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LED professional

BY LUGER RESEARCH

Review

LpR 100

Nov/Dec 2023

PROF. SHUJI NAKAMURA'S BLUEPRINT FOR A BRIGHTER TOMORROW

THOUGHTS FROM A VISIONARY
Mônica Luz Lobo

NEAR-INFRARED LIGHT
A Breakthrough Clinical Study

ISSUE 100 ANNIVERSARY EDITION

AUTOMOTIVE LIGHTING SPECIAL

The Global Information Hub for Lighting Technologies and Design

CREE LED

Brighter Together

Embrace the future with our continued innovation in LED technology

Cree LED launched the LED revolution with the introduction of the world's first lighting-class LED – and the breakthroughs never stop. We continue to lead the industry while developing the next generation of application-specific LEDs, backed with global support, and accompanied by shorter lead times to illuminate the world – today and tomorrow.

See our complete portfolio: cree-led.com/news/2023showcase

Always Innovating. Always Leading.

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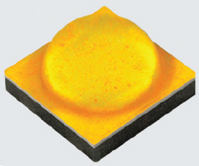
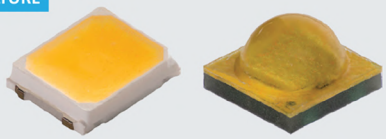
INDOOR / OUTDOOR



XLamp® XP-G4 White LEDs

- Directional lighting in stadiums, arenas, medical applications, torch
- Industry-leading LPW and optical performance
- Precise light control, good color over angle and long-term reliability
- Higher maximum current and lower thermal resistance than competing high-power LEDs

HORTICULTURE



Photophyll Select™ LEDs

- Greenhouse, vertical farming, aquaculture
- Industry's first LEDs entirely binned in horticulture metrics
- The first LEDs with precise control over the green/blue ratio; optimized for use with 660 nm photo red LEDs
- Upgrade output and efficiency of two-channel luminaires by 6%

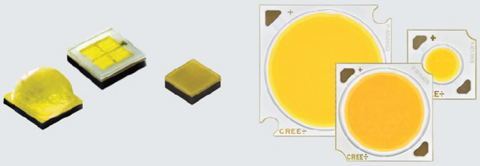
2023 PRODUCT SHOWCASE

INDOOR

J Series® 2835 Pro9™ LEDs

- Downlights, troffers and panel lights in office spaces, retail outlets, hotels and restaurants
- Highest LPW 90 CRI 2835s in the market
- 6500K to 2700K
- Four performance choices available in 3V and 9V options

INDOOR



XLamp® Pro9™ LEDs

- High fidelity directional and retail lighting
- Industry-leading reliability and lumen density
- 15% higher efficacy for 90 and 95 CRI LEDs
- Highest operating temperature rating of 105°C

OUTDOOR

CV94A
High Brightness LEDs

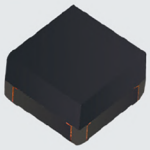
- Roadway signs, LED billboards
- RGB oval 90°/45° beam angle
- Replace multiple through-hole LEDs
- Reduce assembly cost, increase image quality

OUTDOOR

CLMWB
High Brightness LEDs

- Outdoor LED video screens, stadium, and ad displays
- RGB SMD, 1.6 x 1.7 mm footprint
- Wide viewing angle and high brightness
- IPx8 waterproof rated with UV inhibitors

INDOOR



UHD111A
High Brightness LEDs

- Indoor signage, airports, malls, and command centers
- Industry-leading brightness and reliability
- Compact 1.0 x 1.0 mm package
- No wire bonds for significant improvement in black levels and contrast ratios

LpR 100

When we embarked on our journey with the first issue of LED professional Review (LpR) 17 years ago, the idea of reaching a monumental milestone like issue 100 seemed like a distant dream. It wasn't even on our radar at the outset. But here we are today, thrilled to present our loyal readers with the 100th edition of LpR, spanning 104 incredible pages!

This isn't just any edition; it's special. We're unveiling a fresh cover design and a sharper focus on feature interviews, cutting-edge design, technology articles, and, for the very first time, some exciting 'Specials,' including the Automotive Special.

Our heartfelt thanks go out to all the brilliant contributors from academia, industry, and application. And to all of you who sent us your congratulatory messages.

A big shout-out to Professor Nakamura for enhancing this milestone edition with his commentary!

To our cherished readers, we owe you a massive 'Thank You' for your unwavering loyalty. And to our steadfast advertisers, without whom, it wouldn't have been possible to reach this extensive readership, we truly appreciate your continuous business and partnership.

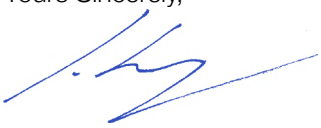
LpR is a result of the collective effort of many, and I personally want to extend my heartfelt gratitude to everyone involved, especially Leon Chen, Zena Coupe, Elio A. Farina, Katharina Fink, Silvia Girardelli, Arno Graber-Meyer, Gerlinde Graf, Kristin Hamre, Lesley Harmoning, Alan Kernc, Theresa König, Jasmine Leger, Brigitte Lindner, Christine Luger, Daniel Luger, Theresa Luger, Sarah Luger, Kelly Pahlen, Amrita Prasad, Priyanka Rai, Bronwen Rolls, Günther Sejkora, Karen Smith-Kernc, Jung-Won Suh, Jill Thibert, Armin Wezel, Lolo Yeung, Iris Yuen, and many others.

In conclusion, we wish you all the very best as we continue our commitment to bring you the latest trends in lighting technology, design, and application from the dynamic worlds of science and industry through LED professional Review (LpR).

Thank you for being part of our incredible journey!

And now, enjoy your read!

Yours Sincerely,



Siegfried Luger

Luger Research e.U., Founder & CEO
LED professional, Trends in Lighting, LpS Digital & Global Lighting Directory
International Solid-State Lighting Alliance (ISA), Member of the Board of Advisors
Member of the Good Light Group and the European Photonics Industry Consortium

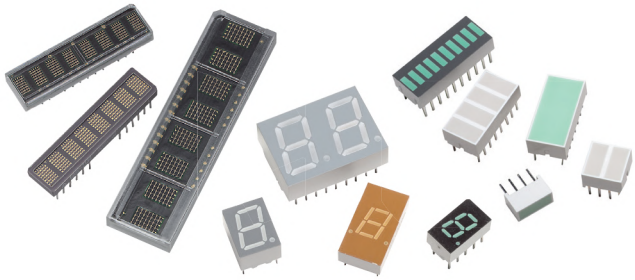
LED Solutions for all your Industrial Applications

LEDs

- High Brightness Surface Mount Lamps
- RGB & Monocolor PLCC LEDs
- ChipLEDs Monocolor, Bicolor & Tricolor
- Automotive 1608, 2835 & PLCC
- Infrared LEDs and Photodiodes
- UV-A High Power LEDs
- High Power white and colored
- High Brightness Through Hole Lamps

LED Displays

- Smart Alphanumeric Displays
- Surface Mount & Through-hole 7 Segment Displays (customizable)
- Light Bars



Choose Broadcom for high performance, efficiency & reliability

Broadcom Inc.

www.broadcom.com/leds

About Broadcom Broadcom Inc. (NASDAQ: AVGO), a Delaware corporation headquartered in San Jose, CA, is a global technology leader that designs, develops and supplies a broad range of semiconductor and infrastructure software solutions. Broadcom's category-leading product portfolio serves critical markets including data center, networking, enterprise software, broadband, wireless, storage and industrial. Our solutions include data center networking and storage, enterprise, mainframe and cybersecurity software focused on automation, monitoring and security, smartphone components, telecoms and factory automation.

Broadcom LEDs Known for its LEDs' performance, efficiency and reliability, Broadcom offers an extensive portfolio of products that include high brightness and high power LEDs, PLCC surface-mount LEDs, and display backlighting module solutions. These LEDs and display modules address a wide range of markets, including electronic signs and signals, automotive, solid state lighting and LCD display backlighting. LED Display customers can rely on products that deliver high reliability, long life expectancy, and are resistant to extreme weather conditions, mechanical vibration, and shock. With our innovative LED Displays, customers can choose products with rich color capabilities, low cost, standard brightness and high ambient light that are designed to meet a variety of industrial and consumer applications.

Why Broadcom LEDs

- Extensive range of LED solutions
- High performance and efficiency
- Long life expectancy and high reliability
- Very robust in extreme weather conditions

New in our Portfolio

IR LEDs
Our latest IR LEDs come in various package platforms and footprints within the 820 nm to 940 nm wavelength range, appropriate for light curtains, smoke detectors, metering, remote control handsets, security systems, video cameras, automated card reader systems and industrial sensors.

UV-A LEDs
We have a wide range of UV-A LEDs and near UV LEDs, typically in the wavelength range of 365nm to 425nm. End applications are industrial ink curing, horticulture lighting, water/air purification, disinfection, medical phototherapy and banknote counterfeiting.

Hot Product
SMT Lamp

Broadcom's unique SMT-Lamp package combines a narrow viewing angle with SMD technology
This product family is an ideal solution for outdoor applications. The robust package has an integrated round or oval lens made from Epoxy, is available in different viewing angles and in all colors.

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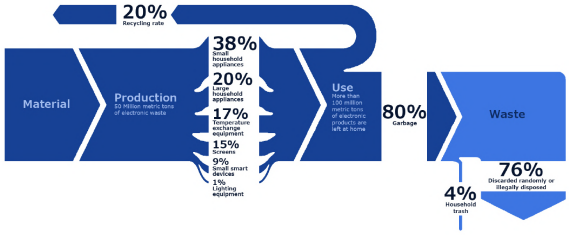

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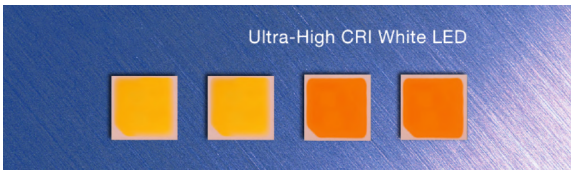

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Prof. Shuji Nakamura

Prof. Shuji Nakamura is a globally recognized pioneer in the field of semiconductor technology, best known for his invention of the blue LED. Born in Ehime, Japan, in 1954, Nakamura's groundbreaking work has revolutionized lighting technology, paving the way for energy-efficient and sustainable lighting solutions. His blue LEDs, combined with red and green counterparts, have transformed electronic displays, leading to the development of white LEDs and blue laser diodes, which underpin Blu-ray technology.

Nakamura's contributions have earned him numerous accolades, including the 2014 Nobel Prize in Physics. Beyond his technical achievements, he has been a staunch advocate for inventors' rights and has championed the cause of sustainable and efficient lighting. Currently, he serves as a professor at the University of California, Santa Barbara, continuing his research and inspiring the next generation of innovators.

Prof. Shuji Nakamura's Blueprint for a Brighter Tomorrow

In the realm of lighting, the future is not just bright; it's transformative. Having dedicated a significant portion of my life to the development and enhancement of lighting technologies, I've witnessed firsthand the evolution from incandescent bulbs to the revolutionary blue LED lights. As we stand on the cusp of another decade, I'd like to share my insights into the future trends in lighting and my overarching goals in this domain.

The world is rapidly transitioning to sustainable and energy-efficient solutions. Lighting, responsible for a significant portion of the world's electricity consumption, is no exception. The invention of the blue LED was a pivotal moment, not just for its ability to produce white light when combined with phosphors, but for its energy efficiency. LEDs consume a fraction of the power of traditional bulbs, and their longevity means reduced waste. But the journey doesn't stop here.

The next frontier in lighting is the integration of smart technologies. Imagine lights that adjust their brightness and color based on the time of day, enhancing our circadian rhythms and improving our overall well-being. Or streetlights that can detect oncoming traffic and adjust their intensity accordingly, ensuring safety while conserving energy. These are not mere fantasies but tangible realities in the making.

Another promising avenue is the fusion of lighting with data transmission. My team's work on lasers has shown that light can be used for high-speed data transmission, a concept known as Li-Fi. As the world becomes increasingly connected, integrating data transmission capabilities into everyday lighting can revolutionize how we access and share information.

From a broader perspective, the future of lighting is not just about illumination. It's about creating holistic environments. Lighting will play a pivotal role in shaping our moods, enhancing our productivity, and even improving our health. The potential applications are boundless, from medical therapies using specific light wavelengths to agricultural practices optimized with tailored light recipes.

My overarching goal has always been to enhance human life through technological innovation. The blue LED was a testament to this vision, transforming industries and paving the way for sustainable lighting solutions. As we move forward, my focus remains on pushing the boundaries of what's possible, ensuring that lighting solutions are not only efficient but also holistic, catering to the multifaceted needs of humanity.

In conclusion, the future of lighting intertwines innovation, sustainability, and human-centric design. As technology rapidly advances, coupled with a deeper grasp of human needs, I am hopeful for transformative lighting developments that reshape our interaction with our environment. My enduring mission is to lead this evolution, catalyzing change and lighting the way forward. Amidst global challenges, I hold that technology, even in sectors as specific as lighting, should champion peace and unity. Our world grapples with diverse issues, from political tensions to environmental threats. Lighting, though seemingly niche, holds immense potential to bridge these divides. It can address energy disparities, curb carbon emissions, and boost economic growth in marginalized areas. By making sustainable technologies accessible, we light up homes and lay foundations for global understanding, collaboration, and peace. My vision transcends lighting; it's about leveraging innovation to foster a cohesive global society. ■

S.N.

LpS DIGITAL SUMMIT

KEYNOTES I PANEL DISCUSSION I AWARD CEREMONY

Exploring Cross-Disciplinary Lighting Innovations

Bright Ideas based on latest trends in General Lighting, Automotive Lighting, Lighting Design, and Regulatory Boundaries.

ELENA SCARONI
Secretary General at LightingEurope

DIRK VANDERHAEGHEN
Senior Director of Lumileds OEM Market Strategy

LAWRENCE LIN
Former Global CEO of LEDVANCE

XAVIER DENIS
Technical Marketing Manager at Nichia

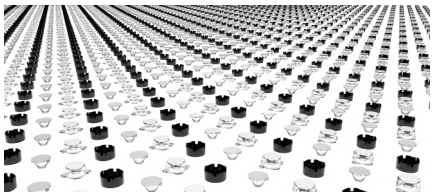
7th December 2023 from 2-5p.m. CET

SECURE YOUR SEAT! REGISTER NOW FOR FREE!

Carclo Optics: Pioneering the Future of Illumination

www.carclo-optics.com

Carclo Optics has been a distinguished leader in the field of optical solutions for decades. With a legacy dating back to 1936, Carclo Optics is recognized as a global frontrunner in designing and manufacturing innovative optical products. Our unwavering commitment to precision and innovation has positioned us at the forefront of the lighting industry. Read on for a comprehensive overview of our journey and our role in shaping the future of illumination.



A Heritage of Excellence
Carclo Optics commenced its journey in 1936 and, over the decades, has evolved into a prominent name within the optical industry. Headquartered in the United Kingdom, our organization has garnered an exceptional reputation for its optical proficiency, catering to a diverse array of applications. From Retail lighting to Industrial solutions, Carclo Optics has continuously expanded its portfolio to address the dynamic requirements of our global clientele.

Our State-of-the-Art Product Portfolio
Carclo Optics is dedicated to remaining at the forefront of optical technology, continually enhancing the performance and aesthetics of lighting systems across multiple applications and diverse industries.

1. **LED Optics:** We specialize in the design and manufacturing of optical components for LED lighting, such as our latest introductions, the wide-angle 10mm and wide-angle 20mm TIR optics. These optics play a pivotal role in regulating light distribution, intensity, and color, ensuring unparalleled performance. Our LED optics serve applications including architectural, UV-C, emergency & landscape and garden lighting.

2. **Optical Systems:** Carclo Optics offers comprehensive optical systems, meticulously customized to address the specific requirements of distinct lighting applications, encompassing street lighting, retail, horticultural and the burgeoning human centric lighting sector. These systems are crafted with a focus on precision and innovation and include the Wall Washer & Wall Grazer full assemblies.

3. **Technical Injection Moulding:** Our technical injection moulding capabilities underpin our ability to fabricate intricate optical designs with exceptional precision and consistency. This technology forms the bedrock of our capability to deliver optics that align with the exacting standards of the contemporary lighting industry.

4. **Design and Engineering:** Beyond our manufacturing capabilities, Carclo Optics provides design and engineering services to assist our clientele in optimizing their lighting solutions. Our end-to-end approach guarantees that our customers receive not only high-quality optics but also expert guidance to achieve optimal lighting performance.

Dedication to Innovation and Adaptation
Carclo Optics' paramount distinguishing feature is our resolute commitment to innovation. In an industry marked by rapid evolution, we maintain a dynamic and adaptable approach, consistently anticipating market trends and consistently pushing the boundaries of optical design. Our robust emphasis on research and development facilitates the creation of optics that not only excel in efficiency but are also aligned with environmental sustainability, an increasingly pivotal consideration in the contemporary world.
Carclo Optics remains responsive to the shifting landscape of the lighting industry, embracing technologies such as extrusion and freeform optics to present solutions that excel not just in energy efficiency but also in aesthetic appeal.

Light + Building Exhibition 2024
We are excited to announce our participation in the forthcoming Light + Building exhibition in Frankfurt in 2024. This showcase underscores our unwavering commitment to leading the way in the lighting industry, where we will present our latest innovations. We invite you to stay informed by visiting our official website https://www.carclo-optics.com or checking out our LinkedIn posts.

In Conclusion
Carclo Optics, with its rich history, unwavering dedication to innovation, and a wide array of cutting-edge products, occupies a prominent position in the optical industry.

As we prepare to unveil our latest innovations at the 2024 Light + Building exhibition in Frankfurt, we invite you to remain updated and to join us on our journey into the future. Our story stands as a testament to the power of innovation and adaptation, underscoring that light, when harnessed with precision and creativity, holds the potential to shape a brighter future for us all. ■

Signify Accelerates the Transition to Energy Efficient Lighting with New UltraEfficient Lamps

www.signify.com

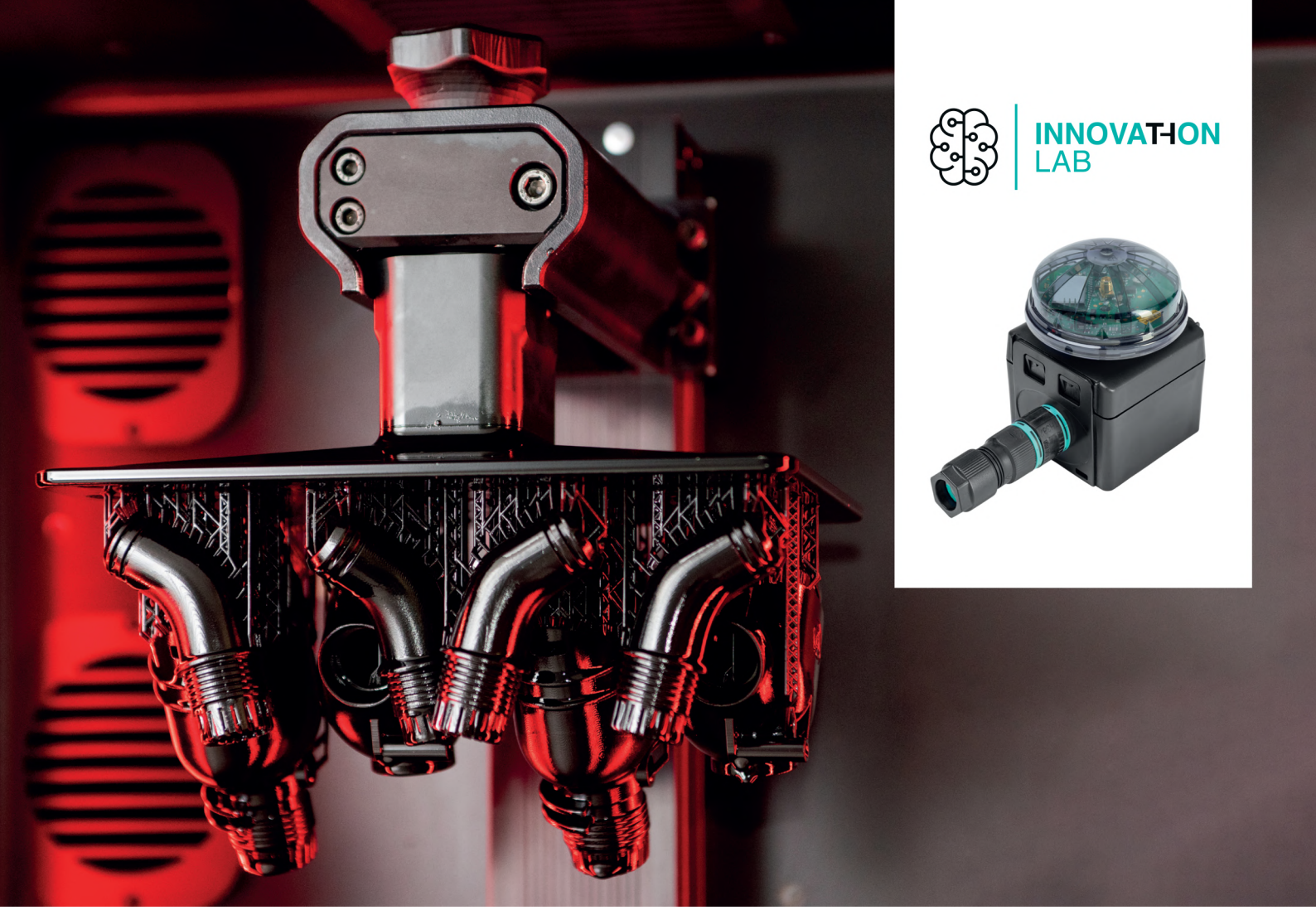
Signify continues to lead the transition to energy efficient lighting, helping municipalities, communities and businesses reduce their energy consumption by replacing legacy conventional lamps with the new Philips MASTER LED SON-T UltraEfficient (UE). Additionally, Signify is further extending its UltraEfficient LED range with the dimmable MASTER LEDbulbs UE and A-class MASTER LEDspots UE.
The new products meet the highest energy label, 'A', under the EU's Ecodesign Regulation, and the Energy Labelling Regulation, which recently came into force. As A-class products, these new bulbs, spots, and lamps consume at least 43% less power to achieve the same output as standard alternative products.

The new Philips MASTER LED SON-T UE lamps are the first A-class LED SON-T lamps with a color temperature of 4,000K registered in Europe. The new lamps have a similar look, feel and light distribution to their conventional equivalents, and can be easily retrofitted into existing SON-T fittings. When upgrading from conventional HID lamps, a potential full return on investment can be achieved in 2.3 years. Replacing 100 units of 100W conventional HID lamps with 42.8W A-class LED SON-T could save €7,046 per year. The lamps are nondirectional and non-dimmable E27/E40 lamps, with a lumen range between 4,000 lm and 9,000 lm.

Availability:

- Philips MASTER LED SON-T UltraEfficient (2,700/4,000K, 19—43W, 3,600—9,000 lumen, 50—100W equivalent)
- Philips MASTER LEDspot UltraEfficient GU10 EELA (2,700/3,000/4,000K, 2.1W, 50W equivalent)
- Philips MASTER LEDbulbs UltraEfficient Dimmable (2,700/3,000K, 4W, 60W equivalent)
- Philips MASTER LEDbulbs UltraEfficient Globe G95 and ST64 (2,700K, 4W, 60W equivalent)
- Philips MASTER LEDluster UltraEfficient (2,700/4000K, 2.3W, 40W equivalent)

The new A-class MASTER LEDbulbs UE and A-class MASTER LEDspots UE GU10 consume at least 45% less energy, compared to standard LED alternatives, as well as lasting at least three times as long. Additionally, the A-class MASTER LEDbulbs UE are now dimmable, allowing for customizable lighting experiences. ■



INNOVATHON LAB

Techno Innovation Lab: New Opportunities for the Lighting Industry

Innovation LAB 3D - Production scalability, quantitative flexibility, and extremely short time to market for highly customized products and solutions. These are the objectives of the Innovation 3D Lab, the functional unit of Techno's Professional Additive Manufacturing dedicated to the design, prototyping and production of solutions and components according to customer project specifications, for various sectors such as modern plant engineering, smart lighting and smart industry.

Structure and Method - For over 20 years, Techno has been using 3D technology for in-house prototyping and product development. With the implementation of the Innovation 3D Lab in its headquarters based in Guanzate (Italy), the company has aimed to introduce Industry 4.0 for 3D printing too, as well as adapting it to the other departments which were already 4.0.

The facility, equipped with a Stratasys OriginONE DLP 3D printer and resin handling equipment, operates under the coordination of the Innovation Team and in synergy with the R&D, Production and Quality departments. The Innovation 3D Lab supports the customer in finalising the product design and selecting the materials, cooperating in the creation of the 3D CAD model or in its development from scratch.

A key feature is the "pre-compliance", i.e., the production of a small quantity of prototypes or products which are subjected to technical-quality tests in the Innovation Lab, in order to detect any critical technical/installation issues and to check their compliance with the application.

The final stage involves pre-series production and - after the customer's approval – mass production, which can also consist of limited quantities or a single unit. Therefore, Professional Additive Manufacturing more readily allows the production of ready-to-sell components to test the market, at lower costs than injection moulding. It can also be used for **contracting** non-catalogue products.

Highlights:

- The Innovation 3D Lab offers tailor-made/custom solutions, mainly to support new IoT projects such as smart lighting and smart industry
- With professional Additive Manufacturing technologies and skills, it is possible to produce small quantities and even single units
- Produces prototypes for the execution of specific pre-compliance tests
- Produces ready-to-sell products with a shorter time to market than injection moulding

In order to guarantee the best possible outcome, a project may involve different types of expertise, e.g. electromechanical and electronic, and be integrated with additional services.

Outlook - Innovation 3D Lab's challenge is to introduce additive manufacturing into an injection-moulding company. Multi-step prototyping - which yields a product which is almost 100 per cent comparable to the sellable product- makes it possible to assess whether to proceed with injection moulding or 3D production. The design support and multidisciplinary approach, along with the company's DNA in designing and manufacturing the finished product, and the possibility of customization according to the customer's specifications, are the factors that link every project which is entrusted to Innovation 3D Lab.

The ability to oversee projects for different sectors in a responsive and flexible way has enabled Techno to expand its existing synergies, develop new partnerships and share with its customers the opportunities offered by markets development. ■

Contact Us

customercare@techno.it, +39 031 976445
Via Bancora e Rimoldi 27,
22070 - Guanzate (CO), ITALY

https://www.techno.it

techno
TECHNOLOGY & INNOVATION

Congratulations on 100 issues of LED professional Review

All the best from the Röhm team and thank you for the exciting reading material!

We have the opportunity to celebrate together: while LED professional Review celebrates the 100th issue of their magazine, we celebrate our 90th brand anniversary of our strong brand for PMMA products: PLEXIGLAS®. Today, PLEXIGLAS® is one of the best-known brands in the plastics industry. Over the past 90 years, we have reinvented PLEXIGLAS® time and again into a material that enables new design forms and technical functions in sophisticated applications across a wide range of industries.

PLEXIGLAS® inspires our customers to create emotional product designs that result from the versatile product properties of PLEXIGLAS® – thanks to its high light transmittance, precise mold surface reproduction and longevity.

Why PLEXIGLAS® is the right material for your next beloved project:

- PLEXIGLAS® is the **best optical material** and impresses in lighting applications thanks to its high light transmittance, precise mold surface reproduction and longevity.
- To meet demand for lenses for high-performance LEDs and cater for the trend toward light guides we have developed several grades that keep their **optical performance while withstanding heat: PLEXIGLAS® Optical HT** for instance meets both requirements and offers extraordinarily good light transmittance and light-guiding properties at temperatures of up to 105°C.
- For **even higher thermal requirements** we recommend PLEXIMID® molding compounds, our PMMI (polymethyl methacrylimide) solution. Due to its higher heat deflection temperature, PLEXIMID® is also suitable for applications with high heat development, such as headlamp lenses in automotive manufacturing or for integrated luminaires. This is confirmed by the recent classification of **PLEXIMID® TT50** as an optical high-temperature material in accordance with UL 746B of up to 130°C.
- **Light-diffusing PLEXIGLAS® molding compounds** are used as diffusor panels for luminaires and as parts for tail lights in the automotive industry. PMMA molding compounds **with different diffuser effects** for uniform, glare-free light scattering. They provide fascinating lighting effects from backlit covers to ambient lighting.
- We celebrate our 90th anniversary with the launch of **PLEXIGLAS® *pro*Terra** molding compounds with **reduced carbon footprint** and with no loss in proven performance. The grade PLEXIGLAS® *pro*Terra 8N is already listed by UL as well as the Automotive Manufacturers Equipment Compliance Agency (AMECA) as a material that complies with applicable standards and can therefore be used for optical lenses and reflex reflectors on vehicles.

Discover exciting case studies now!
Thanks to their wide range of properties and options for use, PLEXIGLAS® molding compounds are an infinite source of inspiration for product designers in a vast array of sectors. www.plexiglas-polymers.com/en/case-studies

Love for light.
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The Health Transformation of LED Lighting

www.goodlightgroup.org

Commentary for the 100th edition of LED professional Review by Jan DENNEMAN

In 2007, the year of the first issue of LED professional Review, LED lamps were primarily used for specific applications such as traffic lights, car taillights, and decorative lighting. At that time, they were not suitable for general lighting due to limitations in color spectrum, efficiency, and light output. However, the past 16 years and 100 editions of LpR have revealed the radical transformation that LEDs have brought about. LEDs are now the dominant light source for both indoor and outdoor lighting. Their energy efficiency, impressive color spectrum, and numerous other benefits have revolutionized the industry.

Despite this progress in LED lighting, the lighting industry currently faces a challenging position. Many manufacturers offer similar energy savings through the use of LEDs, making it difficult to differentiate based on efficiency. This has resulted in a price war, leading to a decrease in market value.
This focus on energy and cost savings has led customers to primarily view lighting as a means to reduce their energy bills. The potential of lighting to improve the quality of life and promote health often remains underemphasized.
Light plays a crucial role in our daily lives. It affects our sleep patterns, moods, mental health, and alertness throughout the day. Indoor lighting during the day is often too weak, while in the evening, it is too strong for a healthy day-night rhythm. More than 40% of people suffer from sleep problems, and these issues affect individuals of all ages. The emphasis on good lighting that mimics daylight can make a significant difference in the quality of life.
To realize this transition to health-focused lighting, substantial innovation is needed. It is a golden opportunity for lighting companies and designers to stand out. The development of lighting solutions that promote people's health is not only a socially responsible step but also opens up new possibilities in the market.

Rather than waiting for another 100 editions of LpR to witness this change, all stakeholders in the lighting industry can take action now. Let's start by telling the story of good lighting, applying it in our own environments, and executing inspiring best-practice projects that demonstrate the power of health-focused lighting. Together, we can transform the lighting market and consider light not only as an energy-saving tool but as an essential tool for our health and well-being.

Let's commit to achieving this shift within the next 25 editions of LED professional Review.
J.D. ■

Jan DENNEMAN is Founder and Chairman of the Board of the Good Light Group as well as Honorary Ambassador of the Global Lighting Association.

The Good Light Group is a non-profit organization that promotes the use of Good Light indoors. Good light is daylight or electric light with comparable beneficial effects. Jan has more than 40 years of experience in executive roles in sustainability, innovation and business development and held senior innovation and marketing roles at Philips Lighting (now Signify) during the industry's transition to LED and Intelligent Lighting Systems. He founded several international consortia, such as the Global Lighting Association, Zhaga Alliance, the Connected Lighting Alliance and LightingEurope. Jan was President of the Global Lighting Association from 2007-2017 and President of LightingEurope from 2013-2017.

The **Good Light Group** is a non-profit organization operating globally. The Good Light Group has a legal structure of a foundation and has been registered in The Netherlands in May 2019. The main objective of the Good Light Group is to stimulate the use of good light indoors. This goal will be reached by communicating the benefits of good light to the people, by stimulating collaborations and by promoting knowledge developments on the topic of good light.

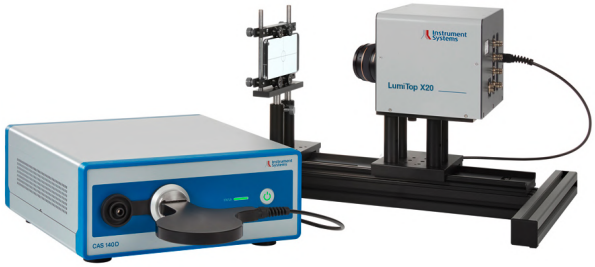
Good Light Group

Instrument Systems GmbH

www.instrumentsystems.com

Display Measurement with Higher and Lower Luminance Values

Instrument Systems developed the new LumiTop X20 and LumiTop X30 imaging colorimeters especially for display production testing under special luminance conditions. The LumiTop X20 and X30 feature high camera resolution (20 MP and 31 MP respectively) and improved dynamics from mcd/m² to Mcd/m². Both cameras are based on the spectrally optimized LumiTop principle, which has proven to be a powerful tool for quality assurance of displays. Using them, display manufacturers are able to perform tests at very high luminance in the range of several Mcd/m² as well as low luminance in the range of 0.001 cd/m² to 0.1 cd/m², taking into account the adaptation of the human eye to dark and bright lighting conditions.



Measurement Setup with Instrument Systems' LumiTop X20 and CAS 140D.

The human eye adapts easily to dark and bright lighting conditions. Modern displays take this into account by dimming their display to low luminance when needed to relieve the viewer's eyes. When designing and manufacturing displays, the luminance and color of the display must therefore be accurately tested, even at low luminance. Typically, these tests are performed at low luminance levels ranging from 0.001 cd/m² to 0.1 cd/m².

Instrument Systems has developed two new models of the proven LumiTop series especially for this application. The spectrally optimized LumiTop X20 and LumiTop X30 imaging colorimeters are ideal for homogeneity measurements and error detection under special luminance conditions. They are characterized by high camera resolutions of 20 MP and 31 MP respectively, as well as high flexibility in the field of view (high-precision motorized lens) and improved dynamics from mcd/m² to Mcd/m². The new flicker electronics are designed for frequencies between 1 Hz and 1 kHz. Both cameras are based on the proven LumiTop principle.

