g., photonic crystals & microcavity effects)
- Surface plasmons

1.2.2. Strategies for improved light extraction and manipulation
- Optical and device modeling for general illumination

1.3. Inorganic Technology Integration

Goal: research technology for high performance LED lamps and luminaires

1.3.1. Phosphors and conversion materials
- Deposition methods and technology, layer packing
- Long-life, heat tolerant (e.g., nanophosphors)

1.3.2. Encapsulants and packaging materials
- High temperature, long-life, UV-tolerant, improved optical extraction (e.g., nanocomposites)
- Thermal management strategies and modeling

1.3.3. Electrodes and interconnects
- Ultra-low resistance
- Piezoelectric contacts

1.3.4. Measurement metrics and human factors
- Productivity, preference, and demonstrations
- Use-dependent metrics for white light
- Standards for electrical and photometric measurement
- Binning strategies

1.4. Inorganic Growth and Fabrication Processes and Manufacturing Issues

Goal: cross-cutting improvements to growth and fabrication processes and manufacturing

1.4.1. Physical, chemical, and optical modeling for epitaxial processes

1.4.2. Design and development of in-situ diagnostic tools for the epitaxial process

1.4.3. Research into low-cost, high-efficiency reactor designs and manufacturing methods

1.4.4. Investigation (theoretical and experimental) of die separation, chip shaping, and wafer bonding techniques

Total for Group 1. Inorganic SSL “Core Technology” Research: 4 tasks and 13 subtasks.

Group 2. Inorganic SSL "Product Development"

***The bullets are descriptive examples and do not represent an exhaustive list or priority areas of research*.**

2.1. Inorganic Materials Development

Goal: develop devices with increased internal quantum efficiency

2.1.1. Substrate, buffer layer and wafer engineering and development

2.1.2. High-efficiency semiconductor materials
- Efficient broadband light emitting materials (including yellow-green, orange, and UV (360nm to 410nm))
- Existing and alternate low-cost materials (e.g., nitride materials)

2.2. Inorganic Device Architecture Development

Goal: develop devices with increased external quantum efficiency

2.2.1. Implementing strategies for improved light extraction and manipulation
- High refractive index encapsulants for improved light extraction
- Large-area light extraction and current injection

2.2.2. Device architectures with high power-conversion efficiencies
- Chip scaling and micro-arrays
- Multi-color chips, arrays on a single substrate

2.3. Inorganic Technology Integration

Goal: develop cost-effective LED lamps and luminaires

2.3.1. Manufactured materials
- Phosphors and luminescent materials
- High temperature encapsulants and mounting materials

2.3.2. LED packages and packaging materials
- Ultra-low resistance contacts, tunnel contacts
- Heat dissipation techniques

2.3.3. Modeling, distribution and coupling issues (chip, device and component level)
- Secondary optics design
- Computer modeling and analysis tools

2.3.4. Luminaire design, engineered applications, field tests and demonstrations

- Practical retrofit lamp designs (e.g., low-voltage reflector (MR-16), screw-in replacements (A-19), integrated solutions (distributed lighting))
- New installation luminaire designs
- Advanced electronics (e.g., standardization, color control)

2.4. Inorganic Growth and Fabrication Processes and Manufacturing Issues
Goal: develop equipment and tools for low-cost, high-yield manufacturing and scaling to larger wafers

2.4.1. Incorporate proven in-situ diagnostic tools into existing equipment

2.4.2. Develop low-cost, high-efficiency reactor designs

2.4.3. Develop techniques for die separation, chip shaping, and wafer bonding

Total for Group 2. Inorganic SSL “Product Development”: 4 tasks and 11 subtasks.

Group 3. Organic SSL "Core Technology" Research

The bullets are descriptive examples and do not represent an exhaustive list or priority areas of research.

