U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Lighting Research and Development Opportunities

BTO Peer Review

Emerging Technologies Strategy Overviews

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Introduction to special section

Today’s Session

Hear our latest thinking now (and later)

Ask questions

Share your feedback

Listen for more from BTO, on strategies

The mission

The Building Technologies Office (BTO) conducts research, development, and demonstration activities to accelerate the adoption of technologies and techniques that enable high-performing, affordable buildings that meet Americans' need for resiliency and health while also supporting a reliable energy system.

90%

The amount of time people spend in buildings.

74%

Amount of electricity consumed by buildings.

$374 billion

Amount spent on energy costs annually.

BTO RD&D Activities Support America

- Energy Efficiency
- Energy Affordability
- Innovation
- Industrial Competitiveness
- Infrastructure
- Energy Reliability and National Security
- Resilience
- Indoor Environment and Health

A practical, inclusive definition of innovation

The Heilmeier Questions:

01 Problem
Stated without jargon

02 Impact
If you succeed, what changes and who cares?

03 Status
How is it done today?

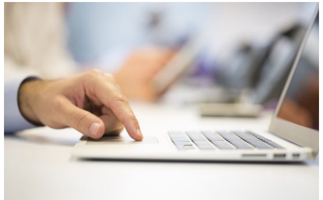
04 Proposal
What is the new approach, why will it succeed, and what will the output be?

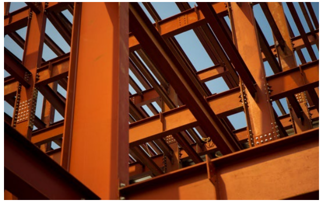
05 Midterm checks
How will we know we're on the right track?

06 How much does it cost?
How long will it take? What are the risks?

Innovation for building technology is broad

It includes R&D for product development, testing, and validation. But also!





Market transformation

Partnership models

Service delivery modes

Value chain

Contractors

Trades

Specifiers

Reps

Supply chain

Materials

Components

System integration

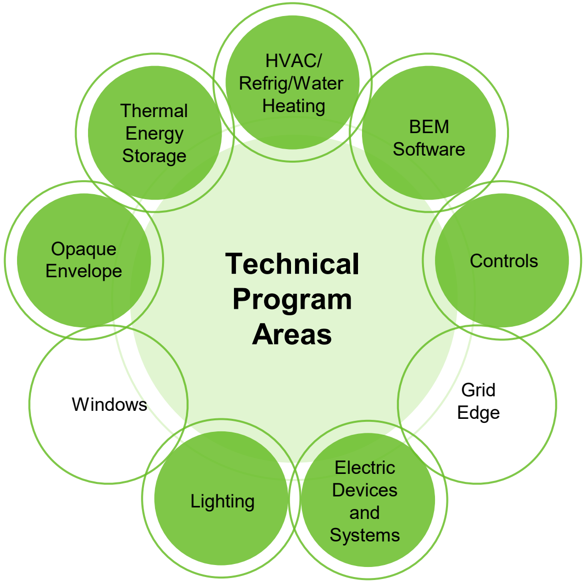
Logistics

Serendipity

Partnerships

Alignment

What does this strategy mean for DOE’s applied R&D for buildings?