Instrument Systems developed the LumiTop series of luminance and imaging colorimeters in particular for display production tests. As the fastest, most reliable and most accurate system, LumiTop has become the reference for high performance testing in display production. The unique combination of a high-resolution camera, fast photometer and extremely accurate spectroradiometer of the CAS series makes the LumiTop system an exceptionally powerful tool for quality assurance of displays, even under low luminance conditions. ■

Instrument Systems
KONICA MINOLTA Group

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Fully automated 7-axis goniometer for very long, curved displays

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- CCT
- EML
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- Uniformity
- LRS Lighting Recipe™ Technology
- Monitoring circadian lighting

Official Website

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available at amazon

Shaping the Leading Edge of Lighting Sensor Technologies

Lighting Recipe Studio (LRS) was founded by Lawrence Lin, former Global CEO of Ledvance (known as OSRAM general lighting). LRS is a professional light research institute and also a leader in the development of forward-looking light products.

Lawrence Lin, Founder of Lighting Recipe Studio

We Build Light for Life

Light is crucial, not only for visual effects but for biological and psychological impacts towards the human body, as well. At LRS the team is dedicated to building the best tool to support a healthy lighted environment. The team is responsible for 'light-as-a-service' and a fully automatic smart lighting system being born. LRS's researchers study and design the formula of well lighting – LRS Lighting Recipe™ – to further improve human health by lighting application.

Inspiration from Light and Health Research

Modern medical studies prove that light shapes human life through its impact on the circadian rhythm and emotions. Implanting the evidence-based scientific research while in compliance with Light Concept in WELL Building Standard™, LRS developed a unique lighting environment monitoring system in order to detect and monitor the spaces and interact with lighting fixtures with Lighting Recipe™ Technology. The ultimate goal is to bring the best lighting quality to humans by monitor and regulate circadian rhythm lighting, leading to better health.

The Most Compact EML Sensor

Using Lighting Recipe™ and smart lighting system, "**In. Licht** *pro*", a *works with WELL product* in progress to be licensed – is designed for practical field application while meeting the criteria of Light Concept in WELL Building Standard™. With overall considerations, plug & play devices and UI, it is a more accurate lighting sensor.

The 5 key lighting indexes it monitors:

- Lux (Illuminance)
- EML (Equivalent Melanopic Lux)
- CCT (Correlated Color Temperature)
- Visual Contrast
- Uniformity

It provides real-time monitoring light data which cover the full aspect of the laboratory's spectrum light meter in a super light-weight (40g), portable pocket-size device. Unlike any other light meters, "**In. Licht** *pro*" captures the key index of circadian rhythm, the Equivalent Melanopic Lux (EML), which can truly reassure residents in the space of a helathy lighting environment.

LRS believes light has infinite possibilities. As Lawrence said, "we care about light, and we care about you". LRS always puts people first, using the science of light as a fundamental to build light for life. ■

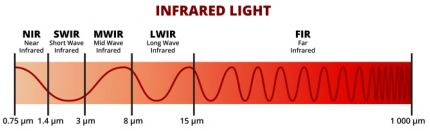
LightingRecipe.com

CONGRATULATIONS ON 100 EDITIONS!

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

Vertical Farming, LiDAR, LiFi and more

Würth Elektronik is one of the few manufacturers that covers the entire spectrum, from UV to infrared.



Würth Elektronik covers the entire light spectrum from UV to IR. Image Copyright: Adobe Stock - petrroudny.

With its knowledge, application know-how and components, the LED division can support innovative and novel applications. A core topic is Controlled Environmental Agriculture (CEA). The Horticulture LEDs are specifically developed for this purpose, help to promote sustainable food production. Indoor Vertical Farming, a part of CEA, is only made possible by LED technology. In addition to its products, Würth Elektronik supports this with a unique service - its own plant scientists develop special light recipes for different quality parameters of the plant. These promote plant growth and are used to develop new cultivation methods directly in the city.

Würth Elektronik developed its own Vertical Farming prototype.

Infrared Technology

Setting the foundation and learning from the experience with visible light, it was the natural step to go beyond and explore further the electromagnetic spectrum. Invisible light is sometimes beneficial, as it can realize many applications without disturbing our visual surrounding.

Using IR emitters and detectors in the wavelength range of 800-1000 nm is the foundation of multiple safety applications. Probably the most well known is the “Time of Flight”, where burst of light are used to measure real time distance. This technology enables ambient recognition systems, and is well known in autonomous driving as LiDAR (Light Radar). Würth Elektronik also develops its own product series that support such technologies. Infrared detection is the backbone for many safety applications. The current development focuses also on Driver and Occupant Monitoring Systems (DMS & OMS). It can detect sleepiness, attention deficit or health issues by driver or passenger, and prevent accidents.

Nevertheless, the automotive industry is not the only driving force for the infrared industry. Part of our Würth Elektronik DNA it is to look beyond and in the future, and follow the words of our CTO Alex Gerfer:

“For us, investing in forward-looking initiatives is a key factor for success and a matter close to our hearts. We strive to meet the needs of today’s and future generations, to act responsibly for a livable tomorrow and the day after tomorrow”.

WE is focusing on the development of smart technologies for the future. Infrared emitters and detectors enable the development of smart energy efficient buildings. Integrating smart lights, that recognize the presence of people, or adapt the light intensity based on the sun light, can reduce the energy usage for many industrial and commercial buildings. IR technology not only enables the smart building, but also makes them safer. Implementing light curtains, smoke & gas detectors, and presence detectors, can also help in early detection of dangerous situations, or help the safety crew locate the people in danger faster.
The diversity of IR applications for sensors and detector is immense, but one more technology is worth mentioning. As we live in a world that heavily depends on the exchange and gathering of information, we need fast and reliable communication. One solution, already implemented in long distance, but slowly coming into everyday life is optical telecommunication. Our focus is to understand the needs of applications, such as fiber or LiFi connections, and provide the correct components and expertise to the industry.

Optocoupler

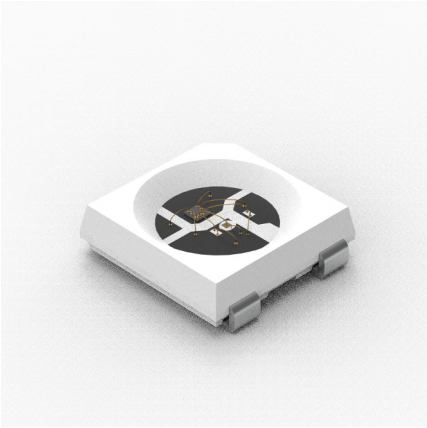
An optocoupler, also known as photocoupler or opto-isolator, is a device, which can transfer an electrical signal across galvanically-isolated circuits by way of optical coupling. Unlike transformers or capacitors, which can only transfer AC signals across the isolation barrier, optocouplers can transfer both DC and AC signals. With the new optocoupler series, Würth Elektronik presents one of the latest additions to its optoelectronic product portfolio. The innovative design features a coplanar structure and high-grade silicone for total internal reflection. This ensures the isolation gap remains fixed during the production process and provides perfect isolation and protection for your application. The total internal reflection provides stable CTR over the entire temperature range and high CTR even at low current operation. Additionally a copper lead frame is used for high reliability.

Ultraviolet LEDs

Another innovative product area is UV LEDs - powerful UVC LEDs for sterilization, surface disinfection or water and air purification expand the UV product range further.

Smart RGB LEDs

RGB LEDs are very popular in signal lighting solutions. Now is time for the next generation: The ICLEDs – a RGB LED with a smart integrated controller.



The new ICLEDs from Würth Elektronik feature a RGB-LED plus a controller.

Their built in intelligence is the best option for dynamic LED lighting. ICLEDs have their own architecture that allows you not only to control the LED chips individually; but also to produce a variety of effects, such as manage the colors, brightness, and timing. Würth Elektronik introduces the newest portfolio of those smart LEDs with a single wire protocol where each color is controlled individually with 8 bits. Additionally a special intelligent LED will also become available with a bypass function and with an IPx7 rating, which is perfect for outdoor applications.

Author: Harun Özgür, Division Manager Würth Elektronik eiSos Optoelectronics

www.we-online.com

Lighting the Way Forward: Thoughts from a Visionary in the Field – Mônica Luz LOBO, IALD President

Mônica Luz LOBO:
"We need to celebrate female characteristics like intuition, multi-tasking abilities, empathy, sensitivity, courage and resilience."

Mônica Luz LOBO, President of the International Association of Lighting Designers (IALD), shares her visionary perspective on the evolving world of lighting design. In this interview, she discusses her unique career journey from architecture to founding LD Studio, a leading architectural lighting practice. Focusing on the IALD's mission, she explores how the organization adapts to changing design and technology landscapes. Mônica highlights transformative trends, technological advancements, and the expanding applications of lighting design. Discover how the IALD nurtures the next generation of lighting designers and embraces global partnerships to shape the future of this dynamic field.

https://iald.org

LED professional: **It is a great honor for us to conduct this interview with you. Since the start of 2022, you have been the President of IALD, and we are especially pleased to speak with you for our 100th-anniversary edition of the LED Professional Review (LpR).**

Mônica Luz LOBO: It's a great honor to be with you.

LED professional: **Could you please provide us with an overview of your professional journey, including your educational background?**

Mônica Luz LOBO: I graduated in 1987 as an architect and urban planner at Sta. Ursula University in Rio de Janeiro, Brazil. By chance, or perhaps a call from the universe, my first job was at the most prestigious lighting design consultancy practice at the time at Consultores de Luminotécnica, based in São Paulo, Brazil. This wasn´t a planned choice; I was simply answering a newspaper ad seeking a junior architect with interior design skills. I spent five great years learning a lot about lighting from Esther Stiller and Gilberto Franco, two absolute pioneers of the profession in Brazil. It was a chance to rediscover architecture through light!

After living in São Paulo for that time, the desire to get back to Rio de Janeiro (the most beautiful city in the world) encouraged me to accept a lead position and establish a commercial showroom for LUMINI, a lighting manufacturer to which Esther and Gilberto contributed their lighting expertise and shaped their product line. This was an incredible opportunity to more fully understand how our industry works, and it gave me the opportunity to build key professional relationships. Four years later, I was confident that my passion was in design and not sales, so I left this partnership and founded LD Studio, now a 26-year successful architectural lighting practice working in a broad spectrum within the built environment.

My lighting education came from my two enlightened first employers and my own self-discipline, learning from an extensive IES library and attending Lightfair, Enlighten, and PLDC´s educational programs.

LED professional: **Can you describe a pivotal moment in your career that led you to the world of lighting design?**

Mônica Luz LOBO: I am an architect who has rediscovered architecture through light. At the beginning of my practice 26 years ago, my inspiration came from observing and revealing architecture through light. My goal at the time was to maintain a near-invisibility of light, like skin on surfaces.

I then began to realize that light could add meaning to the space and that we can reveal that space with intent: to embrace, inspire, guide, communicate, or even intrigue.

In recent years, people have become my inspiration. Every project has a story to tell, and I am fulfilled by the people involved in all aspects of the project — users, architects, clients, engineers, managers, my team, and myself — and all our desires and needs coming together so gracefully.

I started thinking about revealing the built environment through light, and I came to realize that I'm interested in the people who live in this built environment. I have certainty that every project is a new start, a new chapter; and that I will always learn through this process. Light brings soul to what it touches!

LED professional: **Could you please give us a brief overview of IALD and how you see the IALD's mission adapting in response to the rapidly changing landscape of design and technology?**

Mônica Luz LOBO: The IALD is a nonprofit professional trade association with a mission to advance the global profession of lighting design through leadership and advocacy and serve the members by promoting education, community, and engagement.

I think our mission is relevant to the changing landscape that lighting designers will face in the coming years. Education and advocacy will always be necessary as the technologies and stakeholders evolve. I think, therefore, the mission will remain valid. The way in which the Association achieves its mission is likely to evolve. We want to increase access to education and ensure


PRINCIPAL

IALD's Radiance Award for Excellence in Lighting Design. 2019 Winner: Kimpton Fitzroy | London, UK | Lighting Design International | Photo © Gavriil Papadiotis.

that our members are furnished with the best possible tools for their profession.

LED professional: **From your perspective, what are the most transformative trends in lighting design over the past decade?**

Mônica Luz LOBO: Building Information Management (BIM) has been transformational. When drawing became electronic, the transition was to simply replicate the drawing as you would do by hand on the computer. BIM requires a complete shift in process. With large relational databases and greater integration across disciplines what information and when it's delivered is reimagined. It also opens new avenues for the way in which we think about and present design work.

"There is an increased awareness of the necessity of lighting designers, but still as a complementary element to a project. Lighting can add meaning to a space. It can materialize an immaterial thinking, a strong concept."

MÔNICA LUZ LOBO

LED professional: **With the rapid evolution of technology, even with AI, which advancements do you believe have had the most significant impact on lighting design, and how is IALD ensuring its members stay at the forefront of these technological shifts?**

Mônica Luz LOBO: AI holds the potential for a profound transformation in the design process, extending beyond lighting to all fields of design. The opportunities are truly thrilling, encompassing data-driven design, optimization, cost analysis, design simulation, and more.

Though AI isn't quite autonomously designing projects at this point, it remains a topic of great interest to our members. It's an area we'll be concentrating on in the years ahead as the technology continues to evolve, and our members pinpoint the most effective methods for integrating this technology into their professional practices.

LED professional: **How have the applications of lighting design expanded beyond traditional spaces, and can you provide examples of innovative projects?**

Mônica Luz LOBO: The realm of lighting design has expanded beyond its traditional boundaries. Today, we witness projects that influence entire districts at a masterplan level, curating the visual identity of entire urban areas. This progression signifies the growing recognition of the profound impact that lighting can have on our urban environments.

Furthermore, there is a notable convergence of light art, festivals, and greater collaboration across various lighting disciplines, such as art, performance, and architecture. This interplay creates fresh connections between people and the spaces they inhabit, enriching our interaction with our surroundings.

LED professional: **Given the changes and trends we've discussed, where do you see the future of lighting design heading, especially in terms of sustainability, human-centric design, and technological integration?**

Mônica Luz LOBO: Lighting designers have consistently led the way in energy conservation. It's evident how much less energy is now required to achieve similar or even better project results compared to two decades ago. However, this doesn't mean we can become complacent in terms of sustainability. We are actively supporting the Green Light Alliance in their efforts regarding lifecycle assessment and are continuously providing input into regulatory systems worldwide. Lighting designers frequently put guidance into practice on real projects and develop effective solutions, underscoring the importance of our ongoing involvement in this process.

Our understanding of the impact of lighting on both humans and the natural environment has progressed significantly. While we may not possess all the answers, it's crucial that we assess the consequences of our work through this perspective. This becomes especially critical when the most energy-efficient method of illuminating a space may not align with these broader objectives.

LED professional: **How is the IALD ensuring that the next generation of lighting designers is equipped with both the technical skills and the creative vision to excel?**

Mônica Luz LOBO: Twenty-five years ago, the IALD recognized the importance of nurturing the future generations of lighting designers within the profession.

Mônica Luz LOBO, President of IALD, Founder and Creative Director of LD Studio, Certified Lighting Designer, Architect and Urban Planner AsBAI, IALD, CLD.

IALD's Radiance Award for Excellence in Lighting Design. 2021 Winner: Toranomon Hills Business Tower | Tokyo, Japan | Sirius Lighting Office, Inc. | Photo © Fumito Suzuki.

In response, the IALD Education Trust was established. This trust operates independently from the IALD but collaborates closely with it, aiming to provide financial support to students and connect them with high-quality education. Beyond education, these connections are about creating new relationships and linking emerging practitioners with established designers and studios. This integration into the community establishes a framework for long-term support.

Both the IALD and the Trust are committed to increasing their investment in this area in the years ahead. As our industry continues to expand, and we witness the retirement of seasoned professionals, the IALD is eager to take an active role in promoting, recruiting, and training the next generation of lighting experts.

LED professional: How does the IALD ensure that it remains culturally sensitive and inclusive in its approach, given its global presence? Are there any global partnerships or collaborations that you believe could redefine the future of lighting design?

Mônica Luz LOBO: That's an excellent question. Throughout my time with the IALD, even before taking on the role of president, I've consistently seen the impact of regional differences and cultural diversity on designers worldwide. There are commonalities between countries, but cultural influences significantly shape the development of design responses.

The IALD's structure involves the organization of local events, spearheaded by our dedicated region and chapter coordinators. These volunteers are truly remarkable, driven, and committed individuals. They not only make the association accessible to local members but also serve as advocates for their specific regions. They play a vital role in providing feedback to the board, staff, and myself, enabling the IALD to think globally and act locally.

Since the onset of the pandemic, there has been a renewed emphasis within IALD and similar organizations on enhancing collaborative efforts. We are continuously seeking opportunities to establish meaningful partnerships with other organizations.

LED professional: At the conclusion of our interview, could we ask for a key takeaway? What advice would you offer to both communities: the lighting designers and the lighting industry?

Mônica Luz LOBO: The lighting industry and the field of lighting design have consistently been leaders in embracing change. This transformation is quickening in pace, presenting us with a chance to demonstrate the fundamental importance of effective lighting in our constructed and natural surroundings. That can only be achieved through collective efforts and collaborative partnerships.

LED professional: It's been a true privilege to have this conversation with you. We sincerely wish you continued success in your presidency at the IALD and all the best in both your professional endeavors and personal life. Thank you so much.

Mônica Luz LOBO: Thank you. ■

Mônica Luz LOBO's Awards

- 2000: Illumination Award of Excellence for interior lighting design / Edwin F. Guth Memorial Award – Igreja da Lapa dos Mercadores
- 2006: IALD Award of Merit and Illumination Award of Excellence for exterior lighting / Paul Waterbury award – Igreja de São Francisco de Assis da Pampulha
- 2017: Illumination Award of Excellence for interior lighting design / Edwin F. Guth Memorial Award – Museu do Amanhã / Museum of Tomorrow
- 2017: Darc Awards Architectural – Structures low budget and Darc of Darcs – Guindastes do Pier Mauá / Pier Mauá cranes

LDSTUDIO
Av. N. S. de Copacabana, 647 cob.03/04
22050-002 Copacabana RJ Brasil
+55 21 25072087
http://ldstudio.com.br
monica@ldstudio.com.br

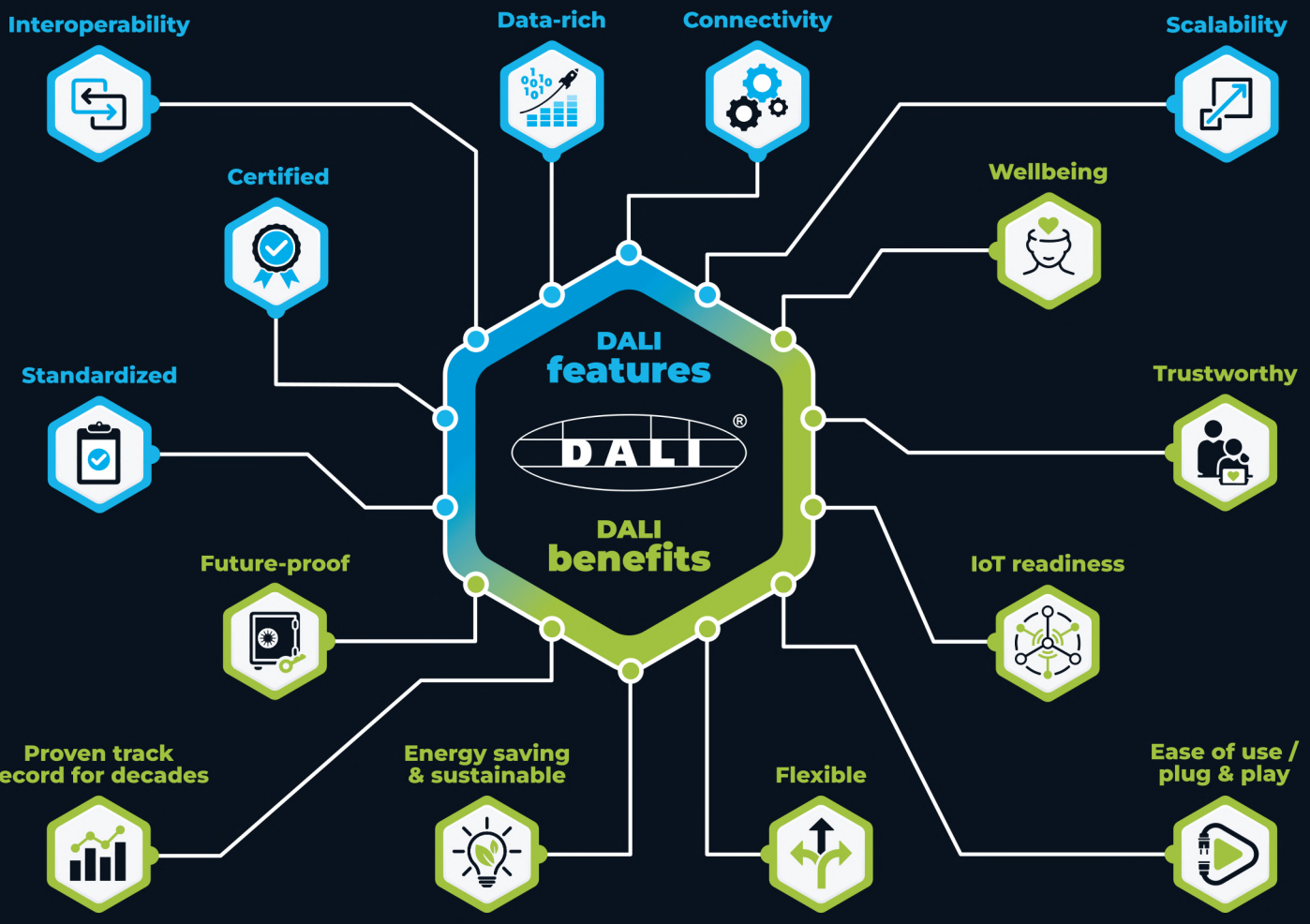
For additional information please visit https://iald.org

IALD

How DALI Enables Efficient, Future-Proof Lighting Control Systems

Designers, architects and building owners must consider a wide range of lighting-related issues, including sustainability, the circular economy, energy consumption, data and analytics.

Advanced lighting-control systems based on a global standard such as DALI can help to address all these issues.



Download our white paper at:

www.dali-alliance.org/downloads

DALI® Alliance

DALI® Lighting Awards 2023

Congratulations on the 100th ISSUE of LED Professional from the DALI Alliance and its members!

ENTRIES NOW OPEN

www.dali-alliance.org/awards2023/

Zerlina Hughes, Creative Director Studio ZNA, and the National Portrait Gallery

Interviewed by Bronwen Rolls, The Doing Collective

StudioZNA, founded by Zerlina Hughes, is a London based practice that is rooted in both collaborative working and a deep and real understanding of light and form. It is the dynamic nature of light and its ability to inform lighting design that stimulates their design process. The projects and experiences that come out of StudioZNA have the ability to touch people. They are a force for connection. With pin-point accuracy, detailed engineering and a large helping of understanding the human need for story and connection, the practice are the go-to designers for those who wish to create spaces, experiences and memories that not only tell a story, but that also form a bond between the content or moment taking place, and those who are experiencing it.

Maverick – Even Sublime

The influence of working in film lighting and set lighting influences the moods and moments StudioZNA create. Drama is formed through storytelling; light is used to take people on storytelling journeys of discovery, learning and sometimes, self-reflection, realization, and recovery. Zerlina Hughes, the founder and creative, director believes it also starts with the individuals' need to care.

"To do a good job - you have to care. It shows if you don't care. We became lighting designers because it is a sensory medium. Yes, its hugely technical but its hugely creative and maverick and even subliminal at times. I think those are the qualities that excite me. Yes, it all has to be backed up with the technical and engineering and I enjoy that rigorous process also."

Zerlina goes on to say,

"Whether it is working with rich content like art or theatre, a commercial project, or a retail space, it is so interesting what human requirements must be considered; it has to be emotive. We recently worked on a project for a large company headquarters. It was so interesting because we had to factor in the new working patterns and how to make people feel their best so they could perform to the best of their abilities. The emotion of lighting crosses over in all our work."

The World's Greatest Portrait Collection

In the heart of London, nestled between the historical landmarks of Trafalgar Square and Leicester Square, sits the National Portrait Gallery, StudioZNA's latest project. This treasure trove of art boasts the world's greatest collection of portraits, spanning over six centuries. The gallery closed in March 2020 for the most extensive renovation process in it 127-year history and this included a totally new lighting concept.

Since opening again this summer there are over 1,100 portraits on display and in addition to displaying many of the best-loved and most familiar portraits, from Holbein's majestic drawing of Henry VIII to Sam Taylor Johnson's film of David Beckham sleeping, the Gallery has also commissioned, acquired, and borrowed new works to present a wider selection of people and stories.

To house these works all the Grade 1 listed galleries have been beautifully refurbished in a scheme created by interpretation designers Nissen Richards Studio in collaboration with the Gallery's curatorial team. They welcomed StudioZNA to design and deliver the complete lighting for all the galleries and the retail space.

The Macro and Micro

When it came to the National Portrait Gallery (NPG) it was a complete museum and all galleries' projects. A large undertaking and a huge privilege. Every gallery, every space that formed the visitor facing displays had to be considered. The NPG was a project for StudioZNA that went from the very macro of the ambiance of the large galleries to the micro work of spotlighting the smallest details of unique artwork. But where does one start with a multiple space project?

"The variety of rooms and architecture had to be navigated. There was a need to respond to each individual space in terms of its artistic content and its physical form while also being aware of a large sense of cohesion to the museum. We also delivered the retail space and the temporary exhibition, which was a separate package of work."

Studio ZNA were brought on by long term collaborators Nissen Richard Studio, who were doing the interpretation and exhibition design, and both teams worked closely with the NPG team and the lead architect, Jamie Fobert.

National Portrait Gallery. Photo Credit: McCartney

"We always think holistically with the story-telling journey. It comes naturally to me, as I started in film and theatre, to tell the story of space and content. It will always sit in the forefront of my arc of the exhibition and lighting thinking. Dr Nicholas Cullinan the Director of the National Portrait Gallery totally understood the role of light in rendering the collection and the building to its very best. There was real support."

A Sustainable Concept

For a project of this scale there naturally had to be a firm and deliverable sustainability policy that underpinned all work on the project. This is especially true when it comes to the lighting infrastructure and this point was key in the product decision making process for the NPG and StudioZNA.

"To be able to curate spaces with the same infrastructure in place, thanks to truly nuanced controls is a wonderful step in product evolution. It is also a key part of a sustainable projects delivery. Intelligent controls in infrastructure that you can modulate is something that we as a practice are exploring and the products that we know are key for us to deliver a project of this scale sustainability. Unless there is a thorough sustainable policy behind a product, we do not use it in a specification. We expect a 20-to-25-year guarantee for parts as a minimum. So, we do not throw away, we offer legacy."

A Journey of Contrasting Light

Part of the NPG is a new entrance way area. The visitor immediately encounters a collection of busts from the classical period through to today. There is a scale of one-to-one dialogue being created between the visitor and the art itself. This one-to-one dialogue was the new theme of the NPG and this experience, and how it is supported through light, sets the mode and the tone of the journey that is one of cross period dialogue and intimacy with all the portraits.

"From the entrance you travel up", explains Zerlina. *"Once on the second floor, you are into the Tudor period and we knew this stepping through time was one that had to be reflected in the design journey. Deep tones, intimate spaces, a sense of connection had to be created. It was to be a jewelry box', a portal into history. Due to conservation regulations and to add a sense of the dramatic we created this dim, warm space to sit in contrast to the more traditional gallery spaces. Miniature fixtures were used, hidden from sight in a return."*

The journey from light to dark, and how the eye needs to be given time and support to adjust was choreographed carefully into the concept and Zerlina and her team worked to engineer a transition that was seamless. There was also the challenge of conservational lighting that did not reduce or undermine the story being told in the larger design concept.

"There are the traditional gallery rooms that are top lit. However, inside the cruciform of more traditional gallery spaces there were also smaller spaces where studies on paper, never displayed before, had to be safely shown. To do this, a high level of sunlight modulation was essential. We wanted to deliver the highest level of conservation lighting as possible."


The Six Wives
of Henry VIII

National Portrait Gallery. Photo Credit: NPG.

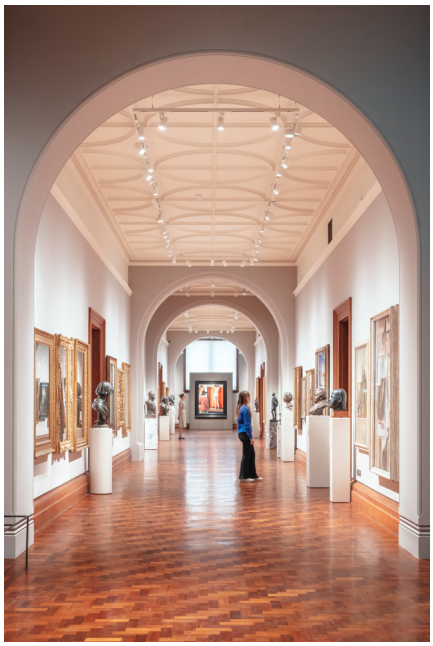
National Portrait Gallery Exterior. Photo Credit: NPG.

National Portrait Gallery Weston Wing. Photo Credit: David Parry.

These little 'pockets' of content, displayed separately from the main gallery spaces were differentiated through the use of color and through the lighting design.

"There are points where we wanted certain things to be highlighted, where a tone changed, where a new time period or theme was explored, where a new connect to the work could be made. We utilized accent lighting to make certain vistas and wall colors pop. Dimmer light levels, color rendering, modulated daylight, light positioning, and beam angles all had to be factored in to form these spaces as part of the larger cohesive story. We have so many years' experiences in lighting exhibitions that we can almost open up a collection because we know what lighting is the very best for conservation and user experience."

When the journey continues through the building the architecture shifts, and so, too, does the role of light. More daylight was brought in through the opening up of windows and this resulted in a lot of onsite testing.



National Portrait Gallery Blavatnik Wing. Photo Credit: Jim Stephenson.

"This is something we did hand in hand with our collaborators. When it came to color, light and material we deliver solutions as one team. We went through a whole array of light stopping films combined with scrims to reach a final light level that we all felt best supported the overall vision of the refurbishment, but never to the detriment of such important artwork. The more delicate work in these spaces sat under windows and works such as oils, that can withstand a light lux level, when placed on opposing walls."

Bringing Ambience to Paul McCartney's Photography

Alongside the central journey that was created in the main galleries there were also pockets of storytelling and experience running alongside it. One of these areas is the temporary exhibition space that, at the time of the museum opening, includes the photographic work of Beatle, Sir Paul McCartney.

Photo Credit: McCartney

"We had to render each work beautifully, but on top of that of that we went on to create an ambient journey. Starting with the works that document the monochrome greys of Liverpool in the 1950s, a monotonal feeling, we then see the work shifts to Paris and Europe. To support this transition in the work we brought in a subtle warmth and broader washes of light, we created an evening tonality. Finally, it is onto the technicolor of the USA where the exhibition, and the lighting that supports the climax in a finale of photographs taken in Miami. Here we have gone for an almost sun-drenched ambience so the floors have heat and the walls wrap you up in the work."

When you visit the NPG today it is a sensory experience. You are taken by the hand and led through time and space to discover and connect with all the faces portrayed – creating that one – to – one dynamic the museum wanted to achieve. The lighting design implemented in the NPG is an optimal museum concept because it enhances the work, without ever placing it at risk. It forms a part of the journey, while simultaneously celebrating the work and its space. ■

Explore the complete portfolio at www.studiozna.com.

Studio ZNA.

Zerlina HUGHES, Founder and Creative Director, StudioZNA

Zerlina Hughes studied at Goldsmith's College and the Bartlett School of Architecture, UCL, and has over 25 year's experience as a lighting designer in architecture, theatre, opera, and film. Early in her career she worked as an assistant to director Mike Leigh on 'Naked', 'Career Girls' and 'Secrets and Lies'. She was lighting design consultant for Warner Bros' 'Batman Begins'. Her theatre designs include projects at the National Theatre, London's West End, New York Broadway, and Sydney Opera House. In opera, she has worked extensively in Europe, particularly in France, Italy, Denmark, and Sweden, where she won best lighting design award in 2003. Zerlina formed her own award-winning lighting design practice StudioZNA in 2006, where she heads a small team of designers specializing in exhibition, gallery, and architectural lighting.

The **National Portrait Gallery (NPG)** is an art gallery in London that houses a collection of portraits of historically important and famous British people. When it opened in 1856, it was arguably the first national public gallery in the world that was dedicated to portraits. The gallery moved in 1896 to its current site at St Martin's Place, off Trafalgar Square, and adjoining the National Gallery. The National Portrait Gallery also has regional outposts at Beningbrough Hall in Yorkshire and Montacute House in Somerset. It is unconnected to the Scottish National Portrait Gallery in Edinburgh, with which its remit overlaps. The gallery is a non-departmental public body sponsored by the Department for Culture, Media and Sport.

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Tailored Lighting Intervention to Promote Entrainment in Myeloma Transplant Patients: A Field Study

Prof. Mariana G. FIGUEIRO, Director, and Allison ANDERSON, Researcher; Light and Health Research Center at Icahn School of Medicine at Mount Sinai

Light is the major synchronizer of circadian rhythms to the local position on Earth. Exposure to light at night and insufficient exposure to light early in the day has been linked with poor sleep and a host of health and behavioral problems. Myeloma patients spend two to three weeks inside their hospital rooms during transplantation, which can lead to circadian disruption due to low light levels typically found indoors. We performed a pilot study to determine whether circadian-effective light could promote entrainment in myeloma patients. We hypothesized that an increase in circadian entrainment would lead to reduced cancer-related fatigue, depression, and sleep problems. Fifty-five participants were randomly assigned to two lighting interventions that used freestanding luminaires to deliver either circadian-effective light ($n = 27$) or circadian-ineffective light ($n = 28$) throughout the hospital room between 7am and 10am during every day of hospitalization. Results showed an increase in nocturnal melatonin levels and an improvement in sleep in those receiving the circadian-effective (active) intervention. The present results suggest that light can be used to help myeloma transplant patients maintain circadian entrainment while hospitalized. Design guidelines and implementation tips to increase circadian stimulus in hospital rooms are also discussed.