3.1. Organic Materials Research

Goal: increase internal quantum efficiency through enabling physics and chemistry

3.1.1. Electro-active organic materials substrate research

3.1.2. High-efficiency, low-voltage, stable materials (host, dopant and transport layers)
- Stable hole and electron blocking layers
- Single and multilayered devices

3.1.3. Improved contact materials and surface modification techniques to improve charge injection
- n and p doped polymers
- Molecular dopants

3.2. Organic Device Architecture Research and Modeling

Goal: increase external quantum efficiency

3.2.1. Strategies for improved light extraction and manipulation
- Optical and device modeling for general illumination

3.2.2. Approaches, structures and systems for improved-performance low-cost white-light devices

3.2.3. Transparent electrode research

3.3. Organic Technology Integration

Goal: research technology for high performance OLED lamps and luminaires

3.3.1. Phosphors and conversion materials

3.3.2. Encapsulation and packaging materials

3.3.3. Electrodes and interconnects

3.3.4. Measurement metrics and human factors
- Productivity, preference, and demonstrations
- Standards for electrical and photometric measurement

3.4. Organic Growth and Fabrication Processes and Manufacturing Issues
Goal: develop equipment and tools for low-cost, high-yield manufacturing

3.4.1. Physical, chemical and optical modeling for fabrication of OLED devices

3.4.2. Tools and methods for manufacturing
- In-situ diagnostic tools
- Organic material purity

3.4.3. Investigation (theoretical and experimental) of low-cost fabrication and patterning techniques

Total for Group 3. Organic SSL “Core Technology” Research: 4 tasks and 13 subtasks.

Group 4. Organic SSL "Product Development"

The bullets are descriptive examples and do not represent an exhaustive list or priority areas of research.

4.1. Organic Materials Development
Goal: develop devices with increased internal quantum efficiency

4.1.1. Electro-active organic materials substrate development

4.1.2. High-efficiency, low-voltage stable materials (host, dopant and transport layers)

4.1.3. Improved contact materials and surface modification techniques to improve charge injection

4.2. Organic Device Architecture Development
Goal: develop devices with increased external quantum efficiency

4.2.1. Implementing strategies for improved light extraction and manipulation

4.2.2. Develop architectures that improve device robustness, increase lifetime and increase efficiency

4.2.3. Demonstrate device architectures: e.g., white-light engines (multi-color versus single emission)

4.3. Organic Technology Integration
Goal: develop efficient and reliable OLED lamps and luminaires

4.3.1. OLED packaging for lighting applications
- Heat management and dissipation techniques
- Encapsulants to create robust devices
- Down-conversion materials for maximizing high-quality lumen output

4.3.2. Characterization tools for modeling OLED devices

4.3.3. Voltage conversion, current density and power distribution

4.3.4. Luminaire design, engineered applications, field tests and demonstrations

4.4. Organic Growth and Fabrication Processes and Manufacturing Issues
Goal: develop equipment and tools for low-cost, high-yield manufacturing

4.4.1. Module and process optimization and manufacturing

- Large-area coating and deposition
- Flexible substrates for roll-to-roll manufacturing

4.4.2. Synthesis of active OLED materials

Total for Group 4. Organic SSL "Product Development": 4 tasks and 12 subtasks.

APPENDIX F

Final R&D Task Areas Developed by Participants at the Workshop

Final R&D Task Areas Developed by Participants at the Workshop

Group 1. Inorganic SSL "Core Technology" Research

The bullets are descriptive examples and do not represent an exhaustive list or priority areas of research.

Task 1.1: Inorganic Materials Research

Goal: increase internal quantum efficiency

Subtask 1.1.1: Large-area substrates, buffer layers, and wafer research
- Low defect density
- Existing and alternate low-cost substrates

Subtask 1.1.2: High-efficiency semiconductor materials
- Efficient broadband materials (including orange, yellow, green, and UV (360nm to 410nm))
- Existing and alternate low-cost materials (e.g. nitride materials)
- p-doping and charge mobility studies
- alloy phenomena

Subtask 1.1.3: Reliability and defect physics for improved emitter lifetime and efficiency
- Dopant and defect physics, device characterization and modeling
- Droop (reduced efficiency at high temperature and current density)

Subtask 1.1.4: Conversion Materials

Task 1.2: Inorganic Device Architecture Research and Modeling

Goal: increase external quantum efficiency

Subtask 1.2.1: Device approaches, structures and systems
- Lasers, resonant cavities
- Nanocomposite sources (e.g., photonic crystals & microcavity effects)
- Surface plasmons

Subtask 1.2.2: Strategies for improved light extraction and manipulation
- Optical and device modeling for general illumination