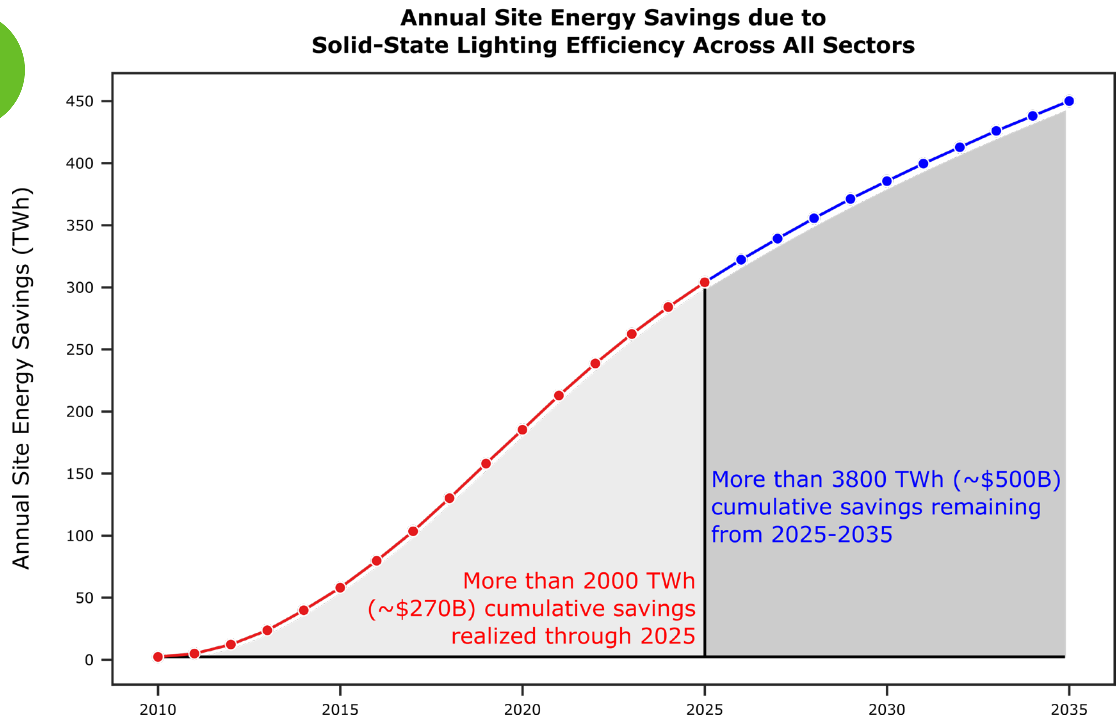
Reduce first costs

Make it easy

Deliver performance that matters

Ask, who’s missing that we need?