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Introduction to Circadian Rhythms

The 24-hour pattern of light and dark that accompanies Earth's axial rotation regulates the physiology and behavior of almost every living thing on the planet. For humans, light reaching the retinas is the primary exogenous (external) cue that synchronizes or *entrains* the body's endogenous (internal) master biological clock and thus our circadian rhythms to the solar day, essentially telling our bodies to do the right thing at the right time. Other secondary exogenous cues include social activity (Salgado-Delgado, Tapia Osorio, Saderi, & Escobar, 2011), meal times (Wehrens et al., 2017), and physical activity (Moreno et al., 2019), among others. Sleeping and waking, feeding and fasting, the regulation of core body temperature, blood pressure, and the secretion of hormones are just a few examples of circadian rhythms. The term "circadian," coined by biologist Franz Halberg (1959), is a blended word derived from the Latin *circa* ("about") and *dies* ("day").

Because the human circadian system free-runs at an average period of about 24.2 hours—slightly longer than the solar day—a daily cue of light and dark is required to advance the circadian system by about 10–15 minutes, thereby continually resetting the master biological clock to maintain circadian entrainment (Czeisler et al., 1981).

But what light gives, light can also take away. Exposure to light at the wrong time, or not receiving enough light at the right time, has become increasingly common since the advent of electric lighting over a century ago. Exposure to light at night, and even a complete reversal of the day-night pattern in the case of night-shift workers, are now facts of life in our 24-hour society.

But exposure to light at night and insufficient exposure to light early in the day has been linked with poor sleep and a host of health and behavioral problems. Long-term disruption of the daily cycle of light and dark can lead to chronic disruption of the circadian system, which has been associated with metabolic dysregulation (leading to weight gain, obesity, and type 2 diabetes) (Depner, Stothard, & Wright, 2014), certain forms of cancer (Samuelsson, Bovbjerg, Roecklein, & Hall, 2018), depression (Germain & Kupfer, 2008), and other maladies (Abbott, Malkani, & Zee, 2018).

Lighting Characteristics Affecting the Circadian Clock

Four characteristics of light and light exposures play crucial roles in the circadian system's response.

1. The amount or level of light received at the eyes: "Is it bright or dim?"
Early circadian research in animal (Sharma & Daan, 2002; Takahashi, DeCoursey, Bauman, & Menaker, 1984) and human (Boivin, Duffy, Kronauer, & Czeisler, 1994, 1996) models found that varying light levels at the eyes differentially affect the nighttime suppression of the hormone melatonin (the release of which prepares the body for sleep) and zeitgeber time (i.e., either advancing or delaying the timing of the circadian system's 24-hour cycle). The greater the amount of light, the greater the melatonin suppression and the greater the advance/delay in zeitgeber time.

2. The spectral properties of the light experienced: "Is it warm (reddish) or cool (bluish)?"
Because it has a peak spectral sensitivity that occurs around 460 nm (Brainard et al.,

2001; Thapan, Arendt, & Skene, 2001), the human circadian system is maximally sensitive to short-wavelength ("bluish") light (e.g., 465–475 nm), which in turn is maximally effective for stimulating the circadian system. For the same photopic light level, a light source emitting short-wavelength light content will be more effective for activating the master biological clock than a light source emitting more long-wavelength ("reddish") light. Because light of all wavelengths evokes an alerting response at any time of day or night, long-wavelength light is especially useful for promoting alertness during the afternoon and evening without disrupting the circadian system (Figueiro, Bierman, Plitnick, & Rea, 2009; Plitnick, Figueiro, Wood, & Rea, 2010).

3. The timing and duration of light exposures: "When, and for how long, was I exposed to light?"
Humans are more sensitive to light stimulus during the evening hours, at night, and in the early morning compared to the middle of the day (Figueiro, 2017; Jewett et al., 1997). Experiencing high levels of light later in the day and in the evening will delay the timing of the master biological clock, causing us to fall asleep later than our usual bedtime and leading us to sleep in or feel tired on waking the next day. Conversely, experiencing high levels of short-wavelength light early in the morning will advance the timing of the master biological clock, causing us to fall asleep earlier and wake up earlier the next day. Morning light will also reset the master biological clock, helping to entrain our circadian system to the solar day. Again, because the circadian system free-runs at a period that is generally longer than the 24-hour solar day, we need light early in the day to maintain regular bedtimes. Longer exposure durations are also more effective at suppressing melatonin (Nagare, Rea, Plitnick, & Figueiro, 2019).

4. A person's history of light exposures: "How much light have I received over the past 24 hours?"
While it is well accepted that exposure to higher light levels results in greater melatonin suppression at night, research also shows that a one-day light exposure of 200 lx suppresses melatonin to a greater degree when it is preceded by three days of dim light (< 1 lx) compared to three days of the same 200 lx source (Smith, Schoen, & Czeisler, 2004). While the visual system's response to light is virtually instantaneous, the circadian system's response to light is cumulative (Figueiro, Nagare, & Price, 2018).

When appropriately specified according to these four characteristics, light exposures can be tailored to remedy symptoms of seasonal affective disorder (Golden et al., 2005), increase sleep efficiency in older adults (including those with Alzheimer's disease) (Fetveit, Skjerve, & Bjorvatn, 2003; Figueiro et al., 2014; Van Someren, Kessler, Mirmiran, & Swaab, 1997); promote circadian rhythmicity in premature infants (Rivkees, 2003); increase alertness at all times of day and night (Badia, Myers, Boecker, Culpepper, & Harsh, 1991; Cajochen et al., 2005; Cajochen, Zeitzer, Czeisler, & Dijk, 2000); and improve alertness and selected measures of performance (Sahin & Figueiro, 2013; Sahin, Wood, Plitnick, & Figueiro, 2014).

Light and Myeloma Transplant Patients

Multiple myeloma (MM) patients undergoing autologous stem cell transplantation (ASCT) experience clinically significant negative sequelae that affect prognosis and survival as well as quality of life. These sequelae include increases in production of inflammatory cytokines, higher rates of neutropenic fever, and higher symptom burden (e.g., depression, pain). These symptoms are associated with circadian rhythm disruption (CRD), a disruption in naturally occurring 24-hour cycles of hormone secretion, temperature, and rest-activity. CRD increases production of pro-inflammatory cytokines, causing a cascade of negative side effects, including higher symptom burden and increased risk of neutropenic fever. CRD has been associated with decreased prognosis and survival.

To address these concerns, we performed a pilot research study to determine whether circadian-effective light could promote entrainment (as measured by an increase in nighttime melatonin levels) in MM patients. For the purpose of this contribution, we limited our focus on the range of negative sequelae experienced by patients undergoing ASCT, and we hypothesized that an increase in circadian entrainment would lead to reductions in cancer-related fatigue, depression, and sleep problems among MM patients, both during and after ASCT hospitalization.

Methods and Materials

Tailored Lighting Intervention

Fifty-five participants were randomly assigned to two lighting interventions delivering either circadian-effective light ($n = 27$) or circadian-ineffective light ($n = 28$) throughout the participants' rooms from 7–10am daily during hospitalization. The circadian-effective light stimulus was specified following the Rea et al. model (Rea, Figueiro, Bullough, & Bierman, 2005). Following the model, the measured spectral irradiance at the cornea is first converted into circadian light (CL_A), which reflects the spectral sensitivity of the circadian system. CL_A is then transformed into a circadian stimulus (CS) value, which reflects the absolute sensitivity of the circadian system. Thus, CS is a measure of the effectiveness of the retinal light for stimulating the human circadian system, as measured by acute melatonin suppression, from threshold ($CS = 0.1$, or 10% melatonin suppression) to saturation ($CS = 0.7$, or 70% melatonin suppression). It is important to note that, strictly speaking, CL_A and CS characterize the spectral and absolute sensitivities of light-induced nocturnal melatonin suppression as regulated by the master biological clock. It is assumed, however, that CL_A and CS characterize the spectral and absolute sensitivities of the entire human circadian system because the biological clock plays a key role in regulating a wide variety of daily bodily functions, such as hormone production and sleep. For the purpose of the present study, it was assumed that the spectral and absolute sensitivities of nocturnal melatonin suppression are similar to those controlling light-induced changes of circadian timing and circadian entrainment.

Acuity Brands developed an experimental freestanding luminaire that used 3000 K, ambient "warm white" light to deliver either a CS of 0.3 for the circadian-effective ("active") bright white light (BWL) intervention (approximately 1000 lx at the participants' eye level) or a CS of 0.1 for the comparison ("inactive") dim white light (DWL) intervention (approximately < 50 lx at the participants' eye level). A warm light source was chosen for both interventions to make the space appear less institutional and more residential.

The interventions used ambient lighting to illuminate the entire room (**Figure 1**), rather than a light box, to reduce patient burden and promote compliance. The luminaires remained in the patients' hospital rooms for the duration of the study. They were pre-programmed to deliver the respective lighting interventions and turn on every morning from 7am to 10am. To ensure that the lighting intervention was successful, Daysimeters (Figueiro, Hamner, Bierman, & Rea, 2013), a type of light meter calibrated to measure CS, were placed behind the patient's bed and on the luminaire. The participants wore a third Daysimeter as

a pendant during waking hours for their entire hospital stay. **Figure 2** shows that, as hypothesized, those in the BWL intervention received significantly ($p < 0.001$) higher CS values than those in the DWL intervention.

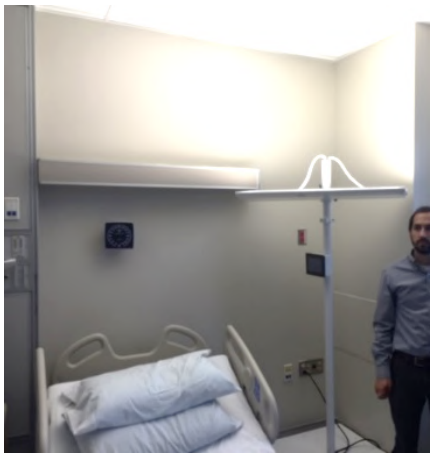


Figure 1: The experimental luminaire used to deliver the BWL (active) and DWL (inactive) interventions in participants' rooms.

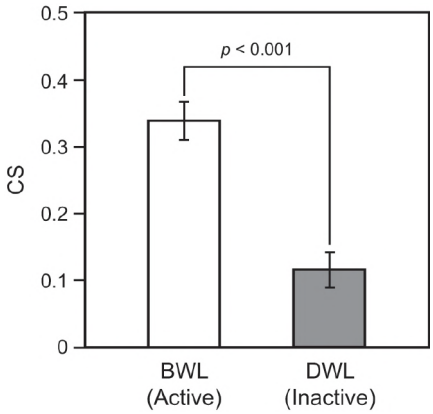


Figure 2: Mean CS values recorded by the bed Daysimeter when the lighting was programmed to be energized (7–10am). (The error bars represent standard deviation).

Outcome Measures

Outcome measures were assessed prior to hospitalization (baseline), on days 2 and 7 post-transplant, and on day 3 of engraftment (i.e., when the body accepts the transplanted stem cells). Day 3 of engraftment is usually the day before discharge from the hospital. We collected 24-hour actigraphy data to obtain objective measures of sleep; nighttime urine to obtain 6-sulfatoxymelatonin (6-SMT), a melatonin metabolite; and questionnaire data on participants' depression and cancer-related fatigue. Only those outcomes that yielded statistically significant (or nearly significant) results from the lighting interventions are reported below, thus excluding the participants' statistically nonsignificant subjective assessments of depression and cancer-related fatigue.

Results

Sleep

At baseline, the participants in the BWL (active) intervention reported shorter (but statistically nonsignificant) sleep time than those in the DWL (inactive) intervention. The sleep time of those in the BWL (active) intervention steadily lengthened over the course of the study, however, while the sleep time of participants in the DWL (inactive) intervention plateaued from days 2 through 7 and actually decreased by day 3 of engraftment compared to baseline. This was reflected in a nearly significant ($F_{4,120} = 2.31$; $p = 0.063$) lighting intervention × assessment time (baseline vs. day 3 of engraftment) interaction for sleep time (**Figure 3**). Overall, sleep time decreased through time in participants who received the DWL (inactive) intervention, while it increased in those who received the BWL (active) intervention.

Creatinine-corrected Urinary Melatonin-sulfate (6-sulfatoxymelatonin, 6-SMT)

There was a steep decline in 6-SMT levels for patients in the DWL (inactive) intervention, while 6-SMT levels for participants in the BWL (active) intervention were slightly higher, suggesting that the latter intervention maintained circadian entrainment during hospitalization. Due to the small sample size, the lighting intervention × assessment time interaction for 6-SMT levels approached significance ($F_{1,47} = 3.92$; $p = 0.054$) but was not adequately powered to reach significance at the 0.05 level (**Figure 4**).

The difference between baseline and intervention was significantly greater ($p < 0.05$) after exposure to the BWL (active) intervention than after exposure to the DWL (inactive) intervention.

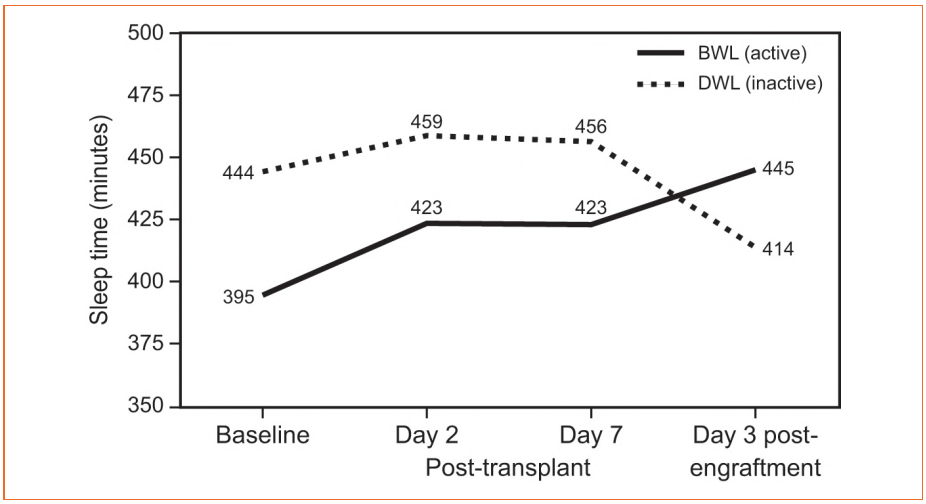


Figure 3: Sleep time in minutes at baseline (before hospitalization), day 2 after transplant, day 7 after transplant, and day 3 of engraftment (generally the day before discharge from the hospital). Sleep time decreased in those exposed to the DWL (inactive) intervention, while it increased in those exposed to the BWL (active) intervention.

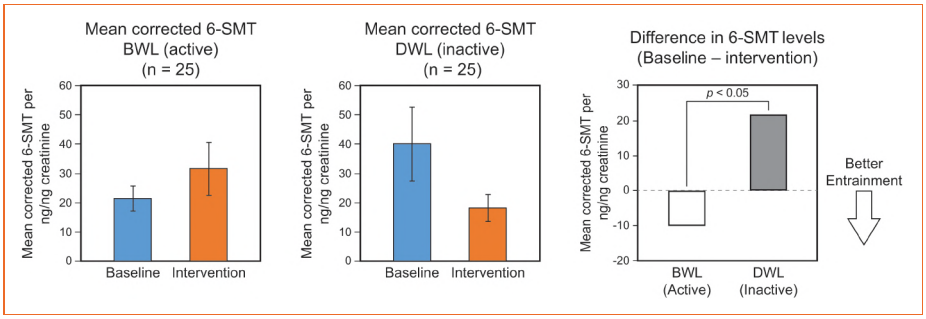


Figure 4: Mean-corrected 6-SMT levels, which increased in those receiving the BWL (active) intervention and decreased in those receiving the DWL (inactive) intervention. (The error bars represent standard deviation.)

Discussion

The results reported here suggest that implementing a robust light-dark pattern in hospital rooms can promote circadian entrainment and improve sleep in MM patients. Given that improved sleep has been linked to a series of health benefits, the active lighting intervention employed in this study could be an important first step in improving patient health, especially among patients who are hospitalized for extended stays, such as those receiving ASCT or those being treated for stroke or traumatic brain injury in rehabilitation units.

Although it was not confirmed by the present study, providing ambient circadian-effective light in hospital rooms has been shown to reduce symptoms resulting from disruption of the circadian system that are commonly experienced by hospitalized and survivor cancer patients, including cancer-related fatigue (Ancoli-Israel et al., 2012; Johnson et al., 2018; Redd et al., 2014) and depression (Desautels, Savard, Ivers, Savard, & Caplette-Gingras, 2018; Sun et al., 2014). Previous studies have also shown that bright white light delivered by light box (Litebook) reduced cancer-related fatigue and improved sleep efficiency among cancer survivors following completion of their treatment and release from the hospital (Wu et al., 2018).

These results should be interpreted in the context of a few important study limitations. Perhaps most importantly, the study is preliminary and was conducted with a small sample size. In our preliminary data, we observed a marginally significant ($p = 0.059$) lighting intervention × assessment time interaction for melatonin. The effect size for this interaction is $f2 = 0.09$, which is midway between a "small" and "moderate" effect size using the Cohen (1988) characterization. Moreover, since the results do not include post-hospitalization assessments, it is not yet known whether circadian-effective light delivered during hospitalization affects cancer treatment symptoms during the post-transplant period. Larger clinical trials measuring immune function biomarkers should be performed to extend these preliminary results.

While we are still learning about the benefits of lighting design for the circadian system, the present research and the work of others in the field clearly show that avoiding disturbance from light at night and creating a robust light-dark pattern can stimulate the circadian system, promote daytime alertness, and yield benefits for health and well-being. Despite the study's limitations, our findings nonetheless demonstrate that this easy-to-deliver, low-cost intervention improves sleep and circadian entrainment among MM bone marrow transplant patients during hospitalization.

Implementation Tips

A patient's stay in the hospital can range from a day to a few months. No matter the duration, lighting in a patient's room can positively impact the patient's psychological and physiological recovery. In addition to providing good visibility, low glare, and good color rendering, lighting for patient rooms should be designed to promote circadian entrainment by delivering high CS during the day and low CS in the evening to increase patients' sleep times and improve their sleep quality.

Circadian-effective lighting for designers and manufacturers

Circadian-effective lighting to promote circadian entrainment requires designers to create a CS schedule that, at a minimum, delivers a pattern of bright light during the day and dim light in the evening. Although not necessarily required, the CS schedule can mimic the spectral properties and illuminance levels that are provided by the daily solar cycle. As indicated in the UL Design Guidelines (Underwriters Laboratories Inc., 2019), the circadian-effective lighting design process includes six essential steps:

- Step 1: Establish a circadian-effective lighting design criterion (e.g., $CS = 0.3$).
- Step 2: Select a luminaire type (e.g., direct/indirect).
- Step 3: Select a light source (e.g., 3000 K LED).
- Step 4: Perform photometrically realistic software (e.g., AGi32) calculations for the building space.
- Step 5: Calculate CS from the vertical illuminance (measured at the eye) and the light source's spectral power distribution (SPD). cscalc.light-health.org
- Step 6: Determine whether the lighting system meets the circadian-effective lighting design criterion; repeat steps 2–6 if necessary.

The space's occupants are the most important considerations in circadian-effective lighting design and the establishment of a design criterion CS for step 1. One important thing to consider is the occupants' ages. Age-related changes to the eye can render CS prescriptions for elementary school students inappropriate for office workers or seniors in eldercare environments. It is also very important to take into account where, when, and how the occupants use the space. Because hospital beds can be angled to position patients upright (viewing the wall and windows) or fully reclined (viewing the ceiling), room lighting should accommodate both patient orientations. It is thus very important that lighting systems can provide appropriate CS levels without glare of direct views of luminaires in both positions. When specifying CS for patient rooms, it is recommended that illuminance be measured at the patients' eyes while sitting up at a 45° tilt and while laying down looking straight up at the ceiling (**Figure 5**). Establishing these parameters helps designers determine appropriate CS exposures and the timing of their delivery.

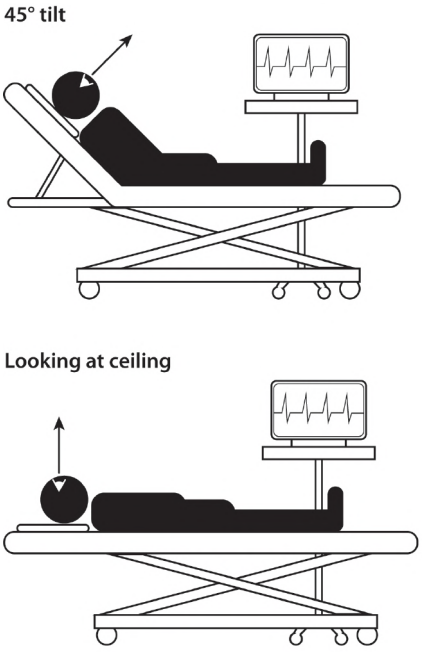


Figure 5: Light measurements in hospital rooms may need to be taken at 45° or 90° (horizontal) to account for patients' orientation(s) in bed.

As shown in **Figure 6**, several major lighting characteristics that are encompassed by design steps 2 and 3 contribute to how well the system can deliver the criterion CS:

- The light source's spectral power distribution (SPD), which represents the radiant power emitted by a light source as a function of wavelength, is crucial for circadian lighting design. Higher short-wavelength content generally delivers greater CS values for the same amount of photopic (lux) light at the eye.
- Vertical illuminance levels, or light at the occupants' eyes.
- The light source's intensity distribution, whether from a single luminaire or multiple luminaires, will determine how the light is distributed into the room and ultimately to the eye and work plane.

- Duration of exposure plays an important role in how the circadian system responds to a given light source. It should be noted that $CS > 0.3$ is based on a 1-hour exposure.

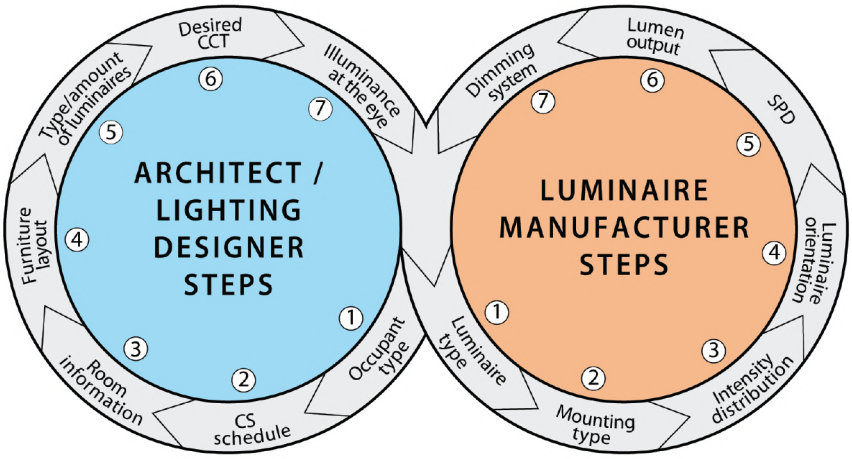
Once the fundamentals of occupant(s) and lighting characteristics are taken into account, the lighting design can be extended to incorporate information about the room to accomplish the aims of step 4. Lighting design software and manufacturers' published photometric data files (IES, or *.ies) are especially valuable tools for step 5, as they permit simulated predictions of luminaire performance, CS delivery, lighting power density (LPD), and energy usage.

Finally, when you reach step 6, it is important to avoid viewing the design process as a hard-and-fast series of steps that inevitably lead to the desired outcome. Successful designs actually grow from a dynamic interchange between architects, lighting designers, and manufacturers, all of whom fit together as important pieces of the puzzle. And like all designs, several iterations may be required, with input from all of these actors, to achieve optimal CS performance. If your design does not meet the criterion CS, try altering one of the components from the diagram in **Figure 6**. Keep in mind that the design must meet all visual criteria established by organizations such as the Illuminating Engineering Society.

Putting it all Together

The varied intricacy and difficulty of visual tasks performed in patient rooms also call for varying lighting specifications. Generally, the higher the light level, the faster the visual system can convert optical stimuli into usable information (Chan et al., 2012). For tasks involving objects that are very small or have low contrast with their environment, high horizontal illuminance (measured on the workplane) levels (> 1000 lx) are required. For tasks involving larger objects or those that have suitable contrast with the environment, where increased light levels provide diminishing returns, low-level ambient lighting (100–200 lx) is acceptable (Chan et al., 2012).

Glare caused by electric lighting, daylight, reflective surfaces, and other sources can be avoided by selecting the appropriate luminaires and making interior design changes within the space. Indirect light sources can be used to avoid glare while still meeting visual and circadian requirements, and other sources of glare can be reduced or eliminated by selecting nonreflective finishes for surfaces, altering window locations, and using window blinds.



ARCHITECT / LIGHTING DESIGNER STEPS		MANUFACTURER STEPS	
1	Occupant type is the most important factor when determining the lighting for circadian design.	1	The type of luminaire will determine the effectiveness of getting the desired CS at the eye.
2	Create a 24-hour CS schedule that promotes circadian entrainment. CS should be ≥ 0.3 during the day (or at least for 2 hours in the morning) and < 0.1 starting 2 hours prior to bedtime.	2	Luminaires can be plugged into an outlet or mounted to the ceiling, walls, or furniture. Creating layers of light can provide the desired aesthetics, task illumination, and circadian-effective light.
3	Information about the size of the room, ceiling height, and material and surface reflectances will aid in determining what type of luminaires are needed and how light will interact with the space.	3	Intensity distribution provides an idea of how light will be distributed in the space.
4	Furniture layout can determine the occupant's field of view and allow for strategic placement of luminaires. If the occupant's location is not known, opt to maintain the same vertical CS levels throughout the entire space.	4	Luminaires can be classified as direct, indirect, direct/indirect, semi-direct, or semi-indirect.
5	Determine what type and how many luminaires are needed in the space based on room dimensions, and the luminaire's intensity distribution and lumen output.	5	Light sources rated as having the same CCT usually have different SPDs, and therefore, will result in different CS. Always use the SPD (not the CCT) and light level at the eye to calculate CS.
6	CCT impacts the atmosphere of a space by providing a warm or cool feel, but for circadian-effective light, you will need to use the SPD provided by the manufacturer or measured in the space.	6	Lumen output helps determine how many luminaires will be needed to achieve the target CS. High lumen output luminaires will help reach the target CS with fewer luminaires, but may cause glare.
7	CS is calculated using vertical illuminance and the light source's SPD. To modulate CS during the day, either use a tunable system that changes the SPD and light level or simply use a dimmer to reduce evening light exposure.	7	Separate lighting switches, dimming controls, and/or a color-tunable system helps with achieving the target CS, which is higher during the day (especially in the morning) and lower in the evening and at night.

Figure 6: Summary of considerations that designers and manufacturers need to account for when designing lighting for the circadian system.

Finally, color rendering is another important consideration for luminaire selection, as accurate color perception is crucial for caregivers' patient diagnoses.

Patient room lighting that provides a robust 24-hour light-dark pattern can have profound positive effects on patient recovery. Lighting for patient rooms should be designed to promote circadian entrainment, providing high CS during the day and low CS in the evening, in order to increase patients' sleep times and improve their sleep quality. Nighttime lighting should be conducive to patient sleep while also accommodating visiting families and permitting caregivers to perform their tasks. Circadian lighting schemes have been shown to be effective for improving sleep in hospital ICU patients (Engwall, Fridh, Johansson, Bergbom, & Lindahl, 2015).

Due to the nature of the population, their temporary removal from the familiar surroundings of home, and the dynamic nature of the hospital environment, circadian rhythm disruption is not uncommon among hospital patients. The patient's

health conditions (e.g., psychiatric and neurodegenerative diseases) can also lead to circadian rhythm disruption, as can critical illness generally (Oldham, Lee, & Desan, 2016). Environmental influences such as ambient lighting in patient rooms can also disrupt the circadian system. A study conducted in three intensive care units found that patients typically sleep for only about 6 hours over a given 24-hour period, with only half of that sleep time occurring at night (Gabor et al., 2003). Improving and increasing nighttime sleep by promoting entrainment of a patient's circadian rhythm to a robust light-dark cycle can lead to improved health outcomes (Engwall et al., 2015).

The recommended lighting pattern (**Table 1** and **Figure 7**) for patients over the course of the day begins with a CS of 0.3 in the morning for at least 3 hours, drops to a CS of 0.2 for the midafternoon, and then drops once again to a CS of 0.1 in the late afternoon through the evening until bedtime. After bedtime, room lighting should be turned off, and nightlights should be added to permit safe navigation.

Time of Day	*CS*
7–10am	0.3
10–11am	0.3 → 0.2
11am–4pm	0.2
4–5pm	0.2 → 0.1
5pm–end of day	0.1

Table 1: *CS* Values by Time of Day.

This schedule can be accomplished using lighting designs that employ either static or tunable CCT systems. ■

Figure 7: Simulations of hospital room lighting delivering high *CS* in the morning (left), medium *CS* in the afternoon (middle), and low *CS* in the evening (right).

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Mariana FIGUEIRO, PhD; Director of the Light and Health Research Center, Mount Sinai

Mariana G. Figueiro, Ph.D., is Director of the Light and Health Research Center (LHRC) at Mount Sinai and Professor of Population Health Science and Policy at the Icahn School of Medicine at Mount Sinai. Dr. Figueiro is well known for her research on the effects of light on human health, circadian photobiology, and lighting for older adults. In 2013, she was elected Fellow of the Illuminating Engineering Society. She is the author of more than 150 scientific articles in her field of research, and her research is regularly featured in national media, including a TEDMED talk.

mariana.figueiro@ mountsinai.org

Allison ANDERSON, PhD; Associate Researcher II, Mount Sinai

Allison Anderson is a seasoned research specialist with a strong background in architectural lighting. Currently serving as a Research Specialist at the Icahn School of Medicine at Mount Sinai since December 2020, she has been actively involved in cutting-edge research for almost 3 years. Prior to that, she honed her research skills as a Research Specialist at the Lighting Research Center, Rensselaer Polytechnic Institute from February 2019 to January 2021. Allison's journey in lighting research began as a Research Assistant at the Lighting Research Center, where she contributed her expertise from May 2017 to August 2018. Her educational foundation is equally impressive, having earned a Bachelor of Architecture (BArch) from Rensselaer Polytechnic Institute in 2018, followed by a Master of Architectural Sciences with a Concentration in Lighting. With a deep passion for advancing the field of architectural lighting, Allison Anderson is dedicated to illuminating the path toward innovative and sustainable lighting solutions.

allison.thayer@mountsinai.org

Mount Sinai Light and Health Research Center

All living things depend upon light for survival. The Mount Sinai Light and Health Research Center was created in 2021 to apply the science of light to improve health outcomes.

Among the many projects underway, we are looking at how robust patterns of light and dark improve sleep for people from many walks of life, from submariners to premature infants to senior citizens and, indeed, to all who work in offices, schools, and factories. We are developing lighting schemes to improve the lives of those living with conditions like Alzheimer's disease and depression, and those who are undergoing cancer treatment or recovering from traumatic brain injury. We are also exploring the science and application of ultraviolet light to improve vitamin D production in populations who do not get enough sunlight, to control agricultural plant pathogens, and to serve as a germicidal disinfection strategy in the built environment. We are also developing new lighting technologies for safer transportation, from less glaring and more effective lighting for emergency vehicles to airport ground lighting that is better visible to pilots.

As Earth's citizens, we are compelled to focus on lighting applications that are both effective and sustainable. This means developing new metrics for characterizing and quantifying light for a healthy planet, as well as developing design guidelines to assist those who are charged with implementing this research in real spaces. We very much hope you are intrigued with our new center and want to be part of its evolution and impact.

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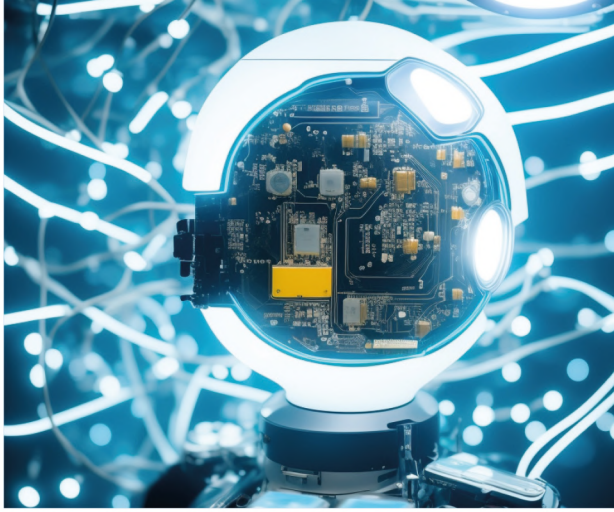

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Unlocking the Health Benefits of Near-Infrared Light: A Breakthrough Clinical Study

Dr. Anne BERENDS, Tom HILGERINK, and Dr. Mike KRAMES,
Seaborough, the Netherlands

While 50% of sunlight consists of invisible near-infrared light, the systemic health effects of light in this spectral window have long been overlooked. As a large part of the population spends their life indoors or is otherwise deprived of natural near-infrared light, there is a big opportunity to bring this light into the built environment and make a positive impact on the lives of many people. A recently published clinical study has shed light on the dose requirements to achieve significant health benefits for generally healthy people. These health benefits can be achieved effortlessly when state-of-the-art high-power infrared emitters are integrated in devices that surround us for hours every day, like display devices. With a clever design, health and well-being benefits can be delivered in 2-3h with an average power draw of only 4W.