Task 1.3: Inorganic Integration Technology Research

Goal: research technology for high performance LED lamps and luminaires

Subtask 1.3.1: High-Efficiency Phosphors and conversion materials
- Deposition methods and technology, layer packing
- Long-life, heat tolerant (e.g., nanophosphors)
- Higher performance converter research

Subtask 1.3.2: Encapsulants and packaging materials

- High temperature, long-life, UV-tolerant, improved optical extraction (e.g., nanocomposites)
- Thermal management strategies and modeling

Subtask 1.3.3: Electrodes and interconnects
- Ultra-low resistance
- Piezoelectric contacts

Subtask 1.3.4: Measurement metrics and human factors
- Productivity, preference, and demonstrations
- Use-dependent metrics for white light
- Standards for electrical and photometric measurement
- Binning strategies

Task 1.4: Inorganic Growth and Fabrication Processes and Manufacturing Research
Goal: cross-cutting improvements to growth and fabrication processes and manufacturing

Subtask 1.4.1: Physical, chemical, optical modeling, measurement, and experimentation for substrate and epitaxial processes

Subtask 1.4.2: Design and development of in-situ diagnostic tools for the substrate and epitaxial process

Subtask 1.4.3: Research into low-cost, high-efficiency reactor designs and manufacturing methods

Subtask 1.4.4: Investigation (theoretical and experimental) of die separation, chip shaping, and wafer bonding techniques

Total for Group 1. Inorganic SSL "Core Technology" Research: 4 tasks and 14 subtasks.

Group 2. Inorganic SSL "Product Development"

Task 2.1. Inorganic Materials and Device Architecture
Goal: increase internal and external quantum efficiency

Subtask 2.1.1. Substrate, buffer layer and wafer engineering and development

Subtask 2.1.2. High-efficiency semiconductor materials
- Efficient broadband light emitting materials (including yellow-green, orange, and UV (360nm to 410nm))
- Existing and alternate low-cost materials (e.g., nitride materials)

Subtask 2.1.3. Implementing strategies for improved light extraction and manipulation
- High refractive index encapsulants for improved light extraction
- Large-area light extraction and current injection

Subtask 2.1.4. Device architectures with high power-conversion efficiencies
- Chip scaling and micro-arrays
- Multi-color chips, arrays on a single substrate

Task 2.2. LED Component Technical Integration
Goal: develop cost-effective LED lamps and luminaires

Subtask 2.2.1. Manufactured materials
- Phosphors and luminescent materials
- High temperature encapsulants and mounting materials

Subtask 2.2.2. LED packages and packaging materials
- Ultra-low resistance contacts, tunnel contacts
- Heat dissipation techniques

Subtask 2.2.3. Modeling, distribution, and coupling issues
- Secondary optics design
- Computer modeling and analysis tools

Subtask 2.2.4. Evaluate component lifetime and performance characteristics

Task 2.3. System Technology Integration and Novel Luminaire Design

Subtask 2.3.1. Optical coupling and modeling

Subtask 2.3.2. Mechanical design

Subtask 2.3.3. Electronics development
- Size, voltage, standardization, color control

- Light engine versus luminaire electronics

Subtask 2.3.4. Thermal design

Subtask 2.3.5. Evaluate human factors and metrics

Subtask 2.3.6. Evaluate systems lifetime and performance characteristics

Task 2.4. Inorganic Growth and Fabrication Processes and Manufacturing Issues
Goal: develop equipment and tools for low-cost, high-yield manufacturing and scaling to larger wafers.

Subtask 2.4.1. Incorporate proven in-situ diagnostic tools into existing equipment

Subtask 2.4.2. Develop low-cost, high-efficiency reactor designs

Subtask 2.4.3. Develop techniques for die separation, chip shaping, and wafer bonding

Total for Group 2. Inorganic SSL "Product Development": 4 tasks and 17 subtasks.

Group 3. Organic SSL "Core Technology" Research

The bullets are descriptive examples and do not represent an exhaustive list or priority areas of research.