Realized and remaining savings from SSL

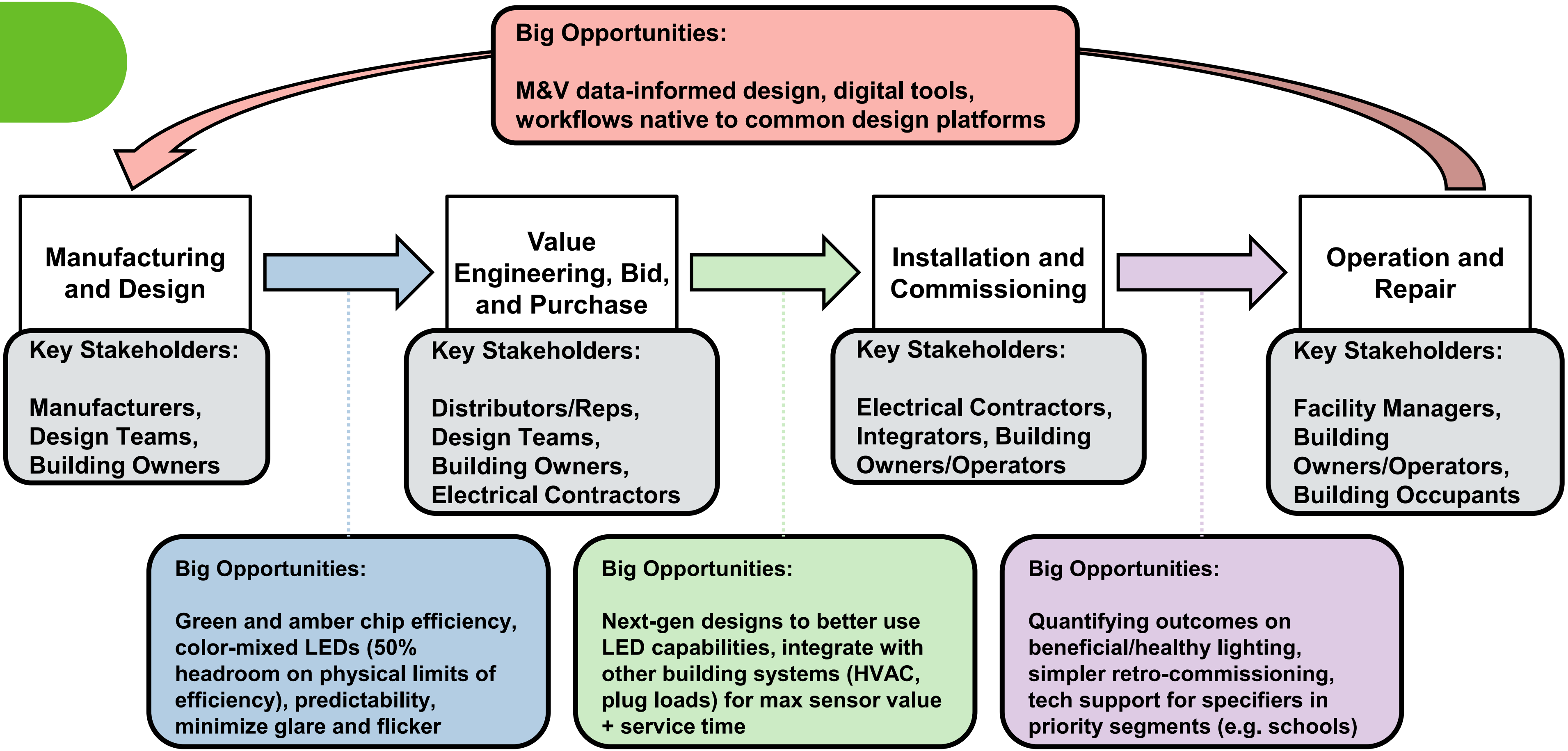


Solid-state lighting has already saved consumers ~$270B cumulatively, but by 2035 it has the potential to save an additional ~$500B with substantial improvements to the impact lighting has on health, productivity, and occupant comfort.

These opportunities are especially prevalent in community-asset buildings such as schools and churches, which are furthest behind on the adoption of efficient, beneficial lighting.

Other emerging applications enabled by LEDs, such as controlled indoor agriculture and germicidal ultraviolet disinfection, have a host of open R&D questions left to address.

R&D Opportunities Throughout the Lighting Value Chain



Barriers and Solutions

R&D Barriers

LED materials and devices are still far (~50%) from their physical limits on efficiency over a broader range of colors and operating conditions, and their performance is not always predictable

Fixtures for advanced lighting concepts are not yet fully optimized for form factor, configurability, building integration, resiliency, efficiency, application benefits

Major opportunity remains for measurement and prediction of human light doses under a broader range of conditions to connect stimulus to health outcomes and guide lighting design and LAE

M&V case studies, retrocommissioning, and translation of research findings to practice is rare among lighting practitioners

Proposed ET Solutions

Component and Fixture Technology Development

- Provide better LED source efficiency, which reduces fixture cost by lowering material requirements for thermal management and improves optical flexibility by getting more light out per unit area
- Advance optoelectronic material discovery and refinement, enhancing optical downconverter performance and viability of color-mixed LEDs
- Support and validate fixtures with novel form factors that dramatically reduce material use and cost

Lighting Science and Application Research

- Work with manufacturers to develop next-generation, flexible, interoperable LED drivers that integrate easily with other building technologies (plug loads controls, HVAC)
- Advance the state-of-the-art for Lighting Application Efficiency (LAE), incorporating optical and spectral tunability that is task-specific and beneficial to building occupants

Analysis, Partnerships, and Guidance

- Update market studies to identify high-impact application areas and priority building types
- Provide clear, comprehensive guidance for practitioners of next-generation lighting applications, including connected systems, lighting for health, and special topics such as GUV and indoor ag

Note: this is not an exhaustive list of all barriers and solutions

What is the stakeholder engagement? How are we getting inputs from others in DC? Others outside DOE?

EXPERT STAKEHOLDER R&D "ROUNDTABLE" MEETINGS

- **10/12/2023** — LED Devices and Materials, 11 Attendees
- **10/19/2023** — Luminaires, LAE, Building Integration, and Sustainability, 12 attendees
- **10/26/2023** — Germicidal Ultraviolet, 12 attendees
- **11/2/2023** — Human Physiological Responses to Light, 25 attendees
- **11/9/2023** — Organic LED Materials and Devices, 9 attendees
- **12/15/2023** — Horticultural Lighting Energy, 20 attendees

WORKSHOPS & WEBINARS

- **5/15-16/2024** — Illuminating Engineering Society/DOE Research Symposium
- **10/21-24/2024** — **BTO Peer Review** ↑ We are here!