Introduction

Human beings evolved over thousands of years, outdoors, in natural sunlight. This is a big contrast to how we live our lives today: most of us spend 90% of our time indoors [1], exposed to electrical lighting. Figure 1 illustrates how different the solar spectrum is from the spectrum of general indoor illumination. It is only fairly recently that the scientific community started to understand how exposure to low visible light intensities and spectral differences within the visible spectral window affect circadian rhythms and, consequently, our health and well-being [2]. While the lighting community and chrono biologists debate on the right metrics for healthy, circadian, or human-centric illumination, a major part of the solar spectrum that is lacking in our indoor environments is being overlooked; the near-infrared (**Figure 1**).

Near-infrared light is not part of the emission spectrum of white LEDs, and also modern window glazing blocks it to improve the insulation of buildings [3], which means that many people don't experience near-infrared light in their normal daily routine.

Invisible near-infrared light induces a biological effect called photobiomodulation, a phenomenon first described by prof. Mester in 1965 [4]. The working mechanism of photobiomodulation relies on activation of mitochondria. These parts of our cells form the fundament of our metabolism and produce ATP, the main source of energy for our body, and other molecules like NO and ROS, each with their own downstream (positive) effects. While the (wavelength dependent) mechanisms of action are still being researched on the cellular level, photobiomodulation has been shown an effective treatment for all kinds of conditions, e.g., accelerated wound healing [5], mitigation of diabetes type II symptoms [6–10], improved brain function [11–16], reduction of depression [17–21], and promotion of eye-health [22–26]. In addition, several wellness or beauty devices have entered the market, claiming a plethora of often unsupported benefits if users are willing to spend enough money (on selling price and energy consumption) and time (generally 30 min daily with constricted mobility) on their treatments.

While the vast body of evidence on the effectiveness of photobiomodulation on medical conditions is convincing and ever growing, the potential positive effects of near-infrared light on the health and well-being of generally healthy people were, for a long time, undetermined. Moreover, most studies and devices are based on the principle of direct irradiation of the treatment area, while the combination of deep skin penetration of near-infrared light and the production of vasodilating NO could hint towards potential systemic effects resulting from enhanced transportation of molecules through the body. To investigate and quantify the positive effects of photobiomodulation on healthy people, to determine the minimum dose of near-infrared light to achieve these effects, and to prove the systemic nature of photobiomodulation, a clinical study was executed. All experimental details and results of this study are published in a paper by Gimenez et al. in the scientific journal Biology [27]. Below we discuss the main findings and conclusions, put these in perspective of natural near-infrared light from the sun, and show how these findings can be implemented in a new generation of photobiomodulation devices that can be seamlessly integrated into daily life.

Clinical Study

In a clinical study, executed by research organization Chrono@work and the University of Groningen, four different doses ($0\,\mathrm{J/cm^2}$, $1\,\mathrm{J/cm^2}$, $4\,\mathrm{J/cm^2}$, and $6.5\,\mathrm{J/cm^2}$) of near-infrared light ($850\,\mathrm{nm}$) were tested in two seasons (summer and winter), on 56 healthy participants. These participants used a special desk lamp (**Figure 2**) with a photobiomodulation module attached to the lamp pole for 4 weeks, 5 days/week, 3h/day at home or in their office.

Subjective and objective effects were measured on short term (1^{st} and 2^{nd} day) and long term (2 weeks and 4 weeks) in three main effect categories: well-being, health, and sleep. For each of these categories the composite score was tested for significance, and if significance was obtained ($\alpha < 0.05$) the underlaying parameters were individually analyzed. As this was an at-home study during the COVID pandemic, several control measures were taken to provide information on the environment of the participants and compliance: the photobiomodulation module automatically switched on and off at pre-determined times, so no user intervention was needed. A distance sensor in the module measured the distance at which the participant was sitting, and the

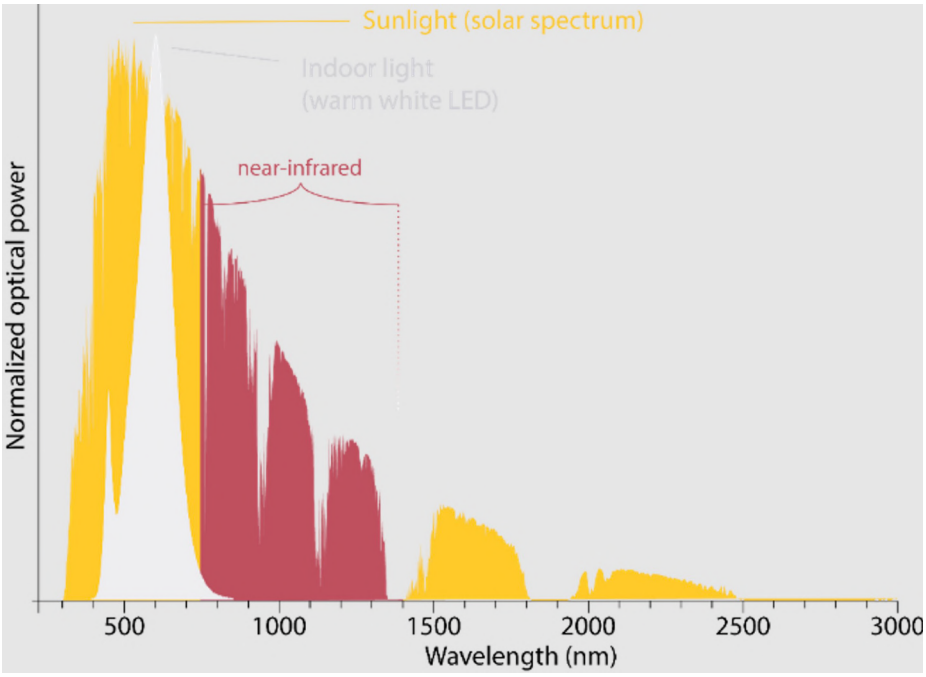

Figure 1: Comparison of the solar spectrum (yellow), with the spectrum of a warm white LED (white), the latter emits only in the visible part of the spectrum. Half of the light coming from the sun falls within the near-infrared spectral window (red).

near-infrared light intensity was adjusted accordingly, to make sure the right irradiance (and thus dose) was delivered at all times. The distance value was saved in a log file, so the researchers could verify compliance (presence) of the participants.

Figure 2: Ikea desk lamp with the square photobiomodulation-module attached to the pole of the lamp.

An ambient light sensor at the back of the module made it possible to check the visible light exposure of all participants during the photobiomodulation intervention, which showed no significant differences. Temperature sensors (worn on both exposed and non-exposed body parts) proved no temperature effects of the near-infrared exposure. Lastly, vitamin D levels in the blood of the participants showed a significant difference in natural sunlight exposure between seasons: in the summer an increase in vitamin D concentration was measured over the course of the study, while there was no increase in the winter (in all dose groups). In addition to these control measures, also low-intensity visible red LEDs were added to the photobiomodulation module, to make sure that all dose groups would have the same visual experience of a working module (i.e., this includes the $0\,\mathrm{J/cm^2}$ dose placebo group).

The first outcome measure discussed is well-being, a subjective, yet important measure as happy people are generally healthier and more productive [28]. **Figure 3**A shows the composite score for well-being, with a division in seasons, for each dose group. The values represent a change of well-being (average score after 2 and 4 weeks) compared to the baseline value of the participants and a higher score is better. A significant improvement in well-being is measured for the $6.5\,\mathrm{J/cm^2}$ group compared to placebo in winter. In summer, there is no significant difference in well-being between the dose groups. The overall difference between winter and summer is significant too: in summer all the participants were scoring better on well-being than in winter. **Figure 3**B-F shows the results of the underlaying parameters for the well-being composite score. From this analysis it is clear that the scores on drowsiness and mood have the strongest contribution to the composite score, as these show significant improvements too. In winter, participants in the $6.5\,\mathrm{J/cm^2}$ feel less drowsy during the day compared to the placebo group, while in summer there is no difference between the dose groups, but all participants feel less drowsy during the day compared to winter (**Figure 3**C). Participants show a strongly improved mood in the $6.5\,\mathrm{J/cm^2}$ group in winter compared to placebo, while in summer there is a slight decrease in mood for the $4\,\mathrm{J/cm^2}$ group compared to placebo. There is also a significant overall difference between the seasons, as in summer all participants have a better mood than in winter (**Figure 3**D). Both parameters, mood and drowsiness, showed significant improvement already in the short term (i.e., 1^{st} and 2^{nd} day).

The next composite score is health, which is built up from objective parameters. **Figure 4**A shows the change of health (average score after 2 and 4 weeks) compared to the baseline value of the participants and a higher score is better. A distinction between the two seasons is made, and a clear improvement in health for the $6.5\,\mathrm{J/cm^2}$ dose group compared to placebo is observed in winter. In summer, there is no significant effect. **Figure 4**B-E shows the individual parameters contributing to the health composite score, with in B and C the plasma (i.e., circulating) concentrations of inflammatory cytokines IFN-γ and TNF-α, respectively. These cytokines are part of our immune system and have a role in fighting pathogens or other invaders. However, in healthy people circulating concentrations of these molecules should be low, as high concentrations can cause autoimmune disease [29–31]. **Figure 4**B shows a strong decrease in IFN-γ concentration in the $6.4\,\mathrm{J/cm^2}$ group in winter compared to placebo, and no effect in summer. The TNF-α results in **Figure 4**C were not significant, until the BMI of the participants was considered in the statistical model. This resulted in a significant decrease of TNF-α concentrations in the $6.5\,\mathrm{J/cm^2}$ groups in both winter and summer. Additionally, there is an interaction effect between BMI and TNF-α concentrations, indicating that a higher BMI hinders to some extent the TNF-α reduction. This effect could be explained by the different metabolism of obese fat cells, producing 5-10x as much TNF-α mRNA compared to lean fat cells [32]. **Figure 4**E shows a significant reduction in resting heart rate in the $6.5\,\mathrm{J/cm^2}$ winter group compared to the placebo group. Resting heart rate is an indicator for physical health and a strong dose-response relation has been reported for resting heart rate and the risk for a variety of serious diseases [33]. The decrease in resting heart rate reported here, is thus a clear sign of improved health. Moreover, the decrease in resting heart rate is an immediate effect, a significant reduction was already observed in the short term, and on days without exposure (e.g., the weekend

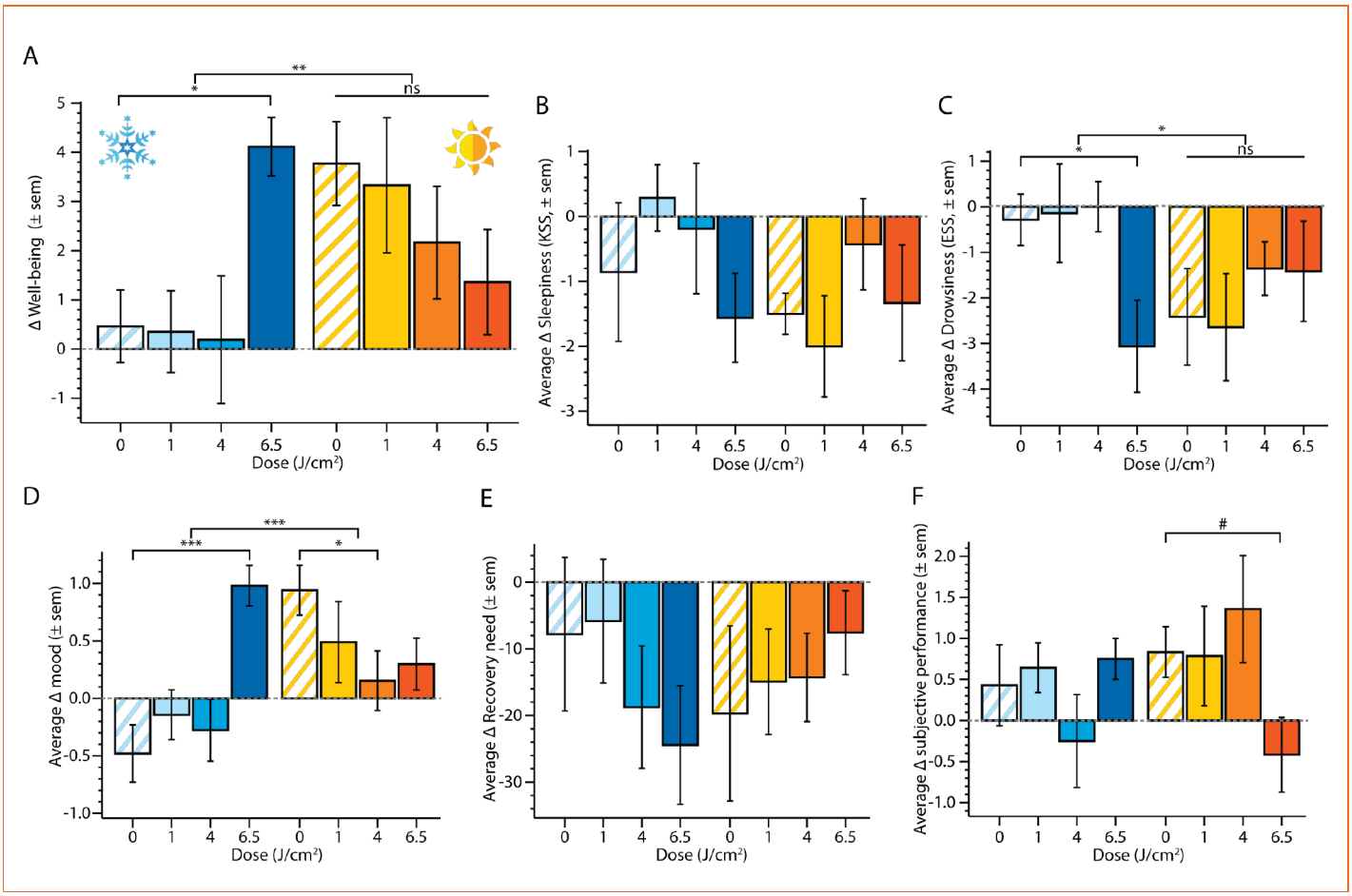

Figure 3: Results of photobiomodulation on the well-being of healthy participants. A. Shows the well-being composite score, B-F show the individual components of the composite score. Significant codes: *** p < 0.001, ** p < 0.01 * p < 0.05, # p < 0.1, ns: not significant.

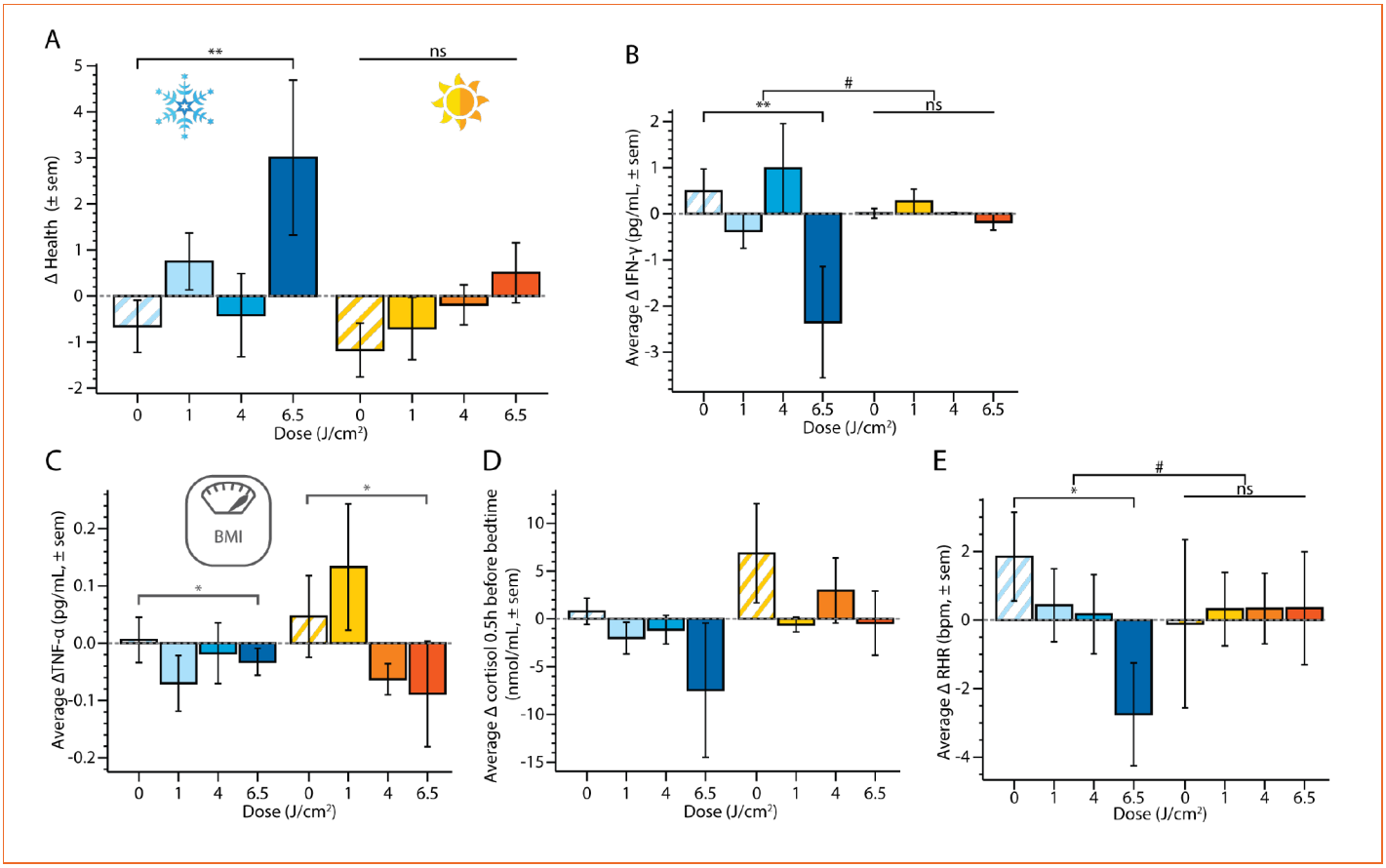

Figure 4: Results of photobiomodulation on the health of healthy participants. A. Shows the health composite score, B-E show the individual components of the composite score. Significant codes: ** p < 0.01 * p < 0.05, # p < 0.1, ns: not significant.

in this study), the resting heart rate remained at the lower level.

The final composite score determined is for the category sleep and shown in **Figure 5**. No significant effects were measured for this composite score, and no significant difference is observed between the seasons.

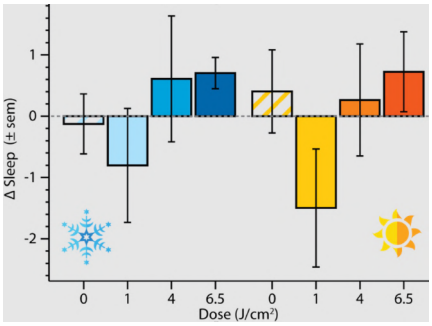

Figure 5: Results of photobiomodulation on the sleep of healthy participants. No significant differences were found.

Thus, concluding on the clinical study results, generally healthy people benefit from near-infrared (~850 nm) light exposure with improved physical health (immune system parameters and resting heart rate) and well-being (mood and drowsiness) when exposure to natural near-infrared light from the sun is low (i.e., in winter months). Several of these parameters were already positively affected on the first day(s) of exposure.

Natural Near-infrared Light

The seasonal variation observed in the clinical study sparked interest in the seasonal variation of sunlight and the sun's near-infrared irradiance compared to the (peak) irradiance used in the study (5 mW/cm^2). (Peak) irradiance is important, and not only the (cumulative) dose in J, as it was shown that in order to induce a photobiomodulation effect, an irradiance threshold should be overcome **[34]**. The exact height of this threshold depends on tissue, wavelength used, and effect monitored. The implications of an irradiance threshold can be further illustrated by a literature based example: for 633 nm light, the threshold for an increased DNA synthesis rate was established to be ~0.5 mW/cm^2 for HeLa cells **[34]**. In real life conditions, light first needs to penetrate the skin before reaching active cells. Based on Mignon et al., the relative photon density of 655 nm light 1 mm in the skin dropped by 70% **[35]**. This means, that one would need an irradiance of 1.6 mW/cm^2 at the skin surface, to reach the threshold of 0.5 mW/cm^2 at 1 mm depth. From the study by Gimenez et al. **[27]** it is clear that systemic health effects can be induced with a 5 mW/cm^2 peak irradiance on the skin for 850 nm light.

Figure 6 shows the integrated irradiance from the sun at different times during the day in summer and winter and on a clear and on a cloudy day in the 800–900 nm spectral window in the Netherlands, based on data published by Van Sark **[36]**. For reference, additionally, the irradiance of an incandescent bulb in the 800–900 nm and 600–1200 nm spectral windows is included, based on a 500 lux illumination level. On cloudy days the solar near-infrared intensities are much lower than the clinically tested peak irradiance, and also an incandescent bulb delivers much lower intensities. Another relevant parameter when discussing the real-life applicability of an electrical source of photobiomodulation compared to sunlight, is the chance for clear or cloudy days. In the Netherlands, i.e. northern Europe, the usual percentage of daylight hours with sunshine is only 38% **[37]**. Yet not all daylight hours with sunshine will reach sufficient near-infrared light intensities, as is clear from **Figure 6**. Apart from geographical regions with little sunshine, there are also very sunny regions where people tend to stay indoors or cover themselves with clothes to protect themselves from either freezing cold or too hot outdoor conditions, and as such won't benefit from photobiomodulation effects since their skin is not exposed. Moreover, there are regions where people have other reasons to stay indoors, for example, severe air pollution. These examples further emphasize the opportunity to make a positive impact on health and well-being of people with an energy efficient way of delivering near-infrared light indoors.

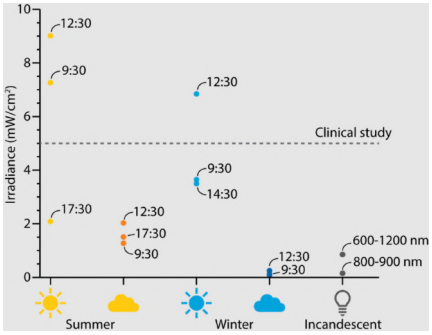

Figure 6: Seasonal, weather, and time-of-day dependent variation in near-infrared irradiance levels in the Netherlands in the 800-900 nm spectral window. The figure also shows the irradiance in the near-infrared spectral window from an incandescent light source at a 500 lux illumination level. The 5 mW/cm^2 peak irradiance at 850 nm used in the clinical study by Gimenez et al. [27] discussed above is indicated with a dashed line.

Indoor Near-infrared Light

Devices claiming photobiomodulation action have been on the market for years and range in everything from light-based helmets to hand-held light boxes, to light "walls", saunas, and even infrared therapy beds. In addition to providing a confusing array of use conditions and thus doses, these products suffer from significant barriers to adoption, mostly due to the uncertainty of their benefits and operational burden placed on the end-user. In all cases, they either demand focused attention, or specialized wearable equipment, or both. Wouldn't it be nice if, instead, photobiomodulation devices could be designed to provide proven benefits while being integrated into everyday life?

The clinical study results in Gimenez et al. **[27]** and discussed above, provide a roadmap for doing just this, since the required irradiation and dose conditions for significant positive health benefits under real-world use conditions and reasonable timeframes are measured and confirmed. The efficacious irradiance level revealed in the Gimenez et al. study are about 30 times higher than for general lighting, insisting that photobiomodulation devices have their power delivered carefully to the end-user's area of interest (e.g., face and neck) and not wasted elsewhere (**Figure 7**).

In Gimenez et al. **[27]**, the beneficial dose was obtained in three hours, but this is when the infrared LEDs were operated in pulsed condition at low duty factor (12.5%). In principle, the dose could be delivered much faster, but this comes at the expense of higher average power draw (and higher cost). In the case where such devices are integrated into daily life, this is unnecessary. To illustrate, typical mobile phone screen time is today more than 3 hours per day, and desk-time at work is typically more than that **[38]**. In the US, daily time spent in front of the television is more than 4 hours per day. All these platforms thus provide potential homes for pulsed-mode photobiomodulation devices that provide low average power draw and low cost.

Luckily, the last few decades have seen the development of a wide range of infrared emitters that can be leveraged for photobiomodulation. Automotive sensing applications drove the development of very efficient high-power infrared LEDs, while mobile sensing applications drove the development of high-power vertical-cavity surface emitting lasers (VCSELs). Meanwhile, solid state lighting spurred the development of highly efficient and low-

cost secondary optics, which can provide a wide range of directed and shaped irradiation patterns for delivering light efficiently to a target surface area. A summary of the performance characteristics of these various devices and implications for photobiomodulation applications is shown in **Figure 8**.

We see that high-power LEDs with integrated primary lenses typically have beam angles of 50 degrees or more, making them suitable for "close-in" applications such as for automobile drivers or people in an aviation setting, with potential staging platforms being the steering wheel, or back of an airplane seat, respectively. Combining high-power LEDs with secondary optics provides stronger focusing capability for "long-throw" applications like general illumination, wherein the photobiomodulation light can maintain its high irradiance from a long distance, provided it is properly aimed. VCSELs have the benefit of potentially offering narrow beams in a very small form factor, suitable for personal devices (such as smartphones, tablets, and laptops) but require an integrated diffusor to avoid laser-eye-safety warning labels.

Example – USB Accessory for Photobiomodulation

Using the guidelines from Gimenez et al. [27], we simulate the performance of a USB-powered accessory product that can be clipped on to a personal computer (or laptop) monitor and/or mounted on one's desk. The design requirements are a meaningful photobiomodulation dose over a 3-hour period at an average action distance of 75 cm (**Figure 9**, left).

The feasibility of a 75 cm working distance was verified with a face-tracking tool based on webcam data, developed by the authors. The tool offers insight into the positioning (in x, y, and z direction) of people's faces when working behind laptop and desktop screens. Checking their presence, horizontal and vertical movements as well as their distance from the screen brought confidence that the selected operating regime fits the dosing requirements: the data shows that people typically move very little in horizontal and vertical directions (**Figure 9**, right). More variation was observed for the distance between a user and a monitor, but the vast majority of the time people are still within the operating window that guarantees a dose completion within 3 hours. When reviewing data from people working on laptops, the average time needed to complete a dose even dropped below two hours as people tend to be closer to their screens.

The product design utilizes three commercially available, high-power infrared LEDs, operating in a 10% duty-factor (1 ms on, 10 ms period) pulsed mode. The typical continuous drive current for these LEDs is 1.5 A, but in the targeted pulsed mode, the allowed LED peak current increase is 3.1 A. This increase in allowed drive current (sometimes called the "crest factor") of slightly more than 2 means that about half the number of LEDs are required as would be the case for the LEDs operating in continuous mode. The facial positioning study

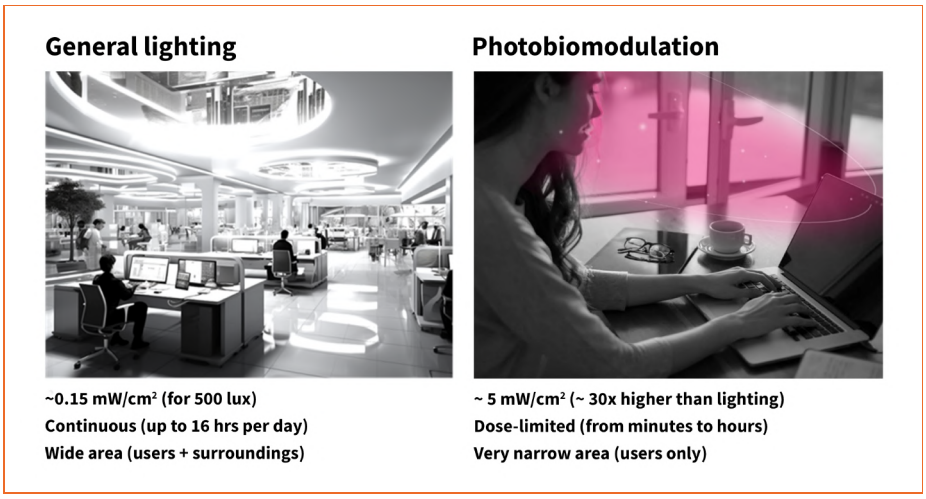

Figure 7: (Left) General lighting requires modest irradiance, but continuously for a large part of day, and must cover a wide range of areas to provide facility simultaneously for work-level tasks, interpersonal communication, and navigation. (Right) Photobiomodulation requires a high-level of irradiance but can be limited in duration and directed to a much smaller target areas.

	Domed High Power (HP) LED	HP LED + Secondary Optic	VCSEL + Diffusor
			
Emitter Efficiency*	35-45%	33-42%	45%
Beam FAHP (deg)	50	10-50	50-100 typ. (20 poss.?)
Max. Peak Output ea (W)	3.5 – 4	3.3 - 3.9	3
Input Power ea (W)**	1.1	1.1	0.7
Aperture (mm)	2.5 - 3	10+	~ 1
Thickness (mm)	3 - 3.5	6+	1.2
Action Distance (cm)	≤ 30	few cm to few m	few cm to few m (?)
Applications	Auto, Aviation	Lighting, Accessories	Smartphone, Tablet, Laptop, TV

*optical vs. electrical watts **assumes 10% duty factor

Figure 8: Summary of commercially available near infra-red emitters suitable for photobiomodulation devices.

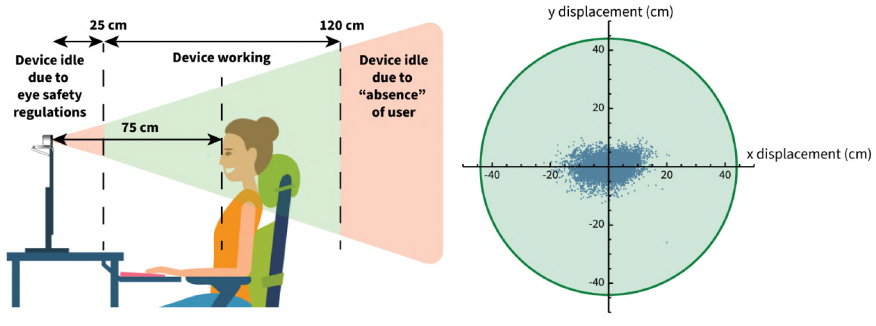

Figure 9: . (Left) Operating regime of the USB accessory. (Right) A representative set of datapoints showing the position of someone's nose (i.e. center of face) over an 8h time period in front of a monitor. The green circle indicates the area with sufficient radiant flux to obtain a photobiomodulation dose in 3h, based on the example design framework discussed in this article.

(**Figure 9**, right) suggests that a beam full-angle-at-half-power (FAHP) of about 20-30 degrees sufficiently covers the face and neck while providing some "guardroom" for the variation in positioning of the end-user's head relative to the platform screen. So, the LEDs are each mounted with a 10 mm TIR secondary optic, which provides a FAHP of 28 degrees. The three LEDs are operated in series and provide, after taking lens losses into effect, a total peak radiated output of 12.7 W (average 1.3 W) with a forward voltage of 10.9 V. Assuming 85% efficiency for the driver, we have an average power draw of 4 W for the 3-LED photobiomodulation accessory, which is within the power draw capability of USB 3.0 (up to 4.5 W). For comparison, a typical videocall "zoom" light or an HD "web cam" can draw about 2–3 W.

The performance results, including an irradiance map, are shown in **Figure 10**. The peak irradiance at the face-area is, on average, 5.9 mW/cm^2. Over the three-hour use duration, the dose is 6.4 J/cm^2 (virtually the same as Gimenez et al. **[27]**) and the cumulative dose through the face & neck is 4 kJ. Thus, this device is fully capable of delivering the health benefits reported by Gimenez et al., but in a very small (and low power consumption) form factor that can be integrated into daily life. Additional "smart" features like the incorporation of a proximity detector enhance both user friendliness and energy efficiency even further. Depending on the exact distance between the user and the device, the exact dosing-time (i.e. on-time) is adjusted, and the device is only on when the user is present.

The design framework described in this article is extendable to a wide range of personal devices, including smartphones, tablets, laptops, televisions, desk lamps or other task lighting devices, and other platforms that are close to people as they go about their daily routine. By utilizing intelligent operation of the emitters and directing the radiation responsibly, meaningful photobiomodulation benefits can be delivered with relatively low power consumption and low cost, and provides a path for bringing back positive health aspects of the outdoor sun to those who don't have the privilege of (or time for) accessing that on a daily basis. ■

LED	High-Power 850 nm (x3)
Optic	10 mm TIR, 28-degree beam (x 3)
Drive	3.1 A, 100 Hz, 10% DF
Distance	75 cm
Peak Irradiance	5.9 mW/cm^2 (avg)
Duration	3 hours
Dose	6.4 J/cm^2
Cumulative Dose	4 kJ (@ face & neck)

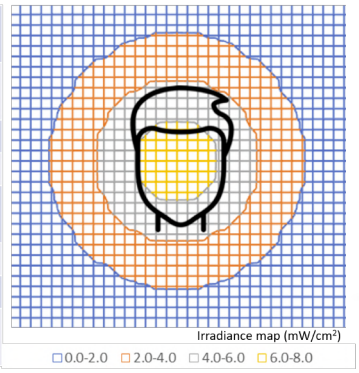

Figure 10: Simulated performance of a photobiomodulation USB accessory device for a personal computer (or laptop) using three high-power near-infrared LEDs. The device achieves the dose levels delivering beneficial effects as described in Gimenez et al. [27] within three hours of use.

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AUTHOR: Dr. Anne BERENDS
Dr. Anne Berends is Program Director Life Science at Seaborough. She holds a PhD degree in chemistry (nano materials science), whereafter her research focus shifted to the biological effects and related applications of light, currently focusing on the near-infrared spectral window. She likes the challenge of translating fundamental insights from scientific research to real-world applications, and explaining how these inventions can make real impact.