3.1. OLED Materials Research

Goal: increase internal quantum efficiency through enabling physics and chemistry

Subtask 3.1.1. Substrate materials for electro-active organic devices

Subtask 3.1.2. High-efficiency, low-voltage, stable materials
- Stable hole and electron blocking layers
- Single and multilayered devices

Subtask 3.1.3. Improved contact materials and surface modification techniques to improve charge injection
- n and p doped organics
- Molecular dopants

Subtask 3.1.4. Fundamental Science

3.2. OLED Device Architecture Research and Modeling

Goal: increase external quantum efficiency

Subtask 3.2.1. Strategies for improved light extraction and manipulation
- Optical and device modeling for general illumination

Subtask 3.2.2. Approaches to OLED structures between the electrodes for improved-performance low-cost white-light devices

Subtask 3.2.3. Research on low-cost transparent electrodes

3.3. OLED Technology Integration

Goal: research technology for high performance OLED lamps and luminaires

Subtask 3.3.1. Down conversion materials

Subtask 3.3.2. Low-cost encapsulation and packaging technology

Subtask 3.3.3. Electrodes and interconnects

Subtask 3.3.4. Measurement metrics and human factors
- Productivity, preference, and demonstrations
- Standards for electrical and photometric measurement

3.4. Organic Growth and Fabrication Processes and Manufacturing Issues

Goal: develop equipment and tools for low-cost, high-yield manufacturing

Subtask 3.4.1. Physical, chemical and optical modeling for fabrication of OLED devices

Subtask 3.4.2. Investigation (theoretical and experimental) of low-cost fabrication and patterning techniques and tools

Total for Group 3. Organic SSL "Core Technology" Research: 4 tasks and 13 subtasks.

Group 4. Organic SSL "Product Development"

The bullets are descriptive examples and do not represent an exhaustive list or priority areas of research.

4.1. OLED Materials Development
Goal: develop devices with increased internal quantum efficiency

Subtask 4.1.1. Substrates for electro-active organic materials

Subtask 4.1.2. Between electrodes high-efficiency, low-voltage stable materials

Subtask 4.1.3. Improved contact materials and surface modification techniques to improve charge injection

4.2. OLED Device Architecture Development
Goal: develop devices with increased external quantum efficiency

Subtask 4.2.1. Implementing strategies for improved light extraction and manipulation

Subtask 4.2.2. Develop architectures that improve device robustness, increase lifetime and increase efficiency

Subtask 4.2.3. Demonstrate device architectures: e.g., white-light engines (multi-color versus single emission)

4.3. OLED Technology Integration
Goal: develop efficient and reliable OLED lamps and luminaires

Subtask 4.3.1. OLED encapsulation packaging for lighting applications
- Heat management and dissipation techniques
- Encapsulants to create robust devices
- Down-conversion materials for maximizing high-quality lumen output

Subtask 4.3.2. Simulation tools for modeling OLED devices

Subtask 4.3.3. Voltage conversion, current density and power distribution and driver electronics

Subtask 4.3.4. Luminaire design, engineered applications, field tests and demonstrations

4.4. OLED Growth and Fabrication Processes and Manufacturing Issues
Goal: develop equipment and tools for low-cost, high-yield manufacturing

Subtask 4.4.1. Module and process optimization and manufacturing

- Large-area coating and deposition
- Flexible substrates for roll-to-roll manufacturing

Subtask 4.4.2. Synthesis manufacturing scale-up of active OLED materials

Subtask 4.4.3. Tools for manufacturing the lighting module

Total for Group 4. Organic SSL "Product Development": 4 tasks and 13 subtasks.

APPENDIX G

Solid-State Lighting Program Commercialization Support Pathway

Solid-State Lighting Program

Commercialization Support Pathway

U.S. Department of Energy

February 2005

Building Technologies Program
Energy Efficiency and Renewable Energy
U.S. Department of Energy

I. SSL R&D Investment Leads to Technology Commercialization

The U.S. Department of Energy has made a long-term commitment to develop and support commercialization of white-emitting solid-state lighting (SSL) for general illumination, including sources, fixtures, electronics, and controls. The plan for DOE's SSL program will require investing hundreds of millions of dollars over a 20 year period on applied research and development targeting technology improvements in six areas: quantum efficiency, longevity, sustainability and control, packaging, infrastructure, and cost reduction. The R&D investment serves the ultimate goal to successfully commercialize the technologies in the buildings sector, where lighting accounts for more than 20 percent of total electricity use.