KEY ANALYSES

Lighting Market Characterization

Lighting Application Efficiency (LAE) Framework Analysis

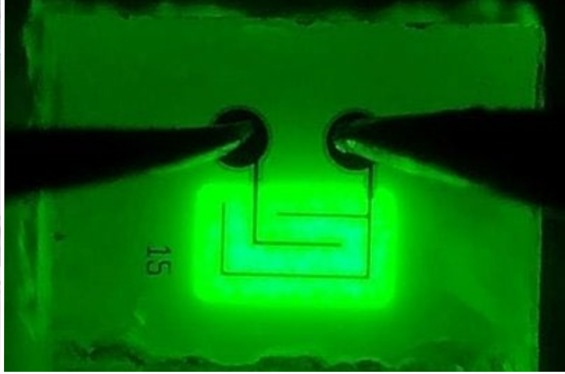
EXISTING PROJECTS

6 Active SBIR Projects

7 Active FOA Projects, 3 New Projects in Negotiation

Lighting Research and Development Priority Areas

1. LED Materials and Devices
2. Luminaire Integration
3. Application Benefits
4. Horticulture Lighting
5. Indoor Air Quality



Technology Opportunities and Application Opportunities

- **LED device technology:** Improvements to the LED technology platform are still possible. In particular, improvements to green and amber LED efficiency enable increased system efficiency and enhanced spectral controllability.
- **Ease of adoption:** LED lighting technology has gone through an initial phase of development where products were not fully refined and often misunderstood by consumers. The technology platform now offers the potential of low-cost, easy to select and use products with exceptional efficiency and energy savings.
- **Building integration:** Next-generation luminaires are a promising platform for connecting other building technologies like HVAC and plug loads to a common sensing and communications framework.

- **Lighting performance:** Lighting performance and optima have been understood within the context of the limitation of previous technologies. LEDs offer new options in intensity control; optical distribution patterns; and spectral power distribution that can improve visibility, reduce glare, improve color discernment, and improve the intended functionality of lighting.
- **Physiological responses to light:** Light plays a critical role in regulating human circadian rhythms which, in turn, support numerous health benefits. Improved understanding of these physiological responses has both health and energy impacts and supports long-term building occupant health.
- **Horticultural lighting:** LED technology is enabling for more advanced controlled environment agriculture (CEA) which can diversify the food production supply chain. Research can improve growth productivity based on new lighting and environmental schemes.
- **Germicidal UV:** Indoor air quality can be improved through the use of germicidal UV in occupied spaces. But research is necessary to optimize source efficiency and delivery methods while maintaining occupant safety.

Technology Opportunities and Application Opportunities

Short- to Medium-Term Impacts

1 "Fleet" efficiency

Advancements to the luminous efficacy and resulting energy savings are still on the table through increased adoption of highest efficiency products. Enormous energy savings are still possible

2 Luminaire advancements

Highly efficient lighting products are coming down in cost and becoming more standardized in performance and installation, enabling easier adoption.

3 Building integration

LED lighting sensor and control systems can provide data streams of occupancy and building use information to other building systems such as HVAC. The controllability of LED technology, and low energy consumption, enables local renewable energy integration as well as potential grid interactivity.

4 Application benefits

LED lighting technology enables health, productivity, safety, and other application benefits, and can reduce ecological impacts of lighting.

5 Lighting application efficiency

LED lighting technologies' more precise control of intensity, spectrum, and optical distribution enable more effective delivery of just the right light at the right time.

6 Horticultural lighting

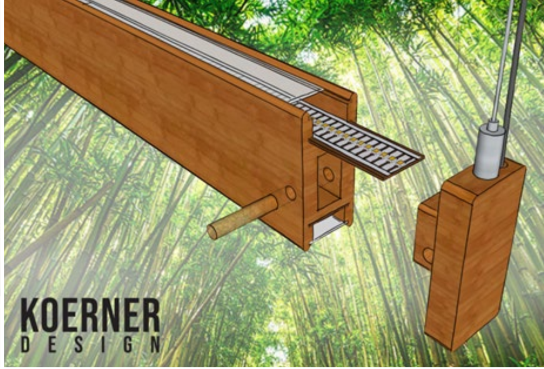
LED technology is enabling for controlled environment agriculture which can increase agricultural productivity while reducing energy consumption.

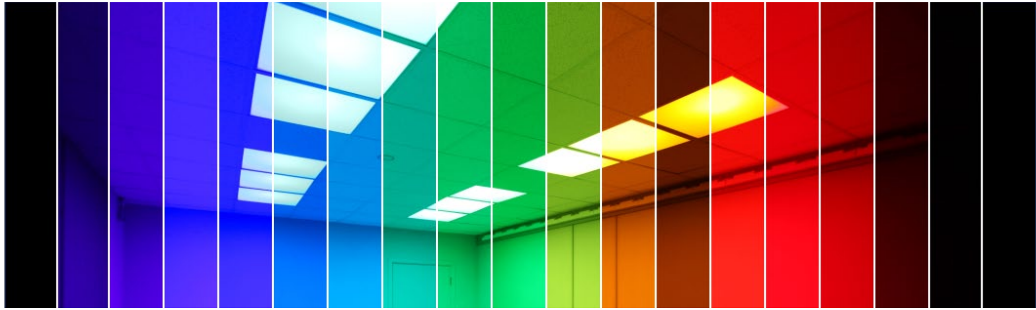
7 Indoor air quality germicidal UV lighting