AUTHOR: Mike KRAMES, PhD, FIEEE, FIES
Mike Krames has more than 25 years of materials, device, and applications experience, with emphasis on solid-state lighting devices and products, including advancing the performance and color quality of LEDs for general illumination. He is currently president of Arkesso, LLC, a consulting firm in Silicon Valley, and Sr. Advisor to Seaborough Research. Dr. Krames' previous roles include Chief Technology Officer of Soraa Inc., and Executive Vice President of Advanced Laboratories at Philips Lumileds. Dr. Krames has over 100 publications and has been granted over 200 patents worldwide. He is a Fellow Member of both IEEE and IES.

AUTHOR: Tom HILGERINK
Tom Hilgerink is a product designer with a background in industrial design engineering and experience in (LED) lighting design. He's passionate about working on innovative and user-centered products to make everyday life more enjoyable. Within Seaborough his main activities are with the SunLED program where he oversees the technology integration throughout all phases of product development.

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Seaborough invents, develops and commercializes groundbreaking innovations for the lighting industry. With these innovations we aim to make a positive impact on the world. Many of our projects are truly breakthroughs yet require stamina to develop from idea to market entry. Therefore, Seaborough runs mostly long-term research and development projects.

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The Luminous Landscape: Light-Loggers and Their Role in Modern Lighting

Dr.-Ing. Oliver STEFANI and Prof. Björn SCHRADER, Lucerne University of Applied Sciences and Arts

In today's rapidly evolving world, the intricate relationship between natural light and human well-being is gaining significant attention. Recent findings indicate that individuals in North America and Europe spend approximately 90% of their day indoors, predominantly under artificial lighting. This shift from the natural light-dark contrasts of the outdoors to static indoor lighting has profound implications for our health and circadian rhythms. Dr. Oliver STEFANI and Prof. Björn SCHRADER from the Lucerne University of Applied Sciences and Arts delve into the transformative potential of light-loggers in their article, "The Luminous Landscape: Light-Loggers and Their Role in Modern Lighting." These devices, designed to record our light exposure in real-time, offer invaluable insights into our daily light interactions.

The article explores the non-visual effects of light, the significance of daylight in architectural design, and the emerging importance of light dosimetry. As we journey through this luminous landscape, the authors invite us to reflect on the profound impact of light on our health, mood, and overall well-being, emphasizing the need for a deeper understanding and appreciation of light's role in our lives.

Lucerne University of Applied Sciences and Arts: Werftestrasse 4, 6002 Luzern, Switzerland. info@hslu.ch

www.hslu.ch

Daylight as a Role Model

Large cross-sectional studies show that people in North America and Europe now spend on average about 90% of the day indoors mostly under electric light, so our daily exposure to light is different from what we would experience outdoors. We are often exposed to static lighting from early morning until late at night.

This is different from the 'light-dark' contrast of the outdoors, which can range from very bright days with 120 000 lx around midday to dark moonless nights below 0.001 lx. In a typical office environment, we would also miss the highly dynamic light changes caused by clouds obscuring and revealing the sun. Clearly, these outdoor conditions would be unacceptable for computer work. But there are other factors that make outdoor lighting unique, too: polarization, sigmoidal variations in illuminance synchronized with color changes from the golden hour to the blue hour in the evening and vice versa in the morning.

Research has shown that many properties of daylight, such as little light at night and sufficient light during the day, are important time cues for accurate biological clocks. Human physiology must be synchronized with the external 24-hour day. This synchronization is mainly mediated by light perception via retinal projections to the central clock in the brain [i.e. the suprachiasmatic nucleus (SCN)]. The SCN, in turn, controls the physiological rhythms of cells, organs, and tissues throughout the body.

In fact, more than 80% of genes in primates are rhythmic. Disruption of the body's physiological rhythms by false timing cues from artificial light can lead to several illnesses, including depression, diabetes, heart disease and even cancer. There are still many gaps in our knowledge of the many factors of daylight that can affect human health, but we do know that a lack of daylight is detrimental to human health.

The following publications provide further insight into this area: **[1,2,3]**. These publications were initiated by working groups of the Daylight Academy, a consortium of international and interdisciplinary scientists, architects and other professionals involved in daylight research **[4]**. One of these working groups addressed the question "Why do we need daylight?" and summarized the key points in a free booklet **[5]**.

For centuries, daylight was an essential criterion in the architectural design of buildings. At the beginning of the last century, the reliance on daylight began to wane and artificial light began to dominate. As energy efficiency measures in other sectors increased, they had an increasingly negative impact on the light transmission of windows: the prevention of heat loss meant that the light transmission of windows decreased. From single glazing to double glazing and now triple glazing, less and less daylight enters today's buildings. At the same time, window reveals have become deeper, further reducing the amount of direct sunlight and indirect skylight entering a room.

Independence from daylight has other consequences, as well: The knowledge and basic methods have been taught less and less in recent decades and have almost disappeared from school curricula. Fortunately, in 2018, for the first time in the EU, a standard (EN 17037 "Daylighting in Buildings") was introduced that promotes the use of daylight in buildings and makes it assessable. This was a novelty in many countries. Due to a lack of knowledge, many architects and designers find it difficult to apply this standard in their daily work. The next few years will be rocky, but with the certainty that daylight is free and

CO2-neutral, a renaissance of this wonderful light source is taking place. In fact, a recent study suggests that sufficient illuminance levels can be achieved in a spaces solely lit by daylight during most of daytime working hours even in the Scandinavian winter [6].

The authors also conclude that the dynamic indoor daylight reduces sleepiness and improves mood compared to static artificial light, although they cannot exactly pinpoint the variables that caused this improvement.

Non-visual Effects of Light and Where to Find Recommendations

Lighting standards usually relate to the workplace and are fundamentally concerned with the visual conditions required for the efficient and safe performance of specific work processes. To support vision, there are many comprehensive recommendations, guidelines, and regulations for lighting environments such as the EN 12464-1 “Lighting of indoor workplaces”. As many work tasks require good vision, photometric measurements based on visual light sensitivity (Vλ) have been useful in characterizing indoor lighting environments. Vλ represents the spectral sensitivity of the human fovea (i.e. the location in the retina with the best vision) to the perception of brightness, but not necessarily to non-visual effects.

The blue hour: Immediately after sunset, color temperatures around 17,000 K are not uncommon in nature. Could this color signal also be a timer for our internal clock? Studies with mice that were exposed to the blue hour under artificial skies synchronized significantly better with the day-night rhythm than without the blue hour. Image Credit: Oliver Stefani.

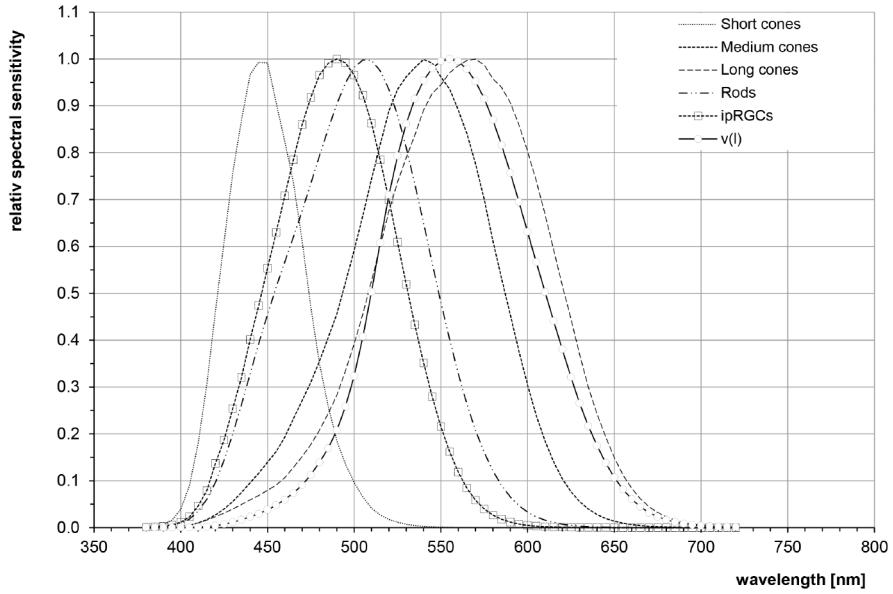
Not a sunset but artificial light at night illuminating the clouds of a night sky from below. During a moonless night, starlight would deliver an illuminance of only around 0.001 lux. Image Credit: Oliver Stefani.

The conventional view that all light information comes only from rods and/or cones is now outdated. Over the last twenty years it has become accepted that a small proportion of the light sensors in the retina belong to a third category, the ipRGCs (intrinsically photosensitive retinal ganglion cells).

As it is not yet possible to fully predict the non-image-forming (NIF) effects of light in humans and the relationships between the individual photoreceptors in the eye based on the intensity and spectral composition of a light source, in December 2018, the international standard CIE S 026:2018 ‘CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light’ proposed a method of measuring light that takes into account the irradiance for each individual photoreceptor in the eye [7].

Many non-visual effects of light are mediated by these ipRGCs. ipRGCs use the photopigment melanopsin to transmit light stimuli to different areas of the brain, in particular to our internal clock. Melanopsin is very sensitive to short-wavelength light, so light of these wavelengths is very effective in its function as a Zeitgeber. Blue and white light with a high proportion of short wavelengths in the evening and at night dampens the natural increase in sleepiness and the release of melatonin. Special attention therefore needs to be paid to lighting design for shift work. In addition to vision, good lighting should also promote the synchronization of our internal clock and related functions such as alertness, performance, health and motivation. It has therefore become essential to integrate these aspects into the lighting design. This integration is called ’Integrative Lighting’ (formerly known as Human Centric Lighting - HCL) [8]. Recommendations addressing non-visual aspects, however, are relatively recent, and not yet incorporated into regulations. A consensus view from a group of experts in lighting, neurophysiological photometry and sleep and circadian research has published “Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults” [9].

The authors suggest that the minimum daytime light exposure to support wakefulness should be at least 250 lx “mEDI”



Based on CIE S 026:2018, own representation by Licht@hslu / Schrader.

measured in the vertical plane near the eye (1.2 m above the floor), and that daylight should be used primarily to achieve these levels. mEDI (melanopic equivalent daylight illuminance) is a metric adopted by the International Commission on Illumination (CIE S 026:2018). This metric weights the spectral irradiance of a test light source with the sensitivity of melanopsin and expresses how much daylight would provide the same melanopic irradiance as the light source under test.

In the evening and at home, it is recommended to reduce the mEDI to less than 10 lx at least 3 hours before going to bed. During sleep, the recommended maximum mEDI is 1 lx. The preference for daylight to achieve daytime levels is also in line with the recommendations of the Daylight Academy and the new EN 17037 "Daylighting in Buildings". Where supplementary electric lighting is required, white light should ideally have a spectrum like daylight, including shorter wavelengths near the peak of the melanopic action spectrum. Although mEDI is one of the first consensus and evidence-based metrics to provide explicit values for non-image-forming effects of light, the metric "mEDI" is often not well understood by lighting practitioners.

To promote health and sleep, the evening rise of the body's own hormone, melatonin, should be attenuated as little as possible. But how much is "little" and how long should this exposure last? What matters more: timing, duration, brightness, or spectral composition of the light? A paper published in the Journal of Pineal Research provides insights into the answer to this puzzle. The authors used machine learning to analyze data from 29 publications. Melatonin suppression was mainly defined by the mEDI. Their model predicts that at 0.5, 1, 2, 3 and 4 hours, melatonin is reduced by 50% when light exposure has a mEDI of 600 lx, 350 lx, 120 lx, 43 lx and 15 lx. The publication and a toolbox (in Supporting Information) can help lighting practitioners better assess the effects of light exposure on melatonin suppression in the evening. Depending on the timing, duration and amount of light exposure, also other photoreceptors might contribute to non-visual effects [10].
The publication, a toolbox (jpi12786-sup-0002-DataS2.xlsx) and a video are available free of charge from the Journal of Pineal Research [10].

Several other publications have indeed shown that there is a dose-response between melanopic EDI, e.g. for alertness, sleep latency, sleep efficiency, pupillary light response or melatonin suppression. Recently, melanopsin has also been shown to contribute to brightness perception. This new research suggests that ipRGCs and S-cones play an important role in the perception of brightness [11].

The Good Light Group, a not-for-profit organization, has produced some easy-to-understand information and recommendations on how to improve people's lighting environment. These recommendations [12] include practical tips such as spending enough time outdoors (about 2 hours), especially in the morning, staying within one meter of a window and installing good lighting that mimics daylight.

However, how best to mimic daylight remains a puzzle to be solved, and portable dosimetry can help to find the missing pieces (see chapter on light dosimetry). One piece of this giant puzzle has recently been added, involving the ultradian dynamics of moving clouds in the sky. This study concluded that even if ultradian light dynamics do not improve our performance, they may make it easier for us to concentrate [13].

People are used to performing under difficult conditions. After all, we have to deliver a certain performance or amount of work during our working hours, even if it is noisy, hot, or the lighting is sub-optimal. But it is the little things, such as good lighting, that can make a difference to how much effort we need to put in to deliver the required performance. Ruta Lasuaskaite has already demonstrated this. She and her colleagues were able to show that 2800 K light produced stronger cardiovascular responses than 6500 K during the same cognitive task. This means that although the participants performed a cognitive task at the same level of performance, the higher correlated color temperature of the light reduced their physiological effort [14].

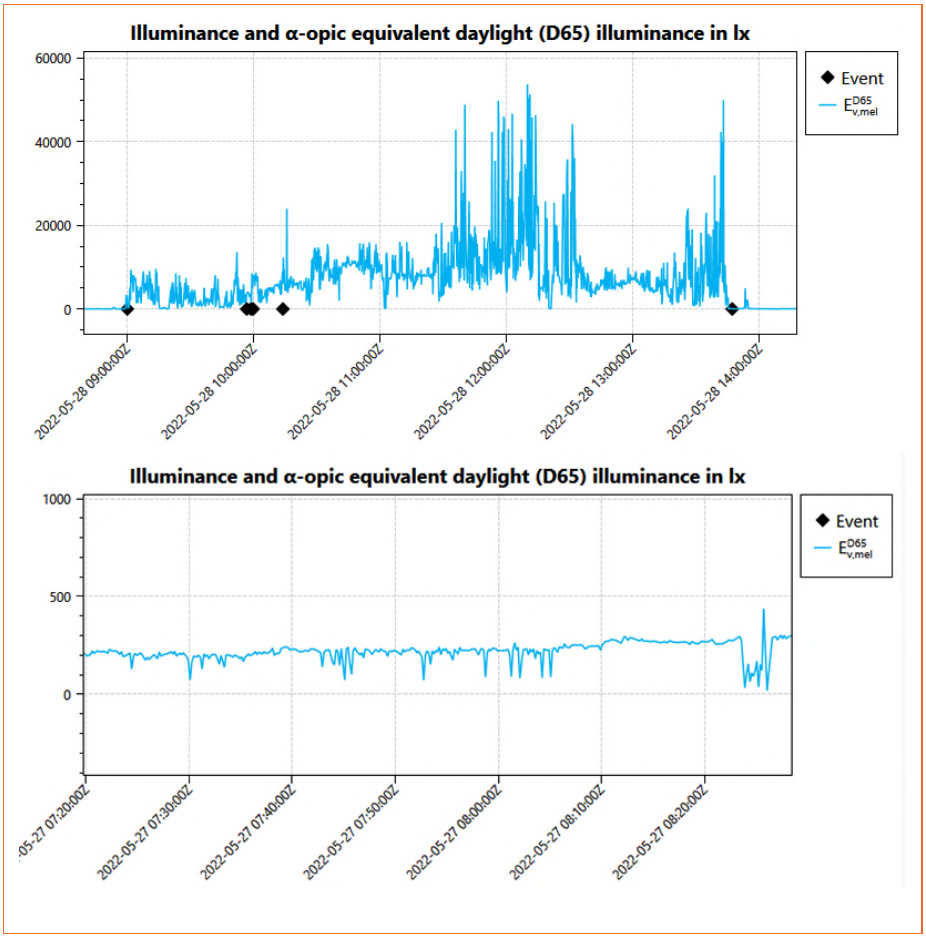
Many of the studies investigating the effects of light on humans are conducted in controlled laboratory environments. To further our understanding of the effects of light in the field, light dosimetry comes into play. Using readings from wearable dosimeters could help us understand how light affects us in our daily environment. Light logger readings could be correlated with our wellbeing, sleep, and health. In the future, this knowledge could provide us with more refined and personalized lighting recommendations based on a person's personal light history.

Why Light Dosimetry?

How the results from laboratory studies translate into the real world is not yet clear. Can we collect enough light with a "daylight shower" within a couple of minutes during the day if it is just bright enough, or should we collect lower but sufficient light levels continuously throughout the day to support a healthy lifestyle? Is it the total lux-hours (the AUC - area under the curve), the median, the mode or the mean illuminance that matters? We don't know, but tracking light history with wearable light loggers could help unravel the mystery. Once we know more, we will be able to give better advice on lighting behavior, e.g., whether it is better to spend an hour outdoors in bright light or to spend the whole

day under moderately higher illuminances. This would have implications for architecture, such as designing more inviting outdoor spaces for building occupants, or larger windows for brighter interiors. As outlined before, light is the main cue that synchronizes the human circadian rhythm with the natural light-dark cycle, so we should be aware of our daily light exposure. Nowadays, we are concerned about our daily calorie intake and the steps we have taken to support our health. However, awareness of our daily dose of light, and more importantly the timing of light, is still of little concern to most people. Fortunately, there are now new books, even bestsellers, that explain the importance of the body clock and lighting in supporting health.

We now know that when we avoid evening exposure to electric light, for example when camping in the wild, we become earlier types, i.e., we wake up earlier. Exposure to higher light levels during the day makes us less sensitive to the melatonin attenuation caused by evening light exposure, and that the homeostatic sleep drive is dependent on daytime lighting conditions. In fact, studies have shown that reduced light levels prior to evening light exposure increase light sensitivity afterwards. Circadian entrainment is stronger in summer than in winter. This has been attributed to increased light exposure as the photoperiod lengthens. Even in laboratory studies, the effects of evening light exposure in winter are expected to be greater than in summer. Schöllhorn et al. (2023) demonstrate the importance of tracking individual light exposure in laboratory studies. In her work, she found that seasonal variation affected the outcome of studies investigating sleep and circadian rhythms, probably due to the seasonal change in global downward solar radiation (DSR) during the day.



Comparison between a light history outdoors and indoors. Outdoors the average mEDI was around 8000 lx peaking at 50000 lx (top). Indoors variability and average mEDI was much lower around 200 lx (bottom).

One example of a wearable dosimeter is "LiDo" (https://light-dosimeter.ch/). It can record the light history measured near the eye and was developed by the Lucerne University of Applied Sciences and Arts.

Therefore, when assessing lighting environments and conducting lighting research, it is important not only to measure illuminance immediately under laboratory conditions, but also to record light history before study participants enter the laboratory [15].

Wearable light dosimeters are currently being developed by various research groups and companies. There are a variety of portable dosimeters on the market, i.e. worn on the wrist, chest or near the eye, which measure light exposure and log it at different intervals to provide a comprehensive picture of an individual's light exposure. An overview of available devices can be found in [16,17,18].

Wearable Dosimeter (LiDo)

It can record the light history measured near the eye and was developed by the Lucerne University of Applied Sciences and Arts and takes into account the CIE S 026 standard and the cosine response correction [19]. Wearable light dosimetry is currently also addressed by the new CIE Joint Technical Committee 20 (JTC20) and also by the European project "MeLiDos" [20].

As it is important to keep metrological recommendations and guidelines up to date to ensure that reliable studies well support health recommendations and policies, the MeLiDos project aims to provide the scientific and industrial communities with tools for the characterization and use of portable light dosimeters. Melidos will also introduce metrology for light loggers to respond to

the needs raised by CIE S 026 for the measurement of melanopsin-related metrics.

More specific goals are:

- The development and validation of new characterization methods
- The development of data analysis methods to verify and improve the quality of the data to make comparisons between different instruments more reliable.
- The analysis of use cases for wearable light loggers based on end-user needs.
- The evaluation of the performance of these devices.
- The liaison with CIE Divisions 2 and 6, and the users of these standards.

The light-dosimeter (lido) is a mobile measurement device used to investigate the non-visual responses to light.

Will Light Loggers be able to Assess a Complex Lighting Environment in the Future?

Several studies propose methods and metrics for quantifying the amount of light perceived by the human eye, and recommend measuring in a vertical plane close to the eye. Most publications, however, do not take into account temporal variations, the optics of the human eye or details of the spatial arrangement of a lighting situation. Corneal illuminance is typically measured with standard illuminance meters ("luxmeters") at eye level in a vertical plane. Most illuminance meters take into account the light coming from a hemisphere covering a 180° field of view. However, the visual field of the human eye is different from that of illuminance meters, and standard measurements may be misinterpreted. Therefore, information about the luminance distribution (i.e. "luminance mapping") of an environment can be helpful in understanding a lighting condition. In particular, Zauner et al. **[21]** highlight the potential for significant error when relying solely on vertical measurements and recommend the use of field-of-view occluders for measurements at eye level for typical viewing directions.

Furthermore, in the real world, outside of a controlled laboratory environment, the real-time exposure of a person's eye to light is a complex process because it involves the movement of a person in space, in addition to head and eye movements. This could be achieved by using wearable light loggers positioned close to the eye. In addition, the optical properties of the eye (e.g. pupil size) would need to be taken into account to estimate the luminous flux received by the retina through the entrance pupil from a luminous environment. Alternative metrics to determine the spatial arrangement of a given lighting environment are: Mean Room Surface Exitance (M_{RS}); average Indirect Corneal Illuminance ($E_{cor,avg(i)}$); Troland (T_d); Sensation of Room Brightness Index (F_{eu}).

Why are these Findings so Important for the Lighting Industry?

As previously outlined, the quality and amount of light perceived by the human eye is a complex process influenced by many environmental factors including the luminaire and its light source. Assessing a complex lighting environment and an individual's light history with light loggers can help with designing a balanced light exposure to support our health and well-being. Altering CCT and illuminance is not the only way to support human health, due to the ongoing expansion of our understanding regarding when and how human photoreceptors interact to impact neurobehavioral, neuroendocrine, and circadian functions. In the future, this should be translated into requirements for evidence-based assessment of a lighting environment, and the lighting industry should be ready to provide technical solutions that can meet the visual and non-visual requirements that are likely to emerge in guidelines and standards. Energy efficiency and sustainability should be considered in a broader context, including human health, well-being and daylight availability. The lighting industry should also work hand in hand with lighting designers and lighting scientists to create a wider awareness of the importance of good lighting. Please do not hesitate to contact us for further information. ■

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Dr.-Ing. Oliver STEFANI
Dr. Stefani, the visionary founder of Chronolight, embarked on his journey with light during his precision engineering studies at Nuremberg's Georg-Simon-Ohm University of Applied Sciences. His early career saw him delve into fiber optic technology as a laboratory engineer until 1998.

Pursuing his passion for design, Oliver earned his Master's from the State Academy of Fine Arts in Stuttgart. He then contributed to the Virtual Environments group at the University of Stuttgart. His expertise led him to head the Visualization Laboratory at the University Psychiatric Clinics Basel, where he honed his focus on the intersections of perceptual psychology and sensory physiology. In 2008, Oliver joined the Fraunhofer IAO's Visual Technologies Competence Team. Here, he championed human-centered lighting concepts, earning accolades like the IAO's Innovation Prize for Technology Management for his groundbreaking "Heliosity" lighting system. His leadership in the research area illuminated the profound effects of light on human well-being.

Throughout his tenure at Fraunhofer IAO, Oliver's expertise was sought by renowned institutions and companies, including Festo, Kesseböhmer, Marienhospital, Merck, Porsche, and ZDF, guiding them towards optimal lighting solutions.

Since 2018, Oliver has worked as a post-doctoral researcher with Prof. Cajochen at the Center for Chronobiology. Their research delves deep into the multifaceted impacts of light – from sleep patterns and circadian rhythms to cognitive performance and even pupil size. Oliver studied the effects of metameric displays on cognition, objective and subjective fatigue, pupil size and sleep. He is a member of the board of directors at the Swiss Lighting Society (SLG).

oliver.stefani@hslu.ch

Prof. Björn SCHRADER
Prof. Björn Schrader is affiliated with the Lucerne University of Applied Sciences and Arts, specifically the School of Engineering and Architecture. He serves as a lecturer at both the Institute for Building Technology and Energy (IGE) and the Center for Integral Building Technology (ZIG). Since June 2011, he has been a full-time lecturer in Building Technology, with a specialization in Artificial and Daylighting Techniques. Additionally, he heads the Light@hslu thematic platform at the Department of Technology & Architecture.

In terms of professional experience, Prof. Schrader has an extensive background in lighting planning. From November 2006 to March 2011, he worked as a Senior Consultant and Project Manager for Artificial and Daylight Planning at Amstein + Walthert AG in Zurich, Switzerland. Before that, from November 2002 to November 2006, he held the position of Project Manager in the same field at the same company. Earlier in his career, between May 2000 and September 2002, he was involved in lighting planning at Zumtobel Staff AG, also located in Zurich.

Prof. Schrader's academic journey began at the Technical University of Braunschweig, where he pursued Electrical Engineering and achieved a Preliminary Diploma in the subject from October 1993 to March 1996. He then continued his studies at the Technical University of Ilmenau from April 1996 to February 2000. Here, he specialized in Electrical Engineering, Electronic Media Technology, with a particular focus on Lighting Technology. In his teaching role, Prof. Schrader covers a range of courses, including "Lighting for Building Technicians," "Lighting-Acoustics-Climate," "Discovering Buildings," "Building Context," and "Modelling and Simulation." His professional expertise lies in Lighting Technology and Colorimetry.

bjoern.schrader@hslu.ch

About Lucerne University of Applied Sciences and Arts

The Lucerne University of Applied Sciences and Arts is the university of applied sciences of the six Central Swiss cantons. More than 7,800 students are working towards a Bachelor's or a Master's degree, while an additional 4,700 participate in continuing and executive education programs. The Lucerne University of Applied Sciences and Arts is the largest university level institution in Central Switzerland.

HSLU Lucerne University of Applied Sciences and Arts

About Chronolight

Chronolight offers independent recommendations for optimal lighting conditions to support performance, health and well-being. An important part of this is the implementation of the latest scientific findings on the non-visual effects of light. Chronolight´s latest publications review current Regulations and Standards for Lighting at Workplaces: https://doi.org/10.3389/fpsyt.2021.652161 and a most cited paper in the Journal of Pineal Research investigated HCL under laboratory conditions: https://doi.org/10.1111/jpi.12714. Together with renown scientists, Chronolight has analyzed the suppression of melatonin by light using data from 29 publications with the help of machine learning. The suppression of melatonin was primarily dominated by spectral composition, specifically by the melanopic EDI, a measure recommended by the CIE for applications such as Human Centric Lighting. However, an exact dosage has not yet been specified. Wouldn't it be convenient to more accurately predict the effect of light on melatonin suppression? The publication and a small toolbox aim to help lighting practitioners better estimate the impact of light exposure on melatonin suppression: https://doi.org/10.1111/jpi.12786. Chronolight consults companies such as SBB (Swiss railway), Skyguide (Swiss air navigation services), Porsche, DLF (German air traffic control). https://chronolight.ch/projekte/ (in German only).

CHRONOLIGHT
the right light at the right time

Beyond Ecodesign: The Expanding Horizons of Sustainable Lighting

Arno GRABHER-MEYER and Tawsif FAISAL, V-Research

Sustainability is multifaceted. The UN has defined 17 sustainability goals, and the EU has already taken measures to support them. Most measures affect every company and organization. Although lighting technology can, for instance, contribute – directly or indirectly – to sustainable cities, health and well-being, less hunger, decent work conditions, clean water, and sanitation, it can also be taken to become sustainable as a company. This is a huge challenge in many respects. The V-Research Computational Sustainability department provides an overview of some of the biggest challenges and shows how sophisticated digitization and computational technologies, including simulations and AI, combined with sustainability and circular economy expertise, can help the lighting industry take the right steps toward a truly bright future.

The Importance of Sustainability and the Circular Economy

The lighting industry is now more related to the electronics industry than ever before. From all electronic products worldwide, currently just 20% are recycled. This means that 80% of precious materials may be lost forever – or at least become hardly accessible again! Aside from being bad for the environment, it would not be much of a problem if these materials were plentiful but most of them are not. In contrast, we are facing the situation that some raw materials will become scarce within the next 20-50 years! And this assumption does even not consider an increasing demand.

But in their report, the International Energy Agency forecasts a threefold increase in demand for many minerals from 2022 to 2050 due to the transition to clean energy of the Net Zero Emission Scenario. And this also affects LEDs and lighting products in general.

Already in 2012, the TU Berlin and the Fraunhofer IZM had a look at the lifecycle of LED-products **[3]**. In their research, they excluded the luminaire or housing and just focused on the components. They identified the most important materials of the system as follows: Gold, silver, aluminum, copper, and tin are present in most components. Other resources are used in specific components, like rare earth metals for phosphors or gallium in the LED dies. They evaluated gold, silver, rare earths, aluminum, arsenic, copper, gallium, indium, and tin regarding criticality and economic relevance.

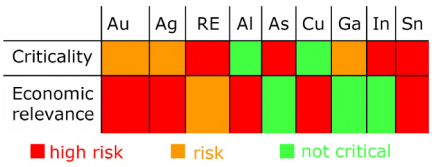


Figure 1: Assessment of the relevance of materials contained in LED products **[3]**.

A recent assessment might differ from the result from 2012 shown in **Figure 4** and look even worse due to events like the COVID19 crisis and the Ukraine war which demonstrated the vulnerability of our business system. Sustainability strategies and circular economy can buffer such events somewhat and mitigate the impacts.

These facts lead to the conclusion that manufacturers must move forward with their products to maximize reuse, refurbish and recycling rates, and hence sustainability to keep businesses running! The European Union has already recognized this, and beyond this, history has proven that the ones that are prepared early for the inevitable change, will be the winners in the end.

EU Actions and Thought Leaders' Advice

As the transformation to a circular economy is inevitable, with the introduction of the new Eco-Design Directive for light sources and supplies on September 1st, 2021, the EU already took measures for more sustainability. It was based on the Directive 2019/2015 and was a significant update to the earlier version. The update became necessary to guarantee the progress in energy saving. But this was just the starting point.

From 2024, all large corporations will have to prepare a sustainability report. The new EU requirements will apply to all large companies (with more than 250 employees and sales of 40 million euros or more), regardless of whether they are listed or not. Small and medium-sized companies will be subject to less stringent reporting standards. In addition, exceptions are possible in a transitional period until 2028.

Furthermore, the EU aims to accelerate the transition to a circular economy. The "R" words Refuse, Reduce, Repair, Reuse, Remake, Redesign and Recycle get to the heart of the matter. With this in mind, they have presented the Digital Product

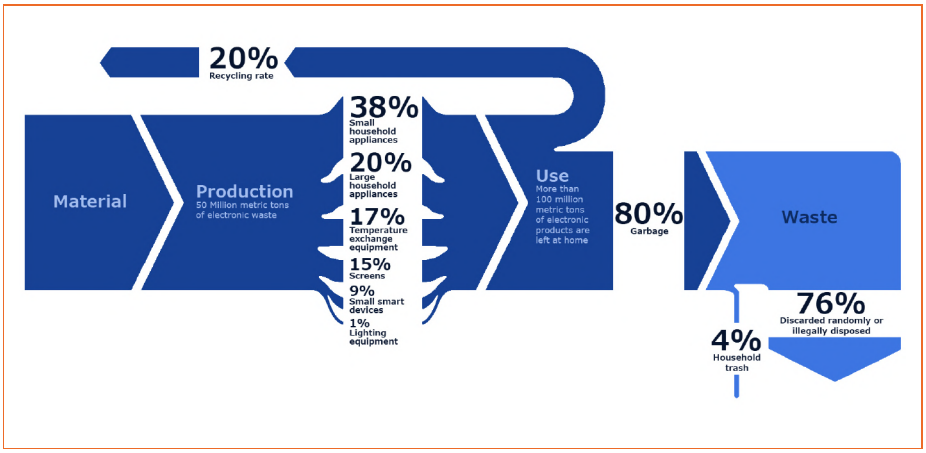


Figure 2: An analysis from the World Economy Forum of the global e-waste flow shows that 80% of e-waste is not properly disposed of and only 20% is currently recycled **[1]**.

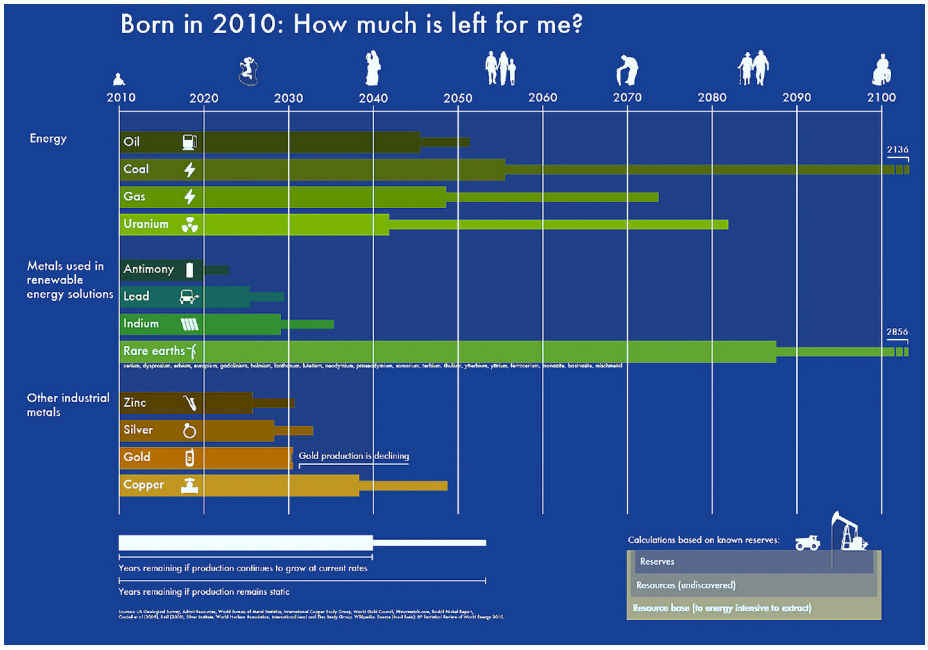


Figure 3: Estimated primary resources availability (without recycling).