Potential benefits are enormous if SSL technology achieves projected price and performance characteristics anticipated under an accelerated investment scenario:

- By 2025, SSL could displace general illumination light sources such as incandescent and fluorescent lamps, decreasing national energy consumption for lighting by about 0.45 quads annually, that is, enough energy saved to serve the lighting demand of 20 million households today.
- The cumulative energy expenditure savings from 2005 to 2025 would translate into more than $25 billion dollars saved.
- The cumulative energy savings from 2005 to 2025 is projected to be over 1.5 quads.

To realize the full promise of solid-state lighting by 2025, major research challenges must be addressed. To help tackle these challenges, DOE is funding selected research and development to improve efficiency and speed SSL technologies to market. Projects are selected to align with a comprehensive R&D plan developed in partnership with industry, research and academic organizations, and national laboratories. DOE has and will continue to maintain a focus on the ultimate goal of supporting commercialization of SSL technologies to decrease lighting energy use while improving and expanding lighting services. Unique attributes of SSL technologies underscore the importance of a long-term, coordinated approach encompassing applied research and strategic technology commercialization support.

Commercialization support efforts must be closely coordinated with research. Effective market introduction of SSL technologies must be informed by and coordinated with the applied research currently underway. As R&D progresses, SSL technologies will attain performance levels that make them appropriate and advantageous for various applications. For example, today's commercially available LEDs offer energy efficiency, maintenance savings, impact resistance, durability, and other benefits for traffic signals, exit signs, airport taxi-way lighting, and other niche applications. White LEDs are approaching performance levels that make them attractive for use in automobiles, aircraft, and elevators. For most general illumination applications, current LEDs cannot yet compete with traditional sources on the basis of either performance or cost. The timing and targeting of commercialization support efforts is as important to the ultimate success of SSL as current R&D investment. Premature commercialization of these technologies will damage the lighting market, wasting the energy efficiency potential of SSL and potentially even reversing progress that has been made in improving lighting energy efficiency through fluorescent and HID technologies.

Optimal performance of SSL technologies depends on appropriate application and system design. In the current excitement about LEDs, a range of white light products are being rushed to market, often with disappointing results. DOE's review (late-2004) of currently available white LED products has found ceiling fixtures, reading lights, and under-cabinet lights marketed as "energy efficient" but providing only one-tenth to one-third of the light output of typical incandescent and fluorescent fixtures in these categories. Realizing the energy efficiency and lighting performance potential of SSL requires comprehensive understanding of the characteristics, benefits, and limitations of the technology. Inappropriate application of SSL puts the potential benefits at risk, creating consumer dissatisfaction, increasing manufacturer and investor risk, and delaying market development.

New technology could fundamentally change the lighting market. Solid-state lighting differs fundamentally from incandescent, fluorescent, and HID lighting technologies, and will therefore require a high degree of coordination with R&D efforts and deep understanding of the technology challenges facing SSL. DOE's long-term involvement in virtually every aspect of SSL technology R&D will aid in the design of appropriate commercialization support strategies for these technologies.

Commercialization of SSL faces specific challenges due to the unique nature of these new lighting technologies. The materials, drivers, system architecture, controls, and photometric properties of SSL differ from traditional lighting technologies. Today's residential light fixtures, for example, are produced by manufacturers who design fashionable packaging for incandescent or fluorescent lamps. SSL will enable completely new and different approaches to household lighting. They may be integrated into building materials, furniture, or cabinetry. They may be linked to whole-house control and communication systems. SSL technology is likely to spark innovations that will change the way lighting is delivered to the market.

DOE's long-term relationships underpin the key Government role in promoting SSL. Solid-state lighting products will continue to be brought to market and will succeed or fail based on their consumer appeal, pricing, and performance. However, the US Government can and should play an important role in establishing guidelines, tools, and incentives to help ensure SSL quality, energy efficiency, and performance. DOE has a responsibility to see that this new technology, which is being developed with the significant support of public funds, is brought to the market in a way that maximizes its chances for success and wide-spread public benefit.