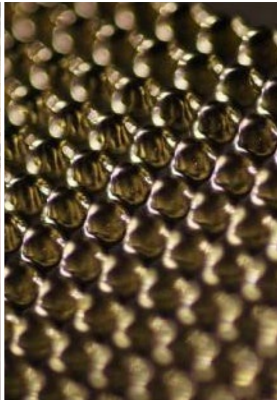
UV LED technology can be used for germicidal applications to reduce the spread of disease.

Next Steps

- Hold annual, topical roundtable meetings to gather stakeholder inputs on priority development activities.
- Publish the DOE lighting R&D vision to guide and influence development activities.
- Collaborate with USDA on research efforts in controlled environment agriculture to improve plant production while reducing energy consumption.
- Integrate stakeholder inputs identified by FOA on SSL R&D topics into lighting R&D vision.







KPIs relating to DOE mission spaces

COMPONENT KPIs		APPLICATION INTENDED FUNCTION
KPI	**Metric**	**Occupant Wellbeing (Health, Safety, Productivity)**
Red LED efficiency	Efficiency	✓
Green LED efficiency	Efficiency	✓
Amber LED efficiency	Efficiency	✓
Blue LED efficiency	Efficiency	✓
Phosphor conversion efficiency	Efficiency	✓
Phosphor spectral efficiency	Luminous efficacy of radiation	✓
White LED	Luminous efficacy	✓

KPIs relating to DOE mission spaces

LUMINAIRE KPIs		APPLICATION INTENDED FUNCTION
KPI	**Metric**	**Occupant Wellbeing (Health, Safety, Productivity)**
Driver efficiency	Efficiency	
Optical efficiency	Efficiency	🪷
Optical configurability	Useful light/total light	🪷
Spectral configurability	Delivered SPD relative to optimal SPD	
Material efficiency	Embodied carbon	
Disassembly/disposal	Embodied carbon	
Reliability/lifetime	L70/L90, failure rates by failure type	🪷
Scarce/toxic materials	Materials reporting	
Cost – fixture payback period	Duration	
Color quality	IES TM-30 (color fidelity)	🪷
Form factor	Total materials, lighting layout, building integration, light levels, glare	
Flicker	CIE TN 006:2016	🪷

KPIs relating to DOE mission spaces

INSTALLED LUMINAIRE KPIs		APPLICATION INTENDED FUNCTION
KPI	**Metric**	**Occupant Wellbeing (Health, Safety, Productivity)**
Minimal light trespass/beam steering	Useful light/total light	
Optical configurability	Useful light/total light	[icon]
Glare	UGR	[icon]
Light levels	Modeling, on-site verification	[icon]
Ecosystem impacts	Light trespass/non-useful light (night)	[icon]
Ease of use – CLS systems	Installation time/skill, bypass rates	
DC power distribution	Efficiency, interoperability	
Maintenance	Maintenance time spent	
Indoor air quality – GUV energy consumption	Energy consumption	[icon]
Sensing	Light level, occupancy, space usage, person counting	
Cost – system payback period	Duration	
Building system integration (HVAC) – communication protocols	Interoperable products and systems	

KPIs relating to DOE mission spaces

APPLICATION KPIs		APPLICATION INTENDED FUNCTION
KPI	**Metric**	**Occupant Wellbeing (Health, Safety, Productivity)**
Visibility, color object discernment	Object visibility subjective testing	
Health, wellbeing, cognitive performance	Objective hormone, alertness markers, cognition	
Energy use – horticulture	Energy, yield – lighting energy, yield per watt	
Safety – GUV	Modeling, on-site verification, irradiance	
Safety – roadway/pedestrian/cyclist	Crash rates wrt lighting setting	
Safety – perception/reassurance	Subjective review of "occupant" sense of security	
Demand flexibility – commercial buildings	Lighting demand offset energy, duration	
Demand flexibility – horticulture	Lighting demand offset energy, duration	
Indoor air quality – GUV effectiveness	Germicidal effect wrt system type and setting	
Light dosimetry	Accuracy, spectral resolution	
Lighting simulation/design tools	Accuracy, predictability	