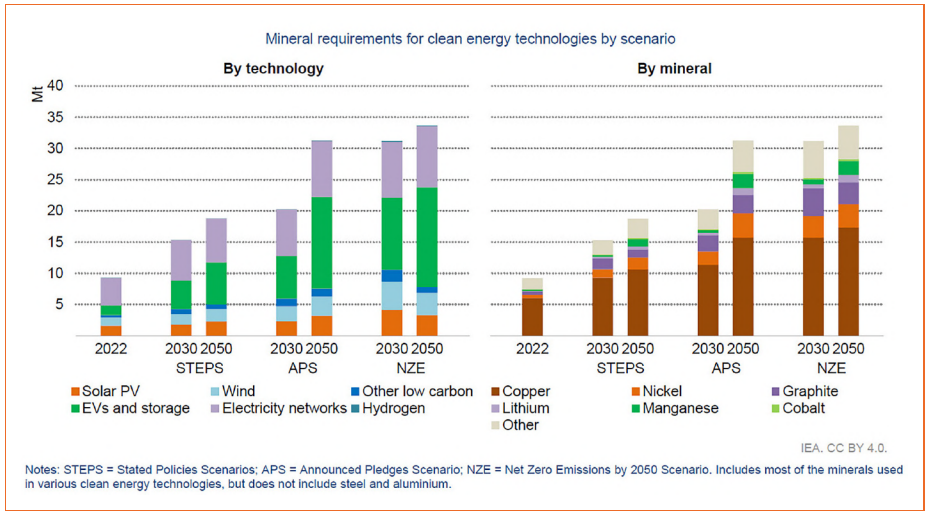


Figure 4: The Net Zero Emission Scenario causes the highest demand for critical minerals **[2]**.

Passport (DPP). From 2024, it will be introduced step by step, starting with the textiles industry and finally become mandatory for all products traded in the EU. The DPP requires a standardized data structure for the product description including components and their origin.

Not just the EU but also the Dutch Platform for Accelerating the Circular Economy (PACE) already recognized how important the transition to a circular economy is, and they worked out their "Action Plan", in which they request actions from government, industry, society and research institutes alike to carry out this necessary transition as quickly and smoothly as possible. They call on the research institutes to provide advice and support to industry on the following outstanding issues:

- Collect and process data on e-waste flows.
- Advance understanding of the environmental and socioeconomic impacts of circular strategies. Develop metrics to measure impact and progress.
- Develop science-based decision support tools for product design, business models, and policies, to balance and optimize impacts over the lifecycle.
- Understand behavior and change management. Develop effective strategies for both consumer behavior and organizational change.
- Develop new technologies in areas such as automated remanufacturing, refurbishment, sorting, and pre-processing.

To deliver this support, besides specific expertise in sustainability and the circular economy, expertise in digitization and data science is essential in any case. As an aside, according to the Cornell University institute of the same name, computational sustainability means combining these fields of knowledge.

As the lighting industry is not much different from other industries in terms of sustainability and circular economy issues, it also needs support and guidance on these points. From the multitude of possible topics in this context, this article will focus on four of the most pressing issues:

- The overriding topic of all: "How do I manage the transformation from the current linear business model to the circular economy? Do the framework conditions allow it? When is the right time to take the individual steps?"
- Gained attention due to COVID-19 and the Ukraine crisis: "How do I minimize supply risks? Where do the risks lie?

How can I identify them? What are my alternatives?"
- A difficult topic to classify for most of us: "What the heck is the digital product passport (DPP) all about?"
- An important cornerstone for a smoothly functioning circular economy: "What are industry symbiosis networks? Why are they so important?"

Fortunately, there is already a set of different tools that can help to find the answers to these questions:

How to Master the Transition to Circularity

At the beginning of the journey, it is all about understanding the current processes and logistics, and being on a level of digitalization that offers a robust dataset and data-handling for sound data-based decisions. That means half the way to success – almost.

Not only if you are not sure you can fulfill all the requirements to start the transition, e.g., if your IT and processes are fit for the transition, an Enterprise Architecture (EA) analysis may help. This analysis provides information about weaknesses, bottlenecks, and the potential for improvement in the processes and the (digital) infrastructure. Various tools are available for this purpose.

A very powerful one is ArchiMate - and it is a freely available open-source modelling tool. While is seems at first, that you could do the same thing with PowerPoint or Visio, there is a huge difference. ArchiMate relies on a model repository from which all the modeled elements and their relations can be used in all the diagrams. A big advantage is that, when modelling, it is possible to argue and explain WHY and HOW we end up in the state of WHAT exists there: It is the most pragmatic simplification of a specific real world problem domain.

With this analysis, we know the status. We have a clear picture of how your business works today. But you can go one step further with an EA-analysis: Therefore, you must extend the model with the new requirements such as the dismantling of a product or adapt your data architecture to encompass the supplier, age, materials, transformations, usages, and so on. Now let us assume that your digital environment is ready for the transition and let us be a visionary: Start designing the ideal version of the whole process for your company in ArchiMate based on the knowledge of

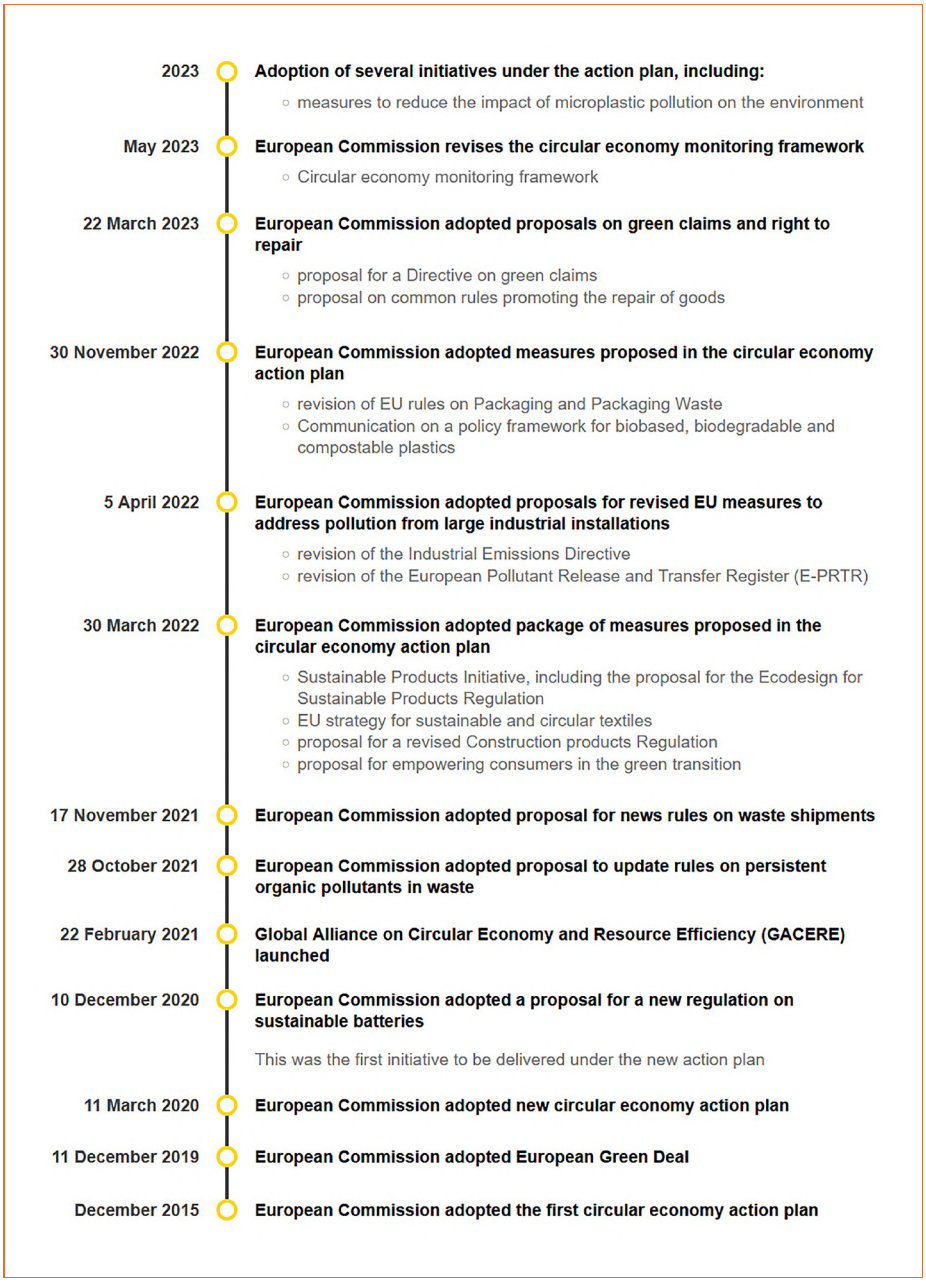


Figure 5: The European Commission started their journey towards more sustainabiliy in 2015 with the first curcular economy action plan. The graph shows additional things that have been done up until now.

circular economy and its appropriate circular business models (CBMs). With this you can quickly identify what needs to be changed and – even more importantly – where to start. You can also think about which single steps could be set. At the end of this process you will have a possible roadmap for the transition to an optimized process.

However, during the EA-analysis, you may recognize that you don't have a clear idea of which CBMs or strategies are most suitable for the company or the different products, especially as the current knowledge gives no information on several important questions, such as:

- What are the implications of not adequately explaining and considering the effects of scale and time?
- What are the impact and effects of individual actor behavior and social interactions among partners?
- How does the external environment impact the viability and adaptability of the proposed business model?

Here, computer simulations can help as simulation models offer opportunities for CBM experimentation. Agent-Based-Simulation (ABS) is widely recognized for being the best choice. Still being the workhorse, ABS is sometimes used in a hybrid system with Discrete Event Simulation or System Dynamics to give even

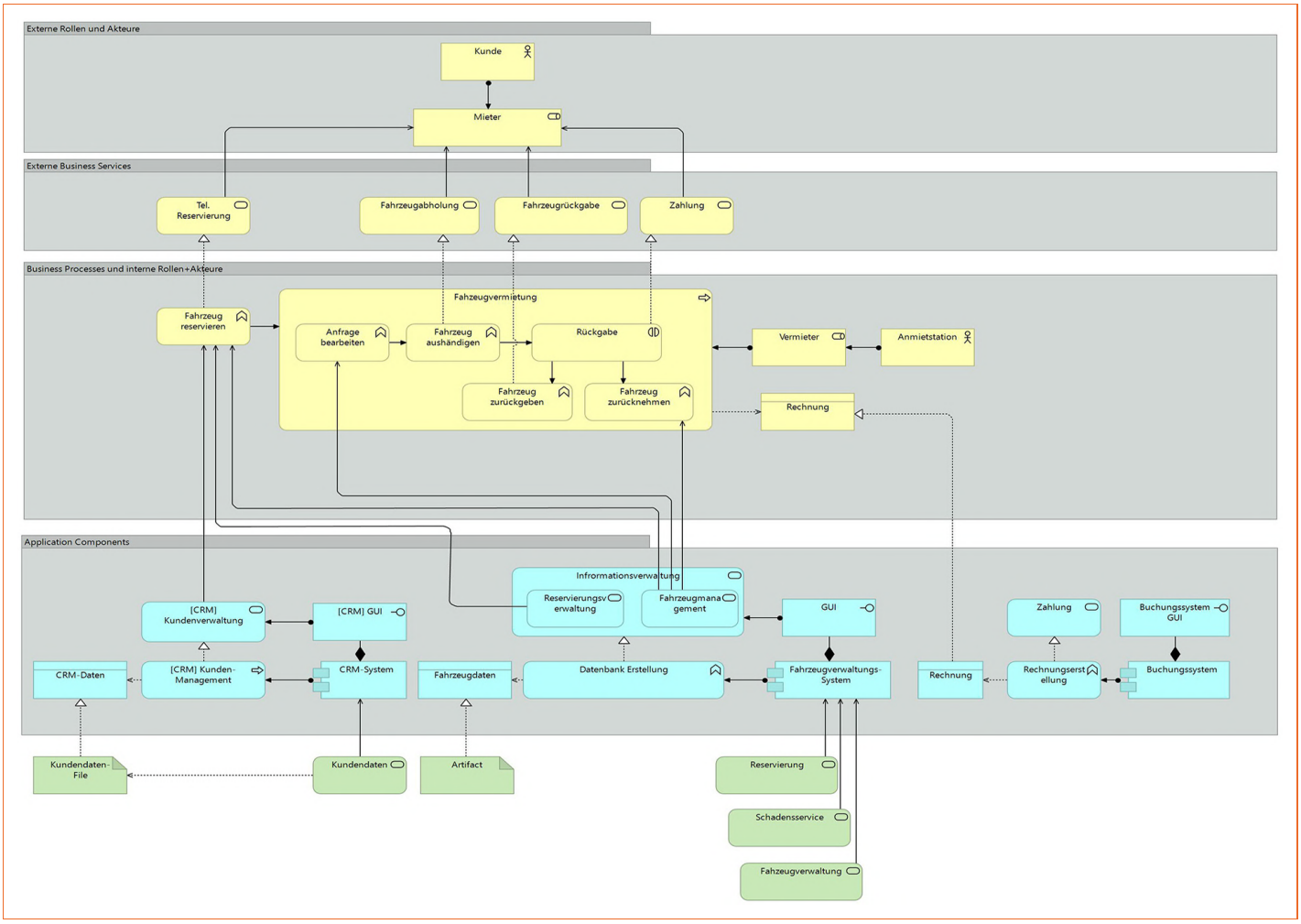


Figure 5: Example for an EA analysis showing a process and the different levels (business level – yellow, software-level – blue, hardware-level - green) with their dependencies and interactions.

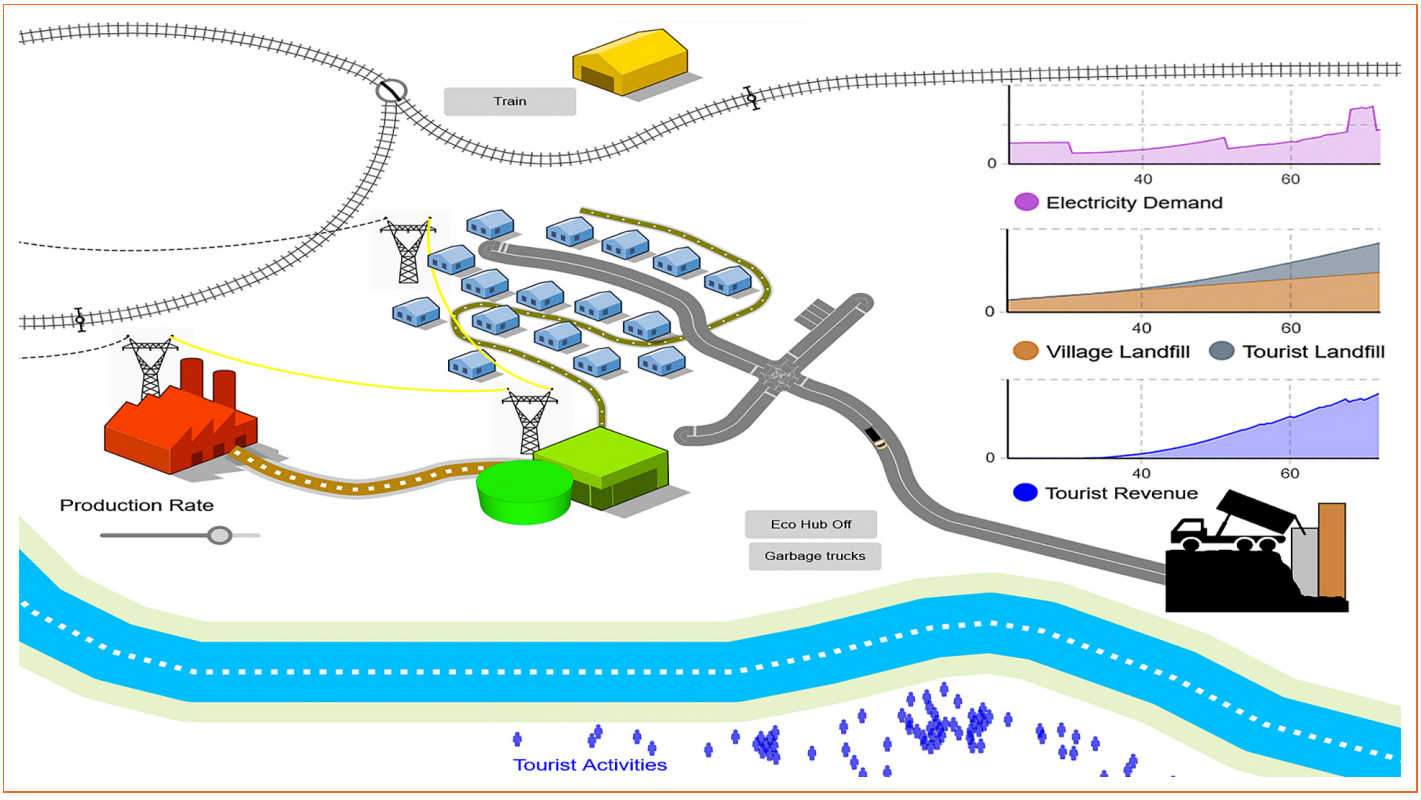


Figure 6: Different tools allow for ABS. Some also offer sophisticated graphical representations (AnyLogic) while others mainly show charts.

better results for some specific questions. But what is ABS respectively, what is an agent-based model (ABM)?
An agent-based model (ABM) is a computational model for simulating the actions and interactions of autonomous agents (both individual or collective entities such as organizations or groups) to understand the behavior of a system and what governs its outcomes. It combines elements of game theory, complex systems, emergence, computational sociology, multi-agent systems, and evolutionary programming. It is already used in many scientific domains including biology, ecology, epidemiology, business, technology, network theory, economics, and social sciences to re-create and predict the appearance of complex phenomena.

In general, sustainable business models aim not only to create, deliver, and capture economic value for the company involved, but also to contribute to environmental and social value creation among a broader span of stakeholders. This increases the complexity and the number of questions that must be considered. Even a generic model can give a good idea of how robust a business model is under the different possible scenarios. In a more sophisticated version with real life data, it can be even extended with artificial intelligence (AI) to react to the change of some KPIs by adapting measures and rules. There are also tools available. NetLogo is also open source and widely used in the research community in the US. But programming such a tool in Python is a viable solution as useful libraries are already available.

With this knowledge, it is time to return to the EA model and to optimize it for the chosen business model(s) and to generate the transition roadmap and timeline. By following this process, you can better figure out a suitable strategy for the transition and your future business model, which will especially help to overcome crises easier. This brings us to the second urgent question that has much to do with crisis.

Detect and Avoid Bottlenecks and Supply Risks in Time

Not only, but maybe most impressively, and still in everybody's mind, the COVID-19 crisis and the current Ukraine crisis demonstrated how vulnerable our supply chains and business systems are, and how important measures to increase resiliency are. Many have certainly learned the hard way where some of their company's vulnerable spots are. But how can we be sure that there are not more of them? And where are they? A criticality analysis may help.

The justifications for conducting material criticality assessments are multifaceted. They arise from the increasing demand from developing nations, the European Union's heavy dependence on imports, ongoing environmental and social concerns, shifts in national policies, and the concentration of production, which can lead to supply monopolies. These factors have prompted the development of methodologies for critical analysis.

The most notable material criticality list has

Screened raw materials in 2023 assessment (new materials in blue)	
Industrial and construction minerals	aggregates, baryte, bentonite, borates, diatomite, feldspar, fluorspar, gypsum, kaolin clay, limestone, magnesite, natural graphite, perlite, phosphate rock, phosphorus, potash, silica sand, sulphur, talc
Iron and ferro-alloy metals	chromium, cobalt, manganese, molybdenum, nickel, niobium, tantalum, titanium, titanium metal, tungsten, vanadium
Precious metals	gold, silver, and Platinum Group Metals (iridium, palladium, platinum, rhodium, ruthenium)
Rare earths	heavy rare earths - HREE (dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium); light rare earths - LREE (cerium, lanthanum, neodymium, praseodymium and samarium); and scandium
Other non-ferrous metals	aluminium/bauxite, antimony, arsenic, beryllium, bismuth, cadmium, copper, gallium, germanium, gold, hafnium, indium, lead, lithium, magnesium, rhenium, selenium, silicon metal, silver, strontium, tellurium, tin, zinc, zirconium
Bio and other materials	natural cork, natural rubber, natural teak wood, sapele wood, coking coal, hydrogen, helium, roundwood, neon, krypton, xenon

Figure 7: Screened raw materials (EU Report 2023).

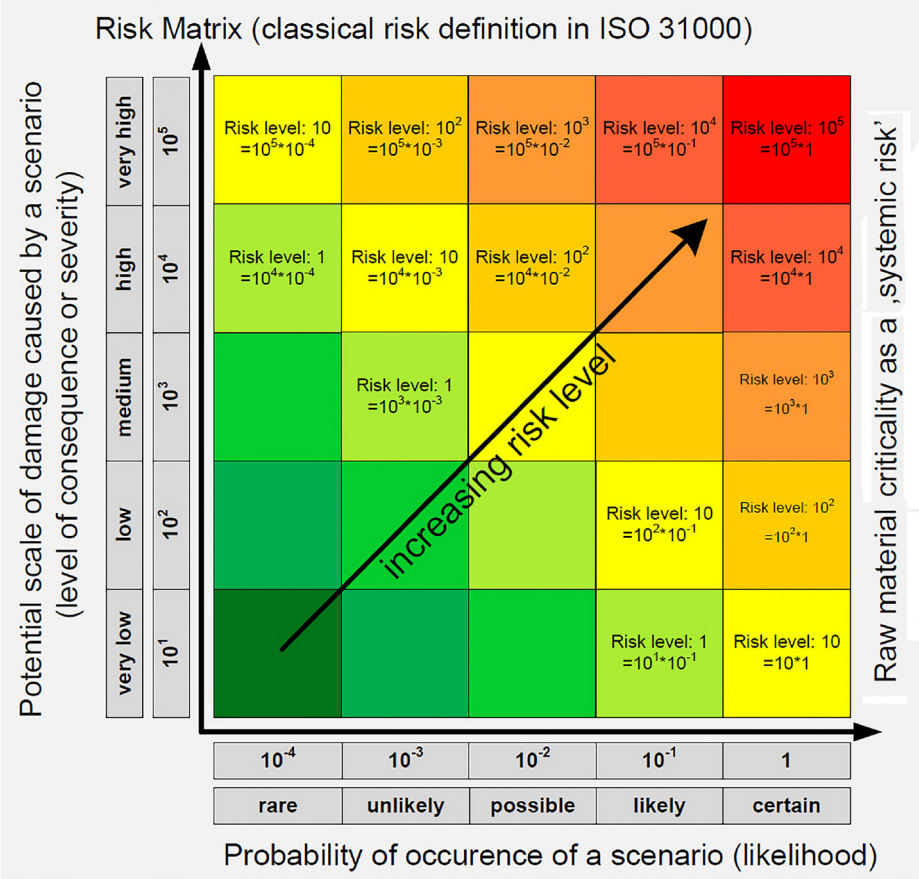


Figure 8: General risk matrix (also referred to as probability impact grids or risk maps) applied in numerous scientific fields such as in safety and environmental engineering and the definition of raw material criticality as an abstraction of classical risk assessment **[4]**.

been developed by the EU. A list of currently 34 key raw materials (CRMs) have been painstakingly compiled by the EU Commission and the list is regularly updated to reflect changing market dynamics and technical breakthroughs. The EU concurred that these CRMs are essential for clean technologies, technological advancement, and industrial competitiveness. But what exactly is a critical analysis and how does it work?

Criticality analysis is essentially a methodical procedure for grading assets' criticality according to the likelihood that they will fail, considering economic and technical dependencies connected with materials, as well as the likelihood of supply disruption. Criticality analysis is the primary tool for assessing the possibility of disruptions in supply and the vulnerability of systems such as a country's economy, its technical infrastructure, or an organization.

However, it is crucial to note that these 34 raw materials may not be equally relevant for all industries and that there may be more materials or even - on another level - components that need to be considered. Furthermore, there is no definitive methodology for conducting a criticality analysis. While substantial progress has been made in this field, medium-term challenges persist. In essence, most methods are guided by three fundamental questions:

- Sustainability of Supply: Can future supplies meet the rapidly growing demand driven by climate-related imperatives, thereby averting potential demand-supply mismatches?
- Diversified Sources: Can supplies be diversified across various sources to mitigate vulnerabilities in the supply chain?
- Clean and Responsible Sourcing: Can materials be procured from environmentally responsible and ethical sources to fulfill environmental goals?

Critical analysis can be conducted using various methods, with many adopting a matrix-based framework.

These methods involve applying and aggregating metrics that assess supply risk and the consequences of supply restrictions to identify materials of critical importance. Supply risk metrics typically address common concerns regarding potential disruptions in the supply chain, often drawing insights from historical supply chain disruptions. To effectively utilize the criticality matrix approach, it is imperative to establish clear definitions and equations. Historically, the terms "critical" and "strategic" have often been used interchangeably without clear differentiation.

As criticality is defined as the probability of failure rating by its consequence of failure rating, the calculation for Raw Material Criticality is expressed as:

Supply Risk × Vulnerability = Likelihood of Supply Disruptions × Economic Consequences

Several stages can be followed to assess material criticality. For example, the European Commission employs a rigorous methodology that considers both supply risk and economic significance based on predefined thresholds. Economic importance is assessed using substitution indexes, cost analysis, and performance evaluation, while production, criticality, and co-production are factors examined to comprehend supply risk fully.

This analysis gives you a good picture of which component must be carefully observed, where measures to secure the supply must be considered to keep the business running, even in a crisis. Beyond this, it gives some relevant information that can be used in strategy, logistics planning and product development. With such reliable information and data in hand, simulations like ABS can be fed. While it is currently still a challenge to get all the necessary information from suppliers, this may change in the future when the digital product passport is established.

Dealing with the DPP

There is still just a minority of the industry aware of the introduction of the digital product passport in 2026 for a good part of the industry. The textiles industry certainly already knows about it and is struggling with the consequences, as they need to introduce it at the beginning of 2024. But what is the intention and what exactly is it?

Very simply put, it is the extension of the German Supply Chain Act. While many details are still open, the purpose is clear: To maximize sustainability and circularity, products and materials are to be traced from mining to incineration over all cycles in-between. Lifespan shall be increased by providing better information for customers on how to repair and at the end of life clear information on where and how to

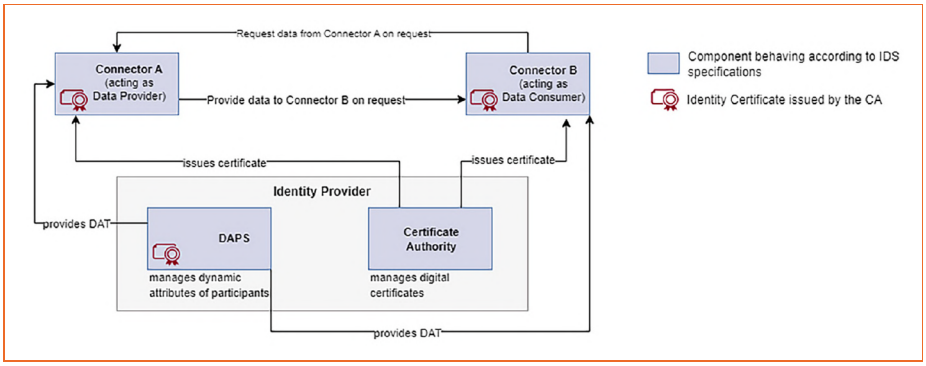


Figure 9: The International Data Spaces **[5]** organization defined a minimum combination of components that enable the creation of a Data Space. They call it Minimum Viable Data Space (MVDS).

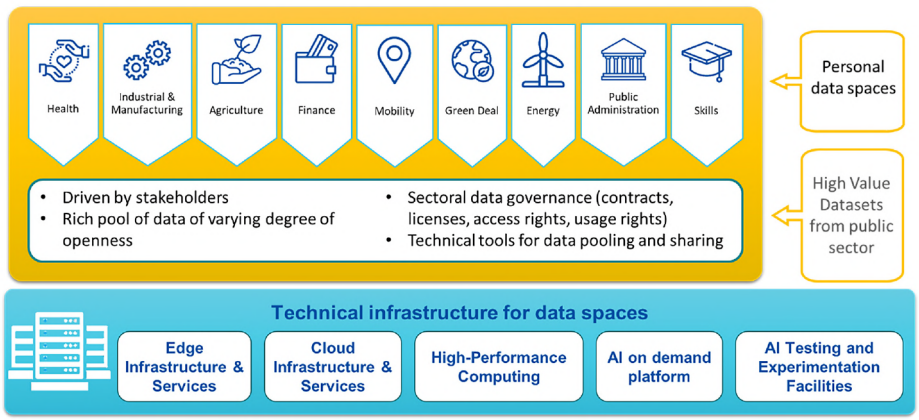


Figure 10: The 9 different Data Spaces of the so-called Common European Data Spaces **[6]**.

dispose of the product for recycling shall be given. Information on all materials inside of a product shall also be given. For this purpose, all physical components and materials have unique digital identities (UIDs). Any time something happens to a product during its supply chain journey, a DPP collects data associated with the UID.

While the purpose and the basic idea are very well described and understandable, some technical aspects and details are still not solved. At the current stage the main advice is to determine the legal requirements for data transparency first. Second, identify the legal requirements your company must meet, as well as any additional information that would be useful for your specific products - not only what the law might require, but also what you think might be valuable for your own operations.

Once you have a clear idea of the information you need, identify any gaps in your current data collection and management processes –like the actions for the transition to more circularity. And again, EA is the tool of choice. Determine what information you need to collect yourself, what information can be found elsewhere in your supply chain, and how you can work with your partners to obtain reliable data. Develop a strategy to fill these gaps and make sure your partners are aware of the requirements.

Very likely you and your partners will or should consider exchanging data via a Data Space – an idea that is also supported by the EU since the Communication of the European Commission in February 2020 presented “A European strategy for data”: The vision is to create single markets of data, called “Common European Data Spaces”, where personal as well as non-personal data, including sensitive business data can flow within the EU and across sectors, are secure and handled under the EU laws and relevant norms, and can be accessed and used according to fair, practical, and clear rules. But what is a Data Space in detail?

In a concise and easy to understand language, a Data Space is defined by Open DEI as “a decentralized infrastructure for trustworthy data sharing and exchange in data ecosystems, based on commonly agreed principles”. One example for this is Gaia-X.

As an emerging paradigm, there are currently a total of 9 different Data Spaces that will be developed with the support of the European Commission: the so-called Common European Data Spaces. All of them have their unique features and guidelines, which depend on the targeted sector. However, they are not exclusive, so an organization can be interested and of course be part of multiple Data Spaces and, as there are other Data Spaces, everyone is free to select another option.

Now you can identify the requirements for a digital product passport system that meets your needs. You can create it (have it created) or search for digital product passport providers on the market that meet your requirements. But beware - review and test these vendors thoroughly. Make sure the providers have a reliable track record in digital product passports and are capable of providing the necessary support and maintenance of the system.

Assuming careful planning in collaboration with your supply chain partners and reliable implementation partners, you are well prepared to introduce the digital product passport as soon as it is required, despite a complex process. By that, you will not only ensure compliance, but also provide your company with significant operational benefits and reputation, helping you stay ahead - and visible - in a rapidly evolving marketplace.

Industrial Symbiosis

For a thorough analysis, it is important to share information among all relevant parties. To achieve shared objectives, such as resource conservation, low carbon emissions, industrial efficiency, economic viability, and corporate social responsibility, teamwork from all involved parties is required. Through the creation of an industrial ecosystem framework, industrial symbiosis seeks to operationalize the idea of system sustainability and to foster this teamwork.

In more detail the industrial symbiosis can be explained by four terms: The flow of materials, energy, water, and nutrients. The differences among them can be analyzed by what state the industries are in in terms of age, technological development, and the cultural factors available for it. Life Cycle Assessment (LCA), environmental footprints, enterprise input-output model, and Material Flow Analysis (MFA) are just a few of the methodologies and methods for analyzing resource flow. MFA quantifies the resource use embodied in goods and services in a system (such as water and energy footprints) and input-output analysis is a top-down method to quantify resource flows through an entire entity or economy.

The material flow analysis firstly provides the overall mass fluxes of resources (energy, materials, food, and pollutants), secondly helps to understand the use of resources, and thirdly assists environmental reporting. Material flow analysis is the “systematic assessment of flow and materials within a system defined in space and time”. Material Flow analysis is needed to understand how to define a system and to understand what the limitation is, what is the geographical or administrative level and the boundary that it is set within.

Specially developed input-output models, called Enterprise Input-Output (EIO)

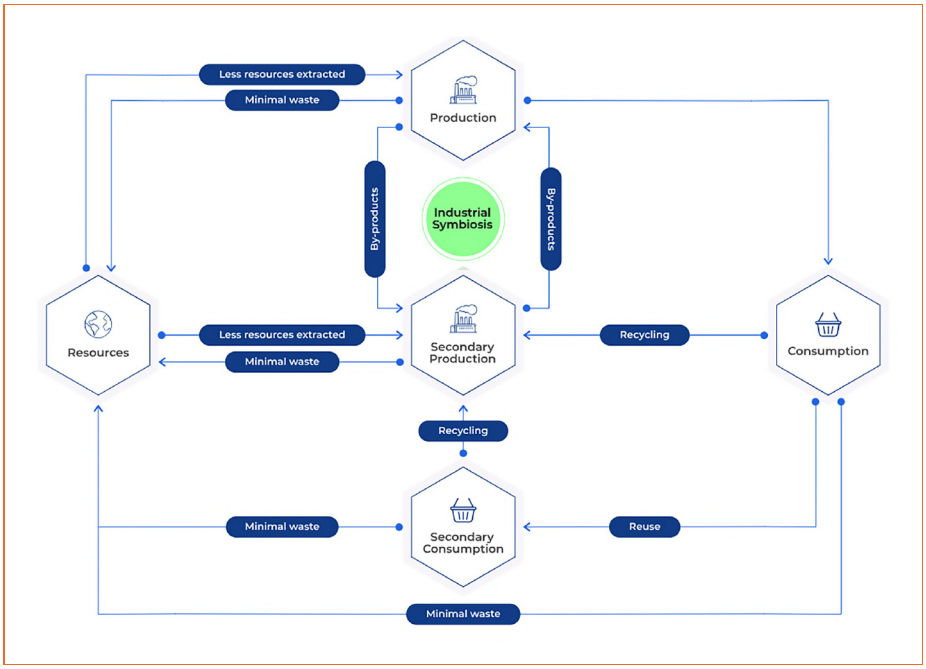


Figure 11: Functionalities of industrial ecology – a scheme of the connections of industrial symbiosis **[7]**.

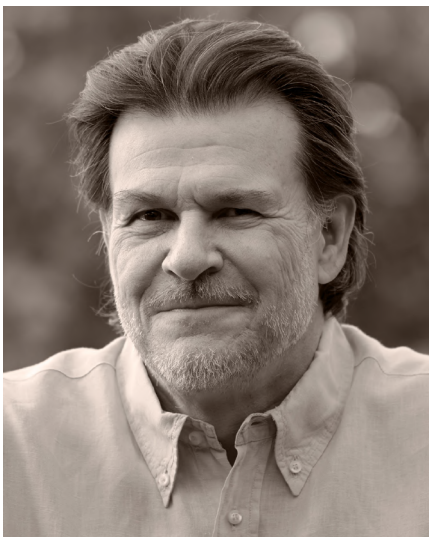
models, are helpful in completing the management and financial accounting systems used by companies. To map the physical (material, energy, and water) and monetary flows among production processes at different levels, EIO models are valuable as a planning and accounting tool inside a single company, between several companies involved in a supply chain, and between various companies that are a part of various supply chains. EIO models are particularly helpful for managing and analyzing internal and external logistics flows as well as supporting strategies for coordination among various manufacturing processes and businesses.

Another useful tool for understanding the trajectory of events in various situations and circumstances is – again - agent-based simulation (ABS). The economic interactions between the partners (suppliers, customers, the government, etc.) and the system border in which they operate can be analyzed by ABS with industrial symbiosis. Together with industrial symbiosis, ABS identifies and provides a contextual analysis of the structural factors and primary driving forces for the growth of the sustainable system in line with potential scenarios (ecological constraints, cultural and behavioral contexts, technological pathways, etc.). Once more, this method adds the dynamics to the theory and analysis.

All these tools and methods support the aims of the industrial symbiosis: Encouraging different companies to collaborate innovatively with the goal of finding ways to reuse one company's waste as another's raw material. With this objective, industrial symbiosis may become an important cornerstone of the circular economy and is worth being considered.

Conclusions

The transition to a circular economy is unstoppable and will affect all industries including the lighting industry. It will certainly be challenging to master it, but it is a chance as well - and there is support available. The regulations must not be seen as a burden, but rather, as the framework to guide the industry through these turbulent times. Tools, methods, and specialists who can apply them are available to assist and to accompany the industry on their way. Finally, the lighting industry especially, has already managed the transition from a comparably comfortably acting industry to a modern and innovative industry. Having this confidence, should be encouragement enough to roll up its sleeves and get to it. ■



AUTHOR: Arno GRABHER-MEYER, Head of the Computational Sustainability department at V-Research
Arno was Editor-in-Chief of LED professional for 15 years and contributed to several lighting research projects at Luger Research. He originally studied biology before switching to electronics and informatics engineering as a second course of education. He joined V-Research in 2021.

AUTHOR: Tawsif FAISAL, Researcher in Computational Sustainability at V-Research
Tawsif joined the V-Research Computational Sustainability department in 2022. He works on circular economy topics and material criticality analysis using simulation tools and data science. He gained his master in 'Erasmus Mundus International Joint Master's Program of Circular Economy' from the Chalmers University of Technology, Sweden and the University of Graz, Austria.

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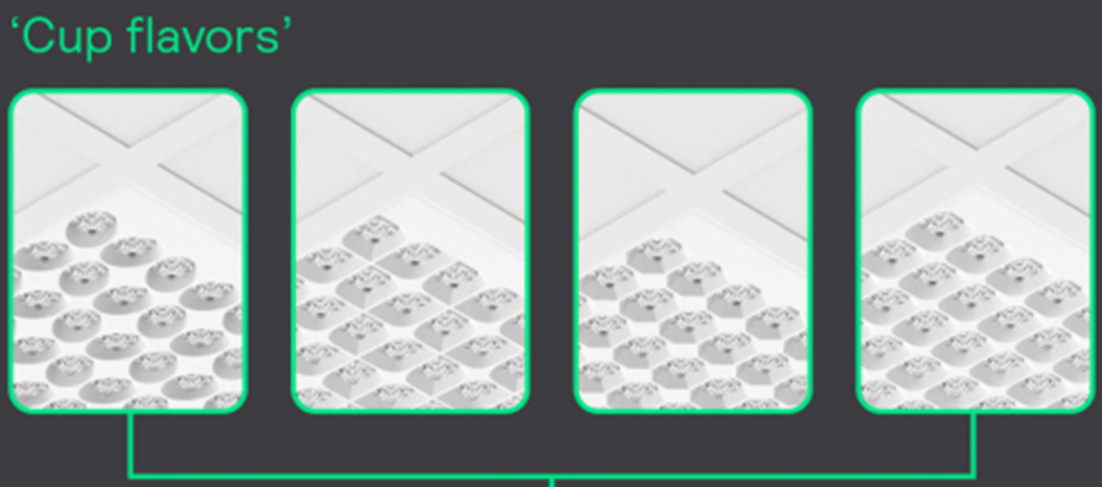
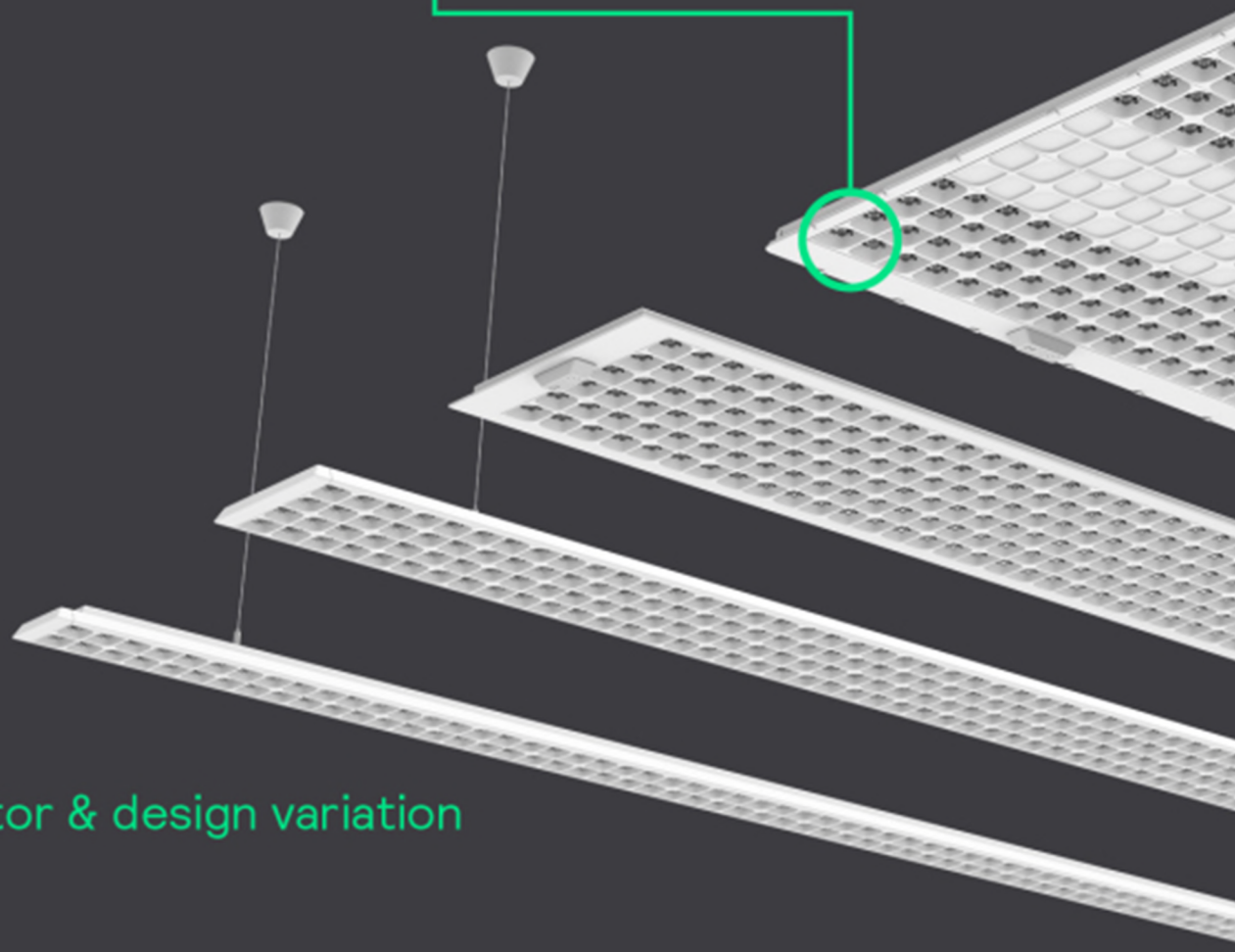




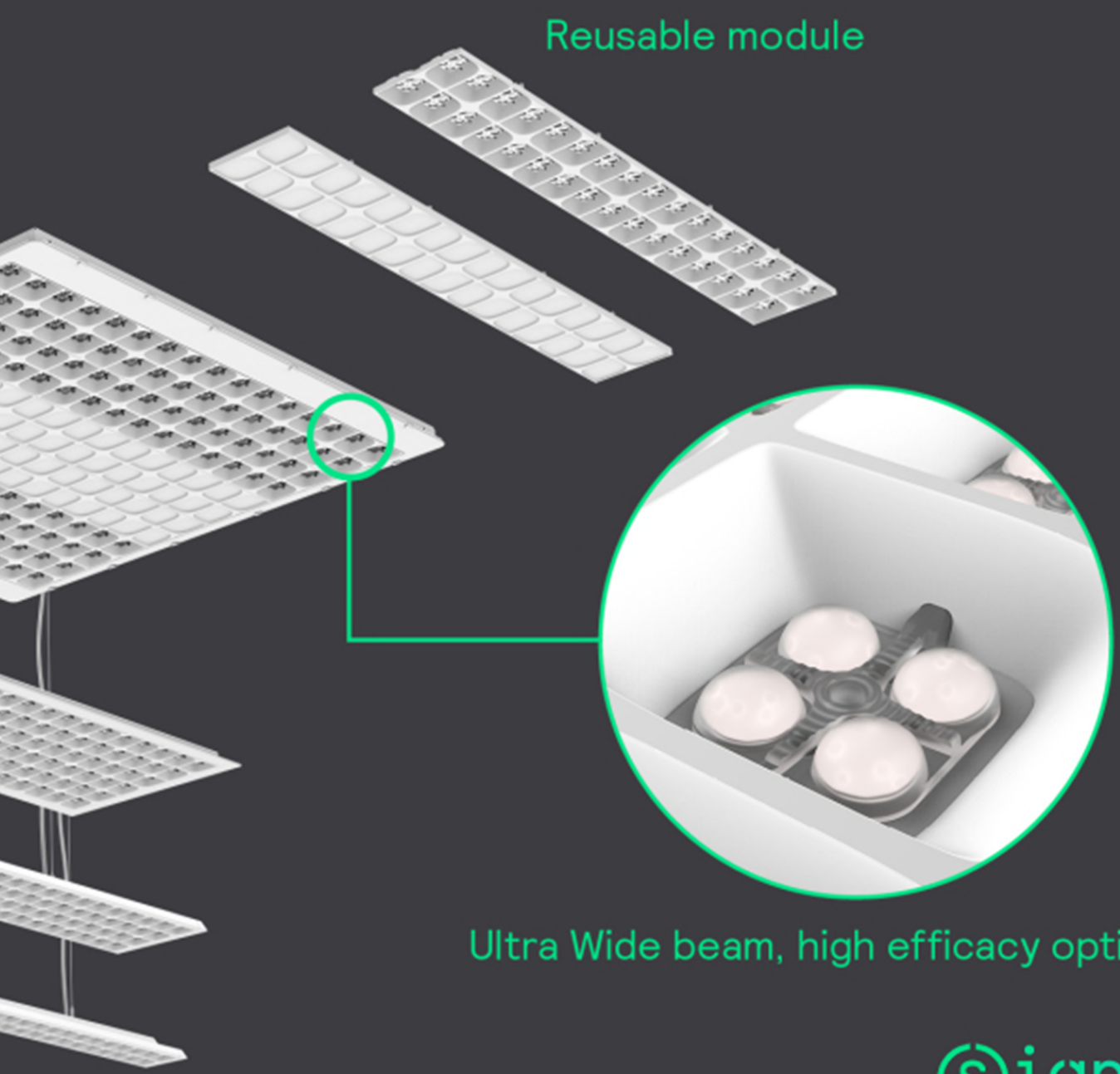
Form factor & design variation

Signify's Generation Flex luminaire prototype combines cutting-edge materials and adaptable 3D printing concepts with ground-breaking energy efficiency and optics that deliver flexibility, reduced energy consumption and an exceptional quality of light. It features a new LED with superior lighting performance, developed in partnership with Samsung Electronics, that together with Signify’s high-efficiency D4i LED driver and state-of-the-art optics enable an efficacy of 196 lm/W while maintaining a supreme quality of light.

L•PRIZE®

U.S. Department of Energy

Signify's winning prototypes – the Generation Flex modular luminaire and Interact Next Gen scalable connected lighting system – were chosen for their exceptional performance across six areas: efficacy; quality of light; connectivity; product life cycle; technical innovation; and diversity, equity and inclusion.



Signify

Built around a housing-agnostic general lighting module, the luminaire supports a variety of form factors for both new construction and renovation projects. The prototype represents a step forward in energy efficiency, consuming 29% less energy as well as a 50% reduction in embodied carbon than the best-in-class commercially available equivalent. Following circular design principles, its cups and electronics can be printed, and its reversible, click and clamp assembly allows for on-demand delivery and repair.

Comfortable LED Upgrade for Sophisticated Office Lighting

Nichia

The offices of one of the world's leading premium sports brands has adopted flexible, sustainable and cost-effective LED technology from Nichia.

The renewal of lighting in an office building presented engineers and lighting experts with a tough challenge. When the replacement of the old lighting solution turned into a conversion to LED, technology from Nichia offered the necessary flexibility and exceeded all expectations, especially in terms of light quality and sustainability.

In times of rising energy prices, climate change and a shortage of skilled workers, companies today have to rethink several areas and remove old structures and outdated technologies. More companies are increasingly upgrading the lighting solutions used in office buildings to LED technology.

Beyond the advantages in terms of savings in electricity, LED conversion also enhances the well-being of employees – if lighting design expertise and the right technology are used. Both energy efficiency and wellness were central to the objectives of redesigned office lighting for a leading global manufacturer of sports branded goods based in Germany. The project presented challenges to the lighting experts involved.

Comfortable for Employees, Kind to the Environment

As the well-known sports brand is committed to the responsible use of energy and resources, the lighting project needs to reduce energy consumption and contribute to the sustainable image of the business. At the same time, the client expressed the desire to achieve the best atmosphere possible for the company's employees and visitors with the new lighting in one of its buildings at the company's headquarters in Herzogenaurach.

The engineering firm Käferhaus GmbH in Vienna was awarded the contract and examined various office lighting solutions available on the market for their suitability. However, the experts did not come to a satisfactory conclusion. At this point, they called in Reinhard Vedder, managing director of the lighting architecture firm Vedder.Lichtmanagement in Munich.

Vedder first evaluated the challenges for the luminaires and the lighting technology, conducting various tests in the process. It quickly became apparent that the architectural concept was very well sketched out and the lighting concept was implemented in a creatively sophisticated design using light modulation.

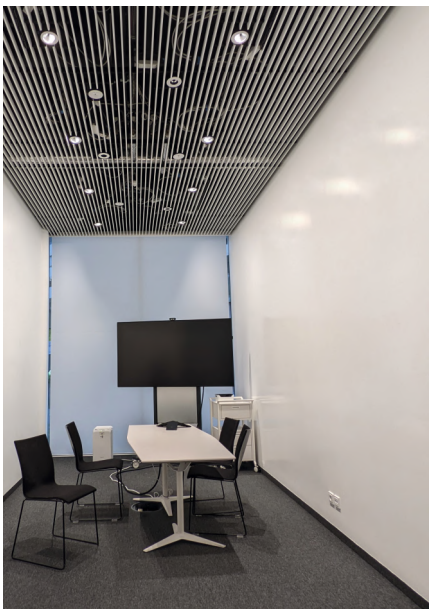
In almost all areas, elaborate and functional solutions were found and housed in suspended ceilings with different soffits. "These were, for example, different light sources that could be mixed or used separately in the rooms for different tasks and occasions," says Vedder. Even in areas of higher foot traffic areas such as hallways and intersections, different light sources, light colors and beam characteristics from floods to spots were used to create a lively spatial experience.

Renew Instead of Replace

Since the existing lighting design could not be faulted and was extremely robust due to the aluminum housings used, a complete replacement proved not to be required. Instead, the task was to convert the existing fluorescent, discharge and halogen lamps to LEDs, taking into account it should closely match the original lighting design.

That decision meant continuing to use the existing luminaire housing and only to replace the lighting technology. Indeed, the ceiling system and existing openings were used without modification in order to produce as little waste as possible – an important factor in terms of sustainability.

In order to give the high-quality aluminum housing a second life, Reinhard Vedder turned to the company LMT Leuchten + Metall Technik GmbH in Hilpoltstein on a personal recommendation. Thanks to LMT's expertise in the field of lighting and metal constructions, the existing luminaire housing could be converted and reused without any problems.



Meeting room with LMT Leuchten + Metall Technik GmbH "NAU" RJR wallwash downlight with Optisolis in 3000K. Photo credit: LMT GmbH.

Reach Your Goal with Materials and LED Expertise

Finding the right LED technology, on the other hand, proved to be more difficult. Instead of relying on low-cost solutions that offer no advantages apart from brightness, the project team focused on quality. What was needed was a solution that would create a more enjoyable working atmosphere with high visual comfort, offering high-quality lighting far above the norm, and one that can be flexibly configured throughout the day while also being cost-effective.

"Many standard industrial products met the low requirements of the standards, but did not create a satisfactory result, i.e. coherent and visually pleasant, room atmosphere," says Reinhard Vedder, summarizing his biggest challenge in the project. For example, a light color of 4,000 Kelvin in combination with low, albeit standard-compliant, CRI values created unattractive rooms and work atmospheres. In the course of a tender, the lighting experts finally found what they were looking for and decided on Optisolis from Nichia. Ultimately, the LED chip's high lighting quality was a key consideration. Due to the performance range and the design of Optisolis, the lighting experts were able to master even special requirements effortlessly for their project in Herzogenaurach.

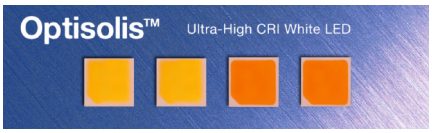
Optisolis Meets Design and Technical Requirements

Optisolis made it easy to implement custom designs in the project. Where previously special luminaires had been installed, Optisolis provided lighting with excellent glare control, high efficiency and no loss of visual comfort. After only two or three modifications, a result could usually be achieved with which the entire team was satisfied.

LMT was able to implement high-quality and robust luminaires with excellent glare control. The light sources are aesthetically pleasing without being obtrusive. Optisolis contributed significantly to this, as the chip offers high luminous efficacy with a very good color rendering quality of > RA 80.

Optisolis also eliminated some of the disadvantages that the old lighting system had to contend with, despite the careful planning. So far, a combination of discharge and halogen lamps has been used in the meeting rooms and VIP areas. However, the halogen lamps reached their maximum brightness much faster than the discharge lamps after switching on. Thanks to the LED technology from Nichia, the users of the building now have sensational lighting with the desired brightness immediately after switching on the lights.

Optisolis also eliminated some of the disadvantages that the old lighting system had to contend with, despite the thoughtful planning. For example, a combination of discharge and halogen lamps had previously been used in the meeting rooms and VIP areas. However, the halogen lamps reached their maximum brightness much faster after being switched on than the discharge lamps. Thanks to Nichia's LED technology, users of the building now have comfortable light at the desired brightness immediately after the luminaires are switched on.



The Optisolis family of LEDs are classified as Ultra-High CRI light sources, as they have maximum scores for all 16 color samples used in the color rendering index metric.

Optisolis also left nothing to be desired in terms of standards. This is particularly evident in the company's workplaces, where very precise and small-scale work needed to be carried out. The entire room was illuminated using a 'watering can' principle before the retrofit. Values of 1,200 and 1,500 lux were sprinkled across all the workstations. However, if the entire room is lit with this level of illuminance, this brings no benefits at individual workstations and instead wastes an unnecessary amount of energy. Now the brightness of light is delivered to where it is needed. In addition, Optisolis' high color rendering is conducive to the precision required in the manufacture of premium products.

Easy-to-Implement, Customer-specific Solutions

Thanks to the Nichia solution, the project team was able to meet all the client's requirements. The LED technology was a winner in terms of a competitive price, flexibility and efficiency. Additionally, it allowed to maintain and improve the previous architectural appearance of the building and all rooms without dramatic changes.

One part of the project has already been completed, the second part is about to be finalized. So far, the customer is very satisfied with the result, which is superior to the old lighting concept in terms of brightness, visual comfort, operability and glare reduction. Initial data on energy consumption is already meeting all expectations. Vedder confirms his satisfaction, adding: "We are receiving very positive feedback."

Part of the project has already been completed, the second part is about to be finalized. So far, the customer has been very satisfied with the result, which is superior to the old lighting concept in terms of brightness, visual comfort, usability and glare control. Initial data on energy consumption are already meeting all expectations. "We've received very positive feedback," says Vedder with satisfaction.

The project has not only given him a sense of achievement, but also practical benefits. He will continue to use Nichia products in the future: "Some carefully developed devices that have been tested in lighting tests are real problem solvers for further projects," he says. With the NAU downwall luminaire, LMT has added one of the luminaires developed specifically for this project to its standard range. "The fact that we were able to continue using the high-quality housings in the project is particularly satisfying, and it shows that customized solutions do not automatically have to be more expensive," concludes Vedder. Results like those from Herzogenaurach show that better lighting quality in office buildings is not only desirable, but also easily achievable with the right technology and capable partners.

Optisolis offers the necessary high quality, flexibility and sustainability that leads to economic results even in demanding office projects. With Optisolis, lighting designers and technicians receive an LED chip that optimally supports them in their work and quickly leads them to the desired results. For companies and their office employees, the LED technology provides a convenient lighting solution that creates visibly better lighting conditions immediately after installation and thus promotes productivity in the long term – without unnecessarily damaging the environment. ■

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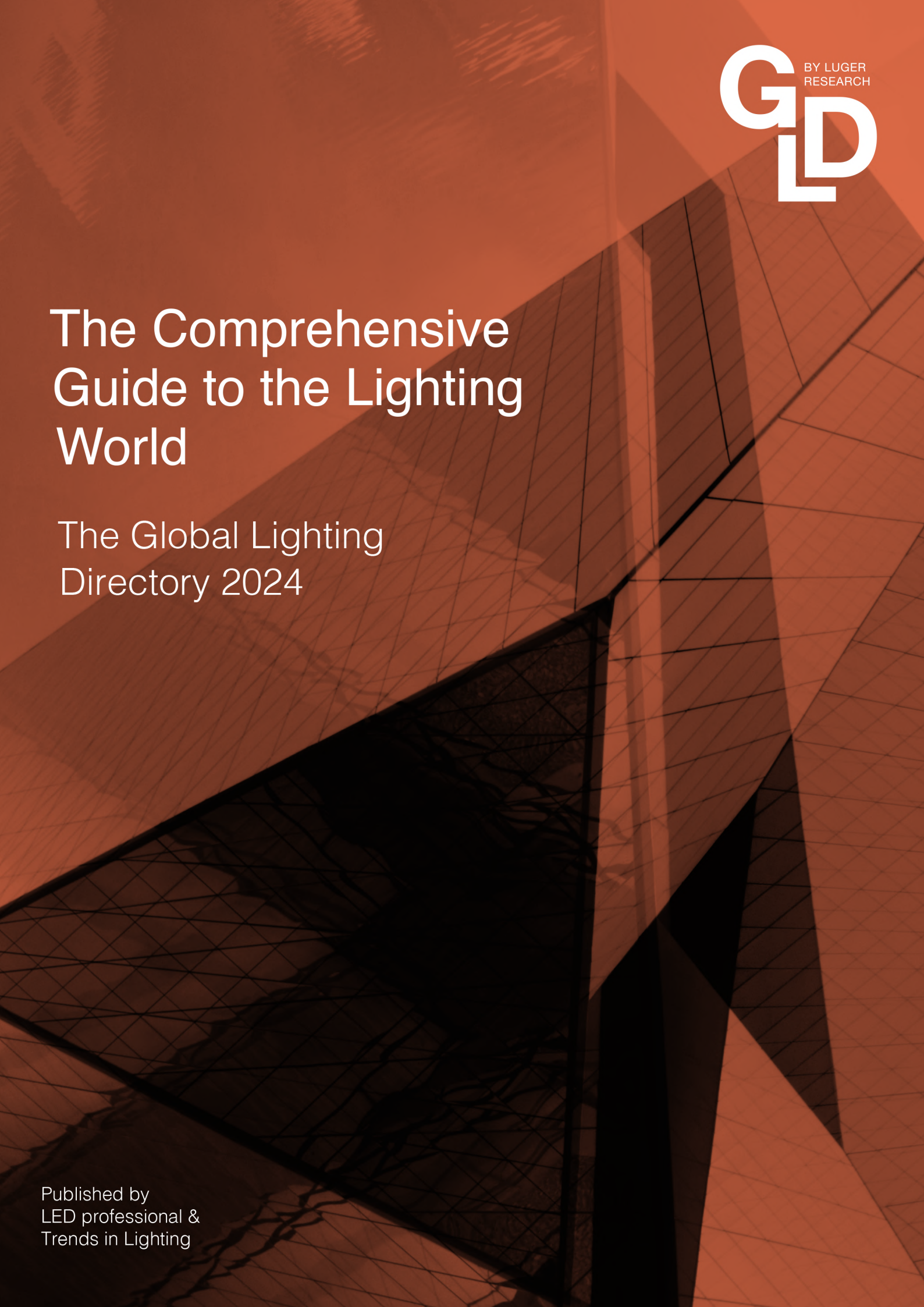

BY LUGER RESEARCH

The Comprehensive Guide to the Lighting World

The Global Lighting Directory 2024

Published by
LED professional &
Trends in Lighting

Lumileds' Dirk Vanderhaeghen on the Future of Automotive Lighting

Siegfried Luger, Publisher of LED Professional

During the ISAL 2023 conference, Siegfried Luger, the publisher of LED Professional, had the privilege of engaging in a serious dialogue with lighting expert, Dirk Vanderhaeghen, who has close to 30 years of industry experience and holds the distinguished position of Sr. Director of Strategic Marketing at Lumileds. Dirk Vanderhaeghen is recognized as a pioneer in the realm of automotive lighting technology and applications. Moreover, his pivotal role as a member of the ISAL 2023 steering committee further underscores his profound influence in the sector. In their conversation, Dirk delved into the intricate facets of the automotive domain, elucidating how Lumileds, through its cutting-edge innovations, is sculpting the future of automotive lighting solutions.

LED professional: With the increasing emphasis on driver safety, how are automotive lighting solutions being designed to enhance nighttime driving and adapt to varying environmental conditions?

Dirk Vanderhaeghen: As lighting has been classified by regulations as a primary active safety-relevant function on a car, improving driver's visibility has always been and still is a never-ending quest. The historic light source technology transitions from combustion lamps (candles, carbide) to electric light sources (incandescent, halogen, gas discharge), and has brought us to the era of solid state light sources (LED, OLED, Laser). Over more than a century of transitions, the performance of vehicles' lighting systems has increased significantly. Not just in terms of brightness of the driving beam , but also in terms of becoming more adaptive to its environmental conditions.

In the early days, you just had a headlamp that you could switch on or off. However, from the 1950-60's onwards, systems started to become more adaptive. The first, so called 'AutoDim' or 'Automatic Beam Control' systems were applied to dim the headlamps in order to avoid glare for oncoming traffic. These systems evolved over time to what we know today as Automatic High Beam or even more advanced Adaptive High Beam Assist systems. The High Beam can be automatically switched on or off or adapted in range, depending on the light seen by a CMOS camera sensor of an oncoming vehicle.

A big step forward was made with Adaptive Driving Beam (ADB) systems, in which specific portions of the High Beam pattern can be selectively switched on or off. The switched areas in the beam correlate to the specific location of detected obstacles such as vehicles, pedestrians, cyclists, animals, traffic signs). The ADB functionality offers the driver a virtual "always-on" High Beam visibility, without disturbing other road users.

ADB functionality can be applied complementarily to an Advanced Frontlighting System (AFS), which was released earlier to the market. Here, the Low Beam (or dipped beam) can be adapted not only as a function of vehicular steering and suspension dynamics but also related to ambient (adverse) weather and visibility conditions, vehicle speed (e.g. motorway, country road, urban city), and road curvature (cornering or dynamic swiveling) (**Figure 1**).

LED professional: Could you elaborate on the development and benefits of adaptive headlight systems that respond in real-time to oncoming traffic, obstacles, and environmental conditions?

Dirk Vanderhaeghen: Advancements in LED light source technology in combination with higher precision optical system design, have accelerated the performance improvement and market adoption of adaptive headlight systems over the last decade. Different customized LED light source configurations are possible, depending on which resolution (beam granularity) the OEM wants to achieve. For basic (entry level) ADB systems, a single row of LEDs is applied as an array of typically 7-30 segments. This gives the basic horizontal segmented ADB.

More premium solutions apply multiple rows of LEDs (matrix of > 30-100 LEDs), which offer the additional benefit of a horizontal and vertical segmented ADB with more angular resolution (smaller areas of the beam can be addressed). Top-end solutions make use of the state of the art high resolution, microLED light sources, which typically have a resolution between 16,000 up to 25,000 individual addressable pixels. Such High Definition 'HD-ADB' systems offer full digital beam control functionality with options for road projection of specific patterns or symbols (e.g. lane markings) (**Figure 2**).

All these ADB systems make use of the front camera systems, which capture the

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driving landscape to detect objects or obstacles of interest. Via image processing algorithms, the location of these objects is calculated and translated into the appropriate beam segments. This image data is sent in real-time from a central electronics processing unit to the ADB system which controls each beam segment individually. Future HD-ADB headlighting systems featuring high resolution MicroLEDs (> 10,000 pixels) require a much more complex electronics system architecture with digital data interfaces and high bandwidth communication protocols. This makes the adoption of such systems today still dependent on the availability of such enabling car electronics architecture.

LED professional: How is the industry addressing the human-centric aspect of automotive lighting, especially in terms of driver fatigue, mood enhancement, and alignment with circadian rhythms?

Dirk Vanderhaeghen: For interior lighting, we see a strong increase of ambient lighting for appropriate mood setting defined by the driver's preference setting or driving condition. Ambient lighting also serves the driver or occupants when surveying the interior of the car to guide and quickly find something.

Lately, new communication and interaction functionality is also being added. Illustrative examples are VW 'communication light' in the ID.3 & ID.4 or Audi's 'Interaction Light' (IAL) for the new Audi Q6 e-tron. Such light strips can "communicate" with the driver by means of colored light animations, to inform them about status or alert them to certain hazardous situations (**Figure 3**).

The issue of tackling driver fatigue is being addressed by a Driver Monitoring System (DMS), which becomes a must have ADAS function for most OEMs. Hereby the driver's face and eyes are illuminated by an IR light source (LED or VCEL) and permanently monitored by an IR camera to detect potential driver distraction, drowsiness or unresponsiveness. In case this happens, the ADAS DMS will trigger an alert to the driver; this can be by means of a visual light signal, an audible noise or putting vibrations on steering wheel or driver's seat.

When it comes to in-cabin functional illumination, today's cars have a rather limited set of lighting features, such as a dome light, reading (map) lights or vanity lights. This is given by the quite low intensity interior lighting level, acceptable during night driving, to avoid glare for the driver or other road users. However, in the future of autonomous driving and robo-taxis, interior lighting can evolve towards a high grade of 'living room' illumination. Such futuristic interior ambient lighting and functional illumination design are fully part of concept car studies to envision the future of AV cars where lighting, visualization and HMI all come together.

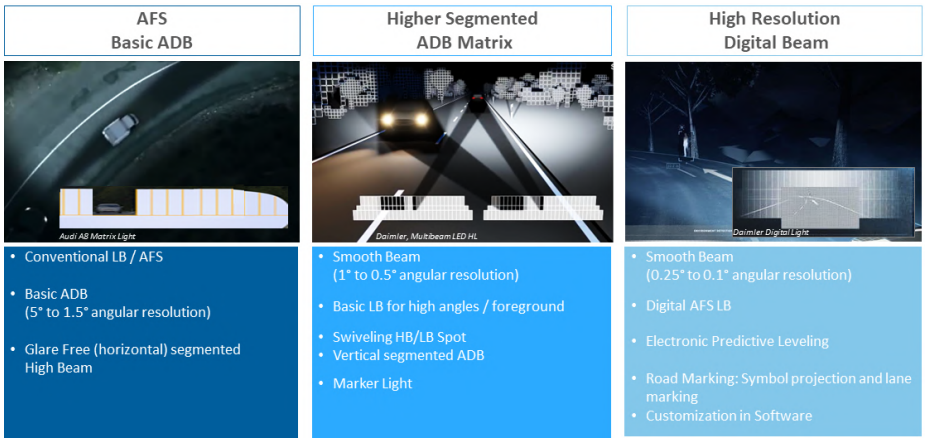

Figure 1: Adaptive Driving Beam pattern granularity and key application benefits. From AFS/ADB to high resolution digital beam.

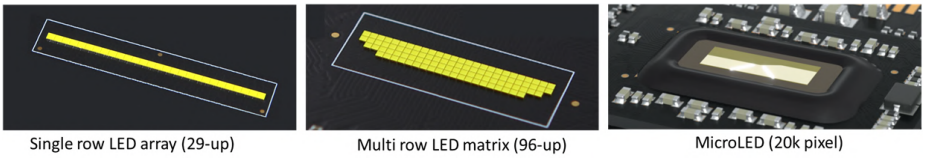

Figure 2: LED light source solutions for ADB and & HD-ADB systems.

Figure 3: Audi IAL light strip in Audi Q6 e-tron. Source: Audi.

LED professional: As innovations in automotive lighting surge, what are the challenges faced in harmonizing global lighting standards? How are manufacturers navigating the diverse regulatory landscapes across different markets?

Dirk Vanderhaeghen: Acknowledging that lighting is a safety relevant function of a car, regulations are a vital need! Two main challenges in regulation are the different regulatory systems across the globe defined by fundamental differences in the related jurisdictions:

- UN-ECE (contracting parties incl. EU): Based on third party certification and type approval.
- FMVSS (US): Based on self-certification process of OEM manufacturers.
- CCC (China): Component certification and vehicle approval in the form of testing standards.

Even though a lot of effort has been historically put in the simplification and har-

monization of lighting standards across the different regulatory systems, it will remain an everlasting challenge! Recent geopolitical developments and an increasing complexity of legislation indicates a tendency for increasing differences in interests rather than a common interest to search for upfront alignment and synergy. Another key challenge is the difference in regulatory adoption speed of the various regional systems; heavily depending on geographical context and political interests. Some actual illustrative examples are:

The delayed and deviating FMVSS-108 regulation for ADB systems in the US, versus the earlier established UN-ECE regulation. This causes a lot of extra engineering and validation work and puts additional costs on manufacturers.
Another one is the difference in adoption speed of cyan marker lights or communication signals for autonomous driving vehicles within China, where first regulatory deployment already hits the road, whereas in the EU (UN-ECE), lighting regulations are still pending on the overall regulatory framework for autonomous vehicles.

Regulations are and will remain a complex matter with a lot of interdependencies. Just to list a few categories, that ultimately all touch vehicle lighting:

- New application functionalities: Road Projections around the car, Car Body Lighting, Automated Driving Signaling and Communication Displays for Autonomous Vehicles, ADAS functionality (e.g. DMS).
- New legal framework for safety regulations for automated and connected vehicles.
- Pedestrian safety and crash impact regulations.
- Energy efficiency and emission norm regulations.
- Environmental & Sustainability: materials use, waste and recycling.

Figure 4: Li Auto 'L9' with cyan ADS marker lights (left) and Honda Legend hybrid; world's first certified L3 car with cyan front marker lights (right).

Figure 5: Merecedes EQS drive pilot concept featuring cyan marker lights for automated driving mode. Function demonstrated in headlamp, rearlamp and side mirrors (ISAL 2023).

Figure 6: Volvo 360c concept study for driverless car.

Manufacturers need to anticipate, be creative and get prepared in a timely manner. One example that demonstrates how carmakers try to mitigate differences in lighting regulations is to create more flexibility in functional specifications by means of software updates, rather than being fully dependent on the installed lighting hardware in a car. The ultimate holy grail remains a 'world digital headlamp' which is fully regionally configurable by means of software only.

LED professional: As vehicles move towards higher levels of autonomy, how is automotive lighting being designed to communicate with external sensors and other vehicles, ensuring safety and clarity?

Dirk Vanderhaeghen: Marker lights for Automated Driving Systems. Preparatory regulatory discussions have taken place which conclude that vehicles driving in automated mode should identify themselves to other road users in a distinctive way. The SAE (Society of Automotive Engineers) worked out a recommended practice (US SAE J3134) providing guidelines for the use, performance, installation, activation, and switching of marking lamps on vehicles equipped with an Automated Driving System (ADS). From the UN-ECE regulatory side, a formal regulation for such ADS marker lights is still pending on the overall regulatory framework for autonomous and connected vehicles. The latter is being worked on by GRVA, the working party preparing such draft regulations for later adoption by the parent regulatory body WP.29 in Geneva. Once this is put in place, the GRE group of experts can further develop the lighting and light-signaling requirements for automated vehicles.

In China, no formal regulation has been fully deployed either. However, type approvals are being given case by case by means of special exemption, similar to what was done in Japan for releasing the world's first certified L3 driving car, the Honda Legend hybrid. China, being more flexible with type approval exemptions, enables a faster emergence of autonomous driving cars on the road (**Figure 4** and **Figure 5**).

An interesting study was explored by Volvo's 360c concept for a distant-future driverless car. A 360 degree light signaling all around the car is demonstrated to communicate the car's intent to pedestrians and other human-driven cars (**Figure 6**).

A next level in communication and information display for autonomous cars to other

road users is the potential use of higher resolution communication displays. In the absence of any kind of formal regulation, here China is also taking the lead and exploring first releases on the road; also done via individual case by case type approvals. Two illustrative examples of cars on the road are:

- Human Horizon's 'Hiphi X & Z' Intelligent Signal Display (ISD) with a couple of hundred individually addressable LEDs.
- SAIC's 'IM L7' rear applique communication display, featuring about 5000 miniLEDs.

Since this is an even more application complex and regulation delicate topic, it will take longer to define and validate which type of communication signals or signs ensure safety and clarity. Multiple application studies are ongoing at OEM carmakers, setmakers and research institutes to define and validate this (**Figure 7**).

LED professional: How are new materials, especially nanoparticle-infused materials, revolutionizing the design and functionality of automotive lights?

Dirk Vanderhaeghen: In the field of solid state light sources and micro optics, such nanoparticle-infused materials create opportunities for novel, optical applications. The most well-known application is Quantum Dot phosphors used in LEDs and displays. But also photonic crystal materials have already found a wide range of applications in thin-film and meta-surface optics. By manipulating light flow or color spectrum, increased optical efficiency and interesting optical effects can be achieved.

With the demand for lightweight and smaller optical systems, miniaturization is a clear driver for such technologies; trending from refractive to more diffractive optics. A couple of years ago, Micro Lens Array (MLA) optics made their first appearance in automotive LED headlighting (first car platforms: Genesis G90 and Lucid Air) and there is still a long way to go to untap the full potential of this new technology.

Another field of interest for new materials development for automotive lamp systems is advanced plastics. The wide range of available plastics for optical components (lenses, collimators, light guides, light blades, cover glass), together with the advancements for injection molding and post processing (e.g. structuring, surface treatments), has increased significantly over the last years. This offers optical engineers more design freedom to create and shape novel solutions.

Related to thermo-mechanical light source module design, the opportunity to apply 2K injection molded thermal conductive plastic materials widens the options for lightweight, custom heatsink design and eases assembly.

LED professional: With the global push towards sustainability, how is the automotive lighting industry addressing its environmental footprint, both in terms of energy consumption and material use?

Dirk Vanderhaeghen: The automotive industry needs to follow strict regulatory guidelines across the globe for environment, health, safety, sustainability, recyclability, and the emission of CO_2. Electrical power consumption, energy efficiency and the use of environmentally friendly and lightweight materials are therefore all vital aspects to consider over the full product lifecycle ('from cradle to grave'). With the ongoing conversion from conventional bulbs (incandescent, halogen, gas discharge) to much higher energy efficient solid state light sources (LED, OLED, VCSEL, LASER), the automotive lighting industry also contributes to such goals.

Figure 8 and **Figure 9** show the historic evolution of the different waves of new automotive application innovation and the related LED technology generations with their respective (still ongoing) performance improvements.

Besides the electrical and optical efficiency of a lighting system, weight remains a

Figure 7: SAIC's IM L7 rear applique display (left) and Hiphi X Intelligent Signal Display (right).

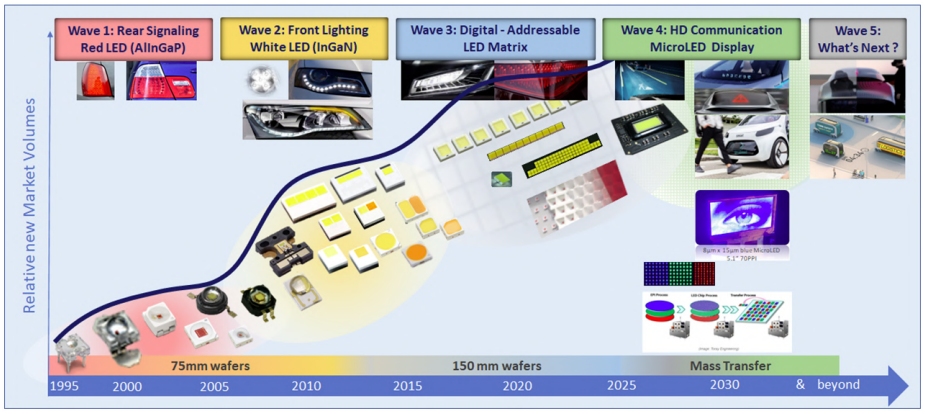

Figure 8: Waves of new application innovation of LED technology generations. Historic evolution of LED technology for automotive. Source: Lumileds.

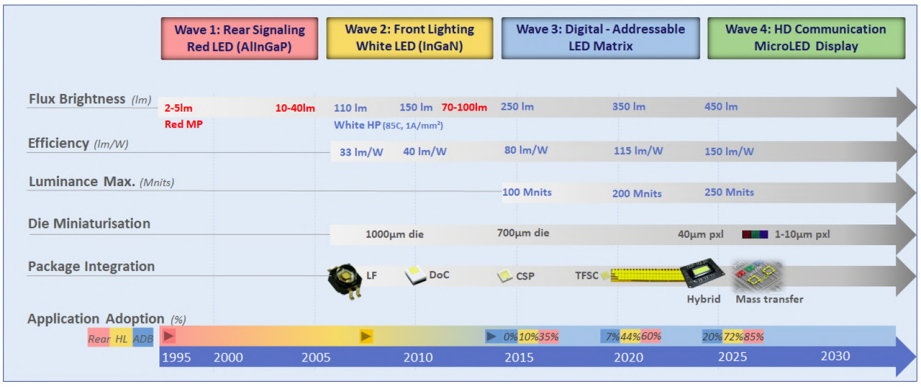

Figure 9: Performance drivers of LED technology generations. Historic evolution of LED technology for automotive. Source: Lumileds.

dominant and limiting factor to further reduce overall energy consumption of the car. Therefore the focus on lightweight materials and overall system miniaturization are crucial aspects of the overall lighting system design.

Complementary to optimizing the overall energy efficiency in the product design itself, also minimizing power consumption during application use, life becomes an increasing topic of interest. A lighting system should always provide the (safety) necessary light distribution during all driving conditions, however it can, given the situation (e.g. environment: urban vs rural roads; ambient light level: dusk, dawn, nighttime; …), dynamically adapt the beam performance to an appropriate (safe) level, which could save significant additional energy throughout the entire vehicle operation lifetime. Such concepts are under consideration for market deployment and regulatory approval.

Regarding a responsible choice and use of materials, Tier-1 set-makers are working on ways to make the full lamp systems more 'green', not only in terms of material selection but also considering recyclability (waste) and repairability (e.g. self-healing plastics).

LED professional: How do you see the automotive lighting market evolving over the next decade, especially with the rise of electric vehicles and increased emphasis on smart cities?

Dirk Vanderhaeghen: The rise of electric vehicles will further accelerate the global conversion to solid state light sources (mainly LEDs) across all applications; at the latest by the end of this decade.
New application functionalities are emerging: decorative car body lighting (grill surface illumination, logo, 'light is the new chrome'), surround-car signaling road projection and exterior communication displays to facilitate interaction between autonomous driving vehicles and other road users.
Lighting functions become more intelligent and smart, adaptive to environmental situations and driving conditions; enabled by higher resolution light source solutions (matrix-LEDs, MicroLEDs).

Lighting is entering the digital age, driven by advanced software controls and customization. The automotive electronics of the future will gravitate towards a centralized system, where all lighting and sensor functions are managed by a primary zone controller or a high-performance processing unit. This shift will be supported by high-speed communication methods, such as the Gigabit Multimedia Serial Link or Ethernet connections, accompanied by high bandwidth interfaces and sophisticated data protocols. As a result, lighting systems will seamlessly integrate into the car's front and rear modules. Furthermore, innovative lighting functions will be introduced, optimizing the vehicle's available space.
Lighting systems will become more embedded in fully integrated front and rear modules of the car. Additional lighting functions will find new real estate on the vehicle.

In summary: Automotive exterior lighting will undergo a paradigm shift from: "See and To be Seen" towards "Communicate and Sense"!

LED professional: What are some of the most exciting innovations on the horizon for automotive lighting, and how do they promise to redefine the driving experience in the coming years?

Dirk Vanderhaeghen: From a light source technology perspective, the next generation of microLEDs, currently being deployed into first of its kind digital headlighting beam applications, has the potential to stretch across various new lighting applications for the exterior and interior of the car.

'On demand light': lighting functionality which is completely invisible when unlit and appears only when required. Embedded light through car body panels or decorative interior surfaces.
'Novel visual Human Machine Interfaces (HMI), for a complete different level of driving experience: Augmented Reality panoramic Head-Up Displays (AR-HUD). Smart, interactive glass windows with embedded MicroLEDs for data visualization and communication. Micro-projections and backlit solutions for interior decorative surfaces.
Lighting is evolving from solely enhancing human vision to also supporting machine and camera vision capabilities. (e.g. InfraRed structured light solutions; high frequency pulsed light; optimized light sources for CMOS camera sensors.

LED professional: Dirk, it was great talking to you and getting a deep insight into the future of automotive lighting and Lumileds' product portfolio.

Dirk Vanderhaeghen: Thank you Siegfried. It was a pleasure talking with you! ■

Dirk Vanderhaeghen, Senior Director of Lumileds OEM Market Strategy
Graduated in 1992 with a Masters electronic engineering degree from the University in Ghent, Belgium. He joined Philips Lighting in 1995 and worked for different application areas in special lighting and digital projection lighting. In 2005 he joined Philips Automotive Lighting Aachen, Germany. From 2009-2013 he worked at Lumileds in San Jose, CA and in mid-2013 he transitioned back to Germany, where he is currently responsible for the market strategy of the OEM automotive business.

dirk.vanderhaeghen@lumileds.com

About Lumileds
Lumileds is a global leader in OEM and aftermarket automotive lighting and accessories, camera flash for mobile devices, MicroLED, and light sources for general illumination, horticulture, and human-centric lighting. Our approximately 6,000 employees operate in over 30 countries and partner with our customers to deliver never before possible solutions for lighting, safety, and well-being.

To learn more about Lumileds' solution portfolios, please visit https://lumileds.com.

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ISAL 2023 – Symposium and Exhibition Review

Editors, LED professional

The 15th International Symposium on Automotive Lighting (ISAL 2023), held in Darmstadt, Germany from 25-27 September, marked a significant milestone as the first ISAL conference following the global Covid19 pandemic. Under the guidance of Prof. Dr.-Ing. Habil., Tran Quoc Khanh and in collaboration with WBG Publishing Services, the conference showcased a plethora of talks and lectures that delved deep into the innovative potentials of automotive lighting technologies, communication, sensor technology, and Artificial Intelligence. The Steering Board for the symposium was graced with distinguished members from renowned institutions and corporations, including AUDI AG, Icahn School of Medicine, ZKW Group GmbH, DVN, and TU Darmstadt, among others. The conference's diverse range of topics spanned from the intricacies of visual performance in automotive lighting and the future of lighting technology to the nuances of AV communication and the sustainability approaches in the industry. Furthermore, the symposium shed light on the advancements in HD headlamps, the evolving standards in rating and regulations, and the innovative strides in car interior and ambient lighting. This conference not only highlighted the current state of the art in automotive lighting but also set the stage for future discussions and innovations in the field.

Visual Performance

The realm of automotive lighting has witnessed significant advancements, with a primary focus on enhancing visual performance, especially during nighttime driving. The ISAL 2023 conference delved deep into this topic, presenting a series of talks and lectures that highlighted the importance of understanding and optimizing visual performance for safer driving experiences.

One of the standout papers from the conference was the study conducted by Korbinian Kunst, Dr. Anil Erkan, David Hoffmann, Markus Peier, Tsoni Vitkov, and Prof. Tran Quoc Khanh from the Laboratory of Adaptive Lighting Systems and Visual Processing at the Technical University of Darmstadt, Germany. Their research centered on the driver's gaze distributions on different road types, namely rural roads, highways, and urban roads, during both the day and night.

The study was meticulously designed, involving 10 test participants who drove a defined route encompassing rural roads, highways, and urban roads. The test vehicle was equipped with GPS and a camera, and participants wore head-mounted eye-tracking glasses to record their gaze. The primary objective was to understand how gaze distributions varied across different road environments and lighting conditions. The findings revealed distinct differences in gaze distributions across the three road types. For instance, during the day, a wider gaze distribution was observed on rural roads, possibly due to drivers spotting hazards earlier or simply admiring the landscape. However, nighttime driving on rural roads showed a narrower gaze distribution, primarily influenced by the reduced brightness and reliance on headlights as the primary light source.

In urban settings, the gaze behavior was broader, especially on residential roads. This can be attributed to drivers scanning the sides of streets more frequently to detect potential dangers lurking between parked cars. The research emphasized the importance of adaptive light distribution that adjusts according to the traffic situation and environment.

On highways, the gaze distribution was the narrowest, both horizontally and vertically. This is likely due to the high speeds and the need for focused attention on the road ahead. The study also highlighted a tendency for drivers to lower their gaze at night while on highways.

In conclusion, the research underscores the significance of understanding gaze behavior to optimize headlamp light distribution. Such insights are crucial for designing automotive lighting systems that cater to the specific needs of drivers across different road environments and lighting conditions, ultimately enhancing road safety.

In the ever-evolving landscape of automotive lighting, ensuring the uniformity of headlamp light patterns is paramount for the perceived quality of a headlamp. Addressing this intricate challenge, a paper titled "Enhancement of a Contrast Threshold Prediction Model by the Implementation of the Dual Tree Complex Wavelet Transform" by Katrin Schier, Mathias Niedling, and Christoph Schierz delves into the complexities of contrast vision. The authors explore the nuances of various headlamp technologies and their inherent challenges in producing a perceptually uniform light pattern. Recognizing the myriad of potential inhomogeneities that can arise, the trio presents an enhanced model that predicts the visibility of contrasts in luminance distributions. By integrating the Dual Tree Complex Wavelet Transform (DT-CWT) into their model, they aim to offer a more accurate and objective evaluation method, setting the stage for future advancements in the domain of automotive lighting.

In recent years, various headlamp technologies have emerged in the market, each presenting unique challenges in producing a perceptually uniform headlamp light pattern. The uniformity of this light pattern is crucial for the perceived quality of a headlamp. Given the myriad of potential inhomogeneity characteristics (e.g., size, position, shape) that can arise from these technologies, there's a need for an objective evaluation method that can predict the visibility of an inhomogeneity, regardless of its type. The authors had previously proposed a model to detect such nonuniformities by predicting the visibility of contrasts in luminance distributions. This model emulated simple contrast processing steps of the human visual system. However, the continuous filter functions of the earlier model could lead to distortions when reconstructing the image. The goal of this paper is to enhance this model by implementing the Dual Tree Complex Wavelet Transform (DT-CWT) to overcome these limitations.

The paper introduces the Dual Tree Complex Wavelet Transform (DT-CWT) as a solution to the shift invariance problem observed in the earlier model. The DT-CWT, developed by Kingsbury, is composed of two parallel discrete real-valued wavelet trees. This transform offers near shift in-

Powerful computers evaluate the data and give the headlights commands for the best possible adjustment of light distribution in all situations. To avoid glare as much as possible, the light is dimmed for oncoming or preceding vehicles, other road users, and traffic signs. Photo credit: Daimler AG

variance, which is crucial for the accurate calculation of contrasts, especially those near the threshold. The DT-CWT filters were shown to deliver a better overall performance when evaluating measured and simulated luminance images. The wavelet filters resulted in a significantly reduced number of visible distortions in the image, providing a more accurate representation of contrasts. The paper also highlights that the DT-CWT filters closely resemble oriented Gabor filters, which have been used to model the behavior of the simple cells of the primary visual cortex (V1). This resemblance suggests that the implementation of the DT-CWT in the model simulates higher processing stages of the human visual cortex, enabling the simulation of effects known to contribute to the contrast threshold.

In summary, the paper offers an enhanced model for predicting the visibility of contrasts in luminance distributions of headlamp light patterns, providing a more accurate and objective evaluation method for the perceived quality of headlamps.

Future Lighting

As the automotive industry propels forward, the realm of lighting is undergoing a transformative shift, with the spotlight on enhancing safety, efficiency, and aesthetics. The concept of future lighting transcends mere illumination. It encapsulates a vision where lighting systems not only guide the way but also communicate, adapt, and even predict. High-definition (HD) headlamps, equipped with state-of-the-art technologies like micro-LEDs, are at the forefront of this evolution. These headlamps promise not just superior illumination but also the ability to project vital information onto the road, thereby amplifying driver awareness and safety. As the industry continues to innovate, the challenge lies in balancing technological prowess with practical applicability, ensuring that the future of automotive lighting is not just bright but also smart and sustainable.

In the paper titled ”Application potential and challenges of HD front lighting” by M.Kropac, A.Freiding, and D.Ceyhun from Hyundai Motor Europe Technical Center in Germany, the authors delve deep into the potential applications of high-definition (HD) front lighting. The main driver for the application of HD front lighting is to enhance visibility and provide assistance functions, directly linked to safety benefits for the driver. The paper considers various potential HD front lighting features, including High Definition Adaptive Driving Beam (HD ADB) with precise multi-masking zones, Lane light carpet, Marking light, Light guiding, Light warning, and Light navigation. The authors emphasize that the most attractive lighting feature is the HD ADB, which provides the driver with maximal illumination without dazzling other road users. The paper also highlights customer feedback, indicating that low or no visibility of symbols on a wet road or during the day was negatively commented on for all projection-based HD front lighting features.

Another significant contribution is the paper ”Headlamp sensor: Visibility sensor based on structured light” by Florian Krieft, Prof. Dr. rer. nat. Cornelius Neumann, and Dr. Mathias Niedling. The authors investigate the feasibility of using high-resolution headlamps as sensors to determine visibility conditions, especially in foggy environments. The research explores how structured light emitted by high-resolution headlamps can be used to gather information about fog conditions. The system capitalizes on the scattering of light in foggy conditions, using it as a data source to determine visibility. The sharpness of the projection borders serves as a reliable data source, suggesting that high-resolution headlamps can play a pivotal role in the future of automated driving.

Lastly, the paper ”Towards Pixelated Single Module Headlamp Solutions” by Christian Knobloch, Reza Larimian, and Patrick Schmidt from ZKW, Austria, offers insights into the evolution of automotive headlights. The authors emphasize the industry’s shift towards more compact and design-centric solutions, championing the cause of pixelated LED array light sources. These sources present a balance between performance, functionality, and complexity, promising a future where headlamps are not just functional but also aesthetically pleasing.

In essence, these research papers collectively paint a vivid picture of the future of automotive lighting, emphasizing the sector’s potential to redefine safety and communication in the automotive world.

Autonomous Vehicles Communication

The evolution of autonomous vehicles (AVs) has brought forth a myriad of challenges and opportunities, with one of the most pivotal being communication. As vehicles become more autonomous, the traditional channels of communication between drivers, pedestrians, and other road users are undergoing a transformation. In the absence of a human driver, the onus falls on the vehicle itself to communicate its intentions and actions. This paradigm shift necessitates the development of innovative communication methods that are intuitive, clear, and universally understood.
The realm of AV Communication explores these very facets, delving into the intricacies of how automated vehicles can effectively convey their intentions to the surrounding environment, ensuring safety and fostering trust among all road users.

Lotus Eletre, shown at ISAL 2023. Photo Credit: Lotus.

Automated driving revolution: Mercedes-Benz announced U.S. availability of DRIVE PILOT - the world's first certified SAE Level 3 system for the U.S. market. Photo Credit: Mercedes-Benz.


Los Angeles
Where to?
05:02
22 min
05:58 pm
21 mi
10 mi
San Bernardino, San...
killer lover boy
SEB
Phone
Joe's
Introduction
Personal
Deco. Image
72°
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Climate Menu
1PM2.5
AUTO
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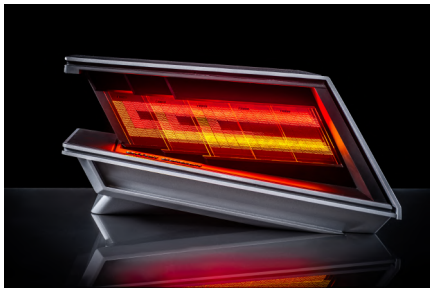
Santa Monica
Manhattan Beach

One of the standout papers in this domain is titled "Communication of highly automated vehicles with the surrounding environment using on-vehicle imaging and displaying devices" by Markus Peier, David Hoffmann, Korbinian Kunst, Elisabeth Kemmler, Dr. Anil Erkan, and Prof. Tran Quoc Khanh from the Laboratory of Adaptive Lighting Systems and Visual Processing at the Technical University of Darmstadt, Germany. This research delves into the potential of on-vehicle imaging devices, such as displays, to facilitate communication between AVs and vulnerable road users. The study emphasizes the need for symbols that can effectively resolve potential conflict situations, especially in scenarios where traditional right-of-way rules might be ambiguous. The authors explore the transferability of results from virtual reality studies to real-world applications, focusing on the differences between virtual environments and actual demo cars. The paper underscores the significance of developing universally understood symbols and tests their applicability in real-world scenarios.



New ALIYOS™ LED-on-foil technology from ams OSRAM creates unprecedented effects in automotive lighting. The components of the LED foil system feature an ultra-thin profile of less than 1mm, which discreetly applies the LED light source to a wide range of base materials. With a luminance level surpassing 10,000 cd/m² and individually controllable segments, ALIYOS™ opens a new realm of application possibilities and innovative engineering approaches both within and outside the vehicle.

Another noteworthy area of research is the exploration into the "eHMI: Communication Matrix". This study delves into the intricate dynamics of communication between AVs and other road users, especially in situations where the AV's intentions need to be clearly conveyed. The research identifies various messages that can be classified into categories such as attention, detection, cooperation, maneuvers, AV-status, and valence. For instance, in a scenario where a pedestrian is at a crosswalk, the AV might display messages like "I have recognized you" or "I will stop." The system provides a platform for negotiation between the AV and other road users, ensuring that both parties understand each other's intentions and actions.

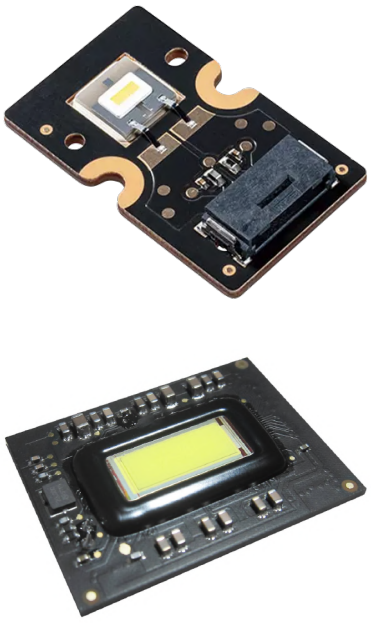
Together, these papers highlight the critical role of communication in the era of autonomous vehicles. As the industry continues to evolve, the development and standardization of communication methods will be paramount in ensuring safety, trust, and seamless interactions between AVs and the surrounding environment.

HD Headlamps

The automotive lighting landscape is witnessing a paradigm shift with the advent of High Definition (HD) headlamps. These advanced lighting systems, characterized by their pixelated light beams, represent the epitome of technological innovation in vehicle illumination. HD headlamps are not just about enhanced brightness; they offer precision, adaptability, and a range of functionalities that were previously unattainable. With the ability to project intricate patterns and symbols on the road, these headlamps extend beyond mere illumination, providing drivers with light-based assistance and communication tools. As vehicles become more sophisticated and the roads more complex, the role of HD headlamps in enhancing safety, improving visibility, and facilitating communication becomes paramount.

A notable paper that delves into this topic is "Application potential and challenges of HD front lighting" by M.Kropac, A.Freiding, and D.Ceyhun from Hyundai Motor Europe Technical Center in Germany. The research underscores the primary driver for the application of HD front lighting: to improve visibility and provide assistance functions that directly benefit driver safety. The paper explores potential HD front lighting features, such as High Definition Adaptive Driving Beam (HD ADB), which offers precise multi-masking zones, and other functionalities like Lane light carpet, Marking light, and Light guiding. The authors emphasize the potential of HD ADB in providing maximal illumination without dazzling other road users. Furthermore, the research delves into the transferability of results from virtual reality studies to real-world applications, highlighting the differences between virtual environments and actual demo cars.

Another significant contribution to the discourse on HD headlamps is "DIGITAL LIGHT – A Résúmé after 4 Years of Series Production" by Dr. Markus Maier, Fabian Priegler, Dr. Axel Müller, and Christopher Weiss from Mercedes-Benz AG, Germany. The paper describes "DIGITAL LIGHT" as the high-resolution headlight technology at Mercedes-Benz. Combined with high-performance ECUs and quality sensor input, it enables several new adaptive high beam assist functions. The authors reflect on their experience after four years of series production, discussing the benefits of high-resolution systems for driver assistance projections and the associated regulatory challenges. The paper also emphasizes the role of in-house software development in ensuring the quality and agility of software-driven light.



Nichia's micro-PLS LED matrix solution, featuring 16,384 micro-LEDs controlled by an Infineon ASIC (top). Lumileds' 20,000-pixel high-resolution monolithic light source (bottom). Both HD light engines are designed for adaptive driving beam applications.

Together, these papers provide a comprehensive insight into the potential and challenges of HD headlamps in the automotive industry. As vehicles continue to evolve, the integration of these advanced lighting systems will play a crucial role in shaping the future of automotive safety and communication.

Rating and Regulations

The automotive industry is undergoing a transformative phase, with the advent of autonomous vehicles, electric mobility, and advanced driver-assistance systems. As these technologies evolve, so does the need for appropriate regulations and ratings to ensure safety, efficiency, and standardization. One of the critical aspects of this transformation is automotive lighting. Lighting not only plays a pivotal role in ensuring the safety of nighttime driving

The HD matrix light illuminates the entire 40-degree horizontal and ten-degree vertical range with a luminous flux of over 1,400 lumens, thereby generating one of the largest and brightest high-resolution illumination areas. It covers the entire high beam range and begins just in front of the vehicle. The light can be distributed in any way within this area and this flexibility makes it possible to improve existing functions and introduce new ones – always with the aim of offering the driver the best possible visibility in any situation. Photo credit: Porsche.

HD Matrix LED Headlights with 16,384 micro-LEDs per LED array. Photo credit: Porsche.

but also serves as a communication tool between vehicles and other road users. With the increasing complexity of automotive lighting systems, especially with the integration of high-resolution technologies, there's a pressing need for clear guidelines and ratings that can evaluate their performance and safety.

One of the papers that stands out in this context is "ADS Marker Lamps – Regulatory Requirements and Technical Implementations" by Daniel Betz and Stefan Töpfer from Mercedes-Benz AG, Germany. The paper discusses the increasing relevance of Autonomous Driving Systems (ADS) in everyday traffic. Mercedes-Benz, as the first manufacturer offering Level 3 driving systems in Germany and other global markets, recognizes the importance of exterior lighting to indicate the autonomous driving status to other road users. The paper delves into the regulatory requirements for turquoise ADS marker lamps, discussing the current standards known for the Chinese and the US market. The authors highlight the common parameters but also identify contradicting requirements.

The paper elaborates on the installation positions of the ADS marker lamps. While the SAE J3134 only describes marker lamps towards the front, the drafted GB-Standard in China requires an installation position in the front, side, and rear of the vehicle, ensuring 360° visibility. Both regulations agree that the illumination towards the front and rear can be achieved either by one central lamp or two symmetrically installed lamps. The chromaticity requirements for the ADS marker lamps are identical in both the SAE J3134 and the drafted GB-Standard. The unique turquoise color is emphasized, which helps in clearly assigning the new lights to the autonomous driving functions in Level 3. The authors stress the importance of conveying the meaning of this specific light color to the public, ensuring its understanding and acceptance.

Another significant contribution in this area is the paper "Headlamps performance prediction to win the IIHS Top Safety Pick" by N. Costa, R. Rabbeni, and D. Novack. The performance of vehicle headlamps is crucial for safe nighttime driving. The Insurance Institute for Highway Safety (IIHS) has developed an assessment method for headlamp performance to promote improvements leading to higher traffic safety and reduced nighttime accidents. This paper introduces a virtual methodology capable of predicting IIHS headlamp ratings. The methodology uses virtual simulators and vehicle dynamics models to predict ratings early in the development process, allowing for timely optimizations. The IIHS rating prediction tool integrates with the SCANeR workstation, running a co-simulation model. The tool has shown a high level of correlation between predicted and