The Department's on-going relationships with the SSL industry and research community are fundamental to this role. To this end, DOE holds 50 to 70 meetings per year with individual companies, trade associations, and other stakeholders. Over the past 25 years with the lighting industry in general, and over the past 10 years with the SSL industry specifically, DOE has developed positive working relationships related to lighting technology, markets, and regulation. DOE holds an annual SSL workshop with industry and has signed a Memorandum of Agreement with the Next Generation Lighting Industry Alliance (NGLIA) to represent those parties with interest in a future SSL market.

Successful commercialization that captures the public benefits of SSL technology requires partnership and effective communication both with the SSL industry and with other organizations that influence lighting use, including electric utilities, energy efficiency market transformation groups, lighting designers, architects, lighting retailers, and lighting fixture manufacturers. DOE has begun strategic outreach around the country in preparation for SSL technology commercialization support activities.

II. Commercialization Support Strategies

DOE has a long-term vision for commercialization support of SSL technologies. Over the next 20 years (2005-2025), SSL technologies for general illumination will continue to improve and evolve, with luminous efficacy increasing and unit costs decreasing. Appropriate commercialization support strategies will be determined by the status of the technology relative to particular applications. Some commercialization support activities are already in progress; the full range of activities planned by DOE includes those described briefly below.

Partnership with Industry Associations

DOE will continue to work closely with industry associations to establish industry standards and reporting conventions, and to address key infrastructure issues affecting the SSL industry. Current and on-going industry partner relationships include the NGLIA, the American Lighting Association (ALA), and the National Electrical Manufacturers Association (NEMA).

ENERGY STAR® for SSL Technologies

DOE will establish ENERGY STAR® specifications for SSL technologies used in various sectors and applications, including the residential and commercial sectors. Separate specifications may be needed to address new construction and retrofit applications.

Technology Procurement

DOE will use the technology procurement approach to pull into the market new SSL systems and products that meet established energy efficiency and performance criteria, and link these products to volume buyers and market influencers. Volume buyers may include the federal government (FEMP, DLA, GSA), utilities, or various sub-sectors including hospitals, lodging, retail, etc. DOE has employed this approach successfully with other lighting technologies, including sub-CFLs and reflector CFLs.

Design Competitions

DOE will sponsor lighting fixture/system design competitions to recognize and promote innovative new designs incorporating SSL for specific market segments. This effort will build upon the success of the “Lighting for Tomorrow” competition sponsored by DOE in partnership with the residential lighting industry through the American Lighting Association, and the utility and energy efficiency communities through the Consortium for Energy Efficiency.

Demonstration and Performance Verification

DOE will gain real-life experience and data involving SSL installations in various applications through demonstration and performance verification, including measurement of energy consumption, light output, color consistency, and interface/control issues.

Technology Tracking and Information Services
DOE will continue to track SSL products and technologies to provide an independent, third-party source of information on the performance characteristics of the technology and a record of technology development over time.

Consumer Awareness Programs
DOE will design advertising and public education materials to help consumers evaluate SSL products, determine appropriate applications for SSL technology, and understand the energy and other benefits of the technology.

Retailer Training Programs
DOE will develop information and training materials to aid lighting retailers in communicating about SSL technologies with their customers.

Builder Programs
DOE will develop and deliver technology transfer and training programs to increase homebuilders' awareness and technical knowledge of SSL.

Designer Programs
DOE will support development of materials and curricula for interior design and lighting design professionals.

Education Programs
To support development of the next generation of engineers and designers who will implement SSL, DOE will develop materials and information on SSL technologies for schools, supporting SSL-related projects in the context of class work and science fairs.

Utility Promotion and Incentive Programs
DOE will continue to work with electric utilities and other program sponsors that are active in promoting energy-efficient lighting. Energy efficiency programs have proven to have a significant impact in bringing new technologies to market, through cooperative advertising with retailers, targeted financial incentives, retail and builder programs, and technical assistance and training.

Federal Programs
As the largest single purchaser of lighting products in the nation, the federal government can play an important role in demonstrating new technologies. DOE will coordinate promotion of SSL with other federal government programs including the Federal Energy Management Program (FEMP), the Defense Logistics Agency (DLA), and the General Services Administration (GSA).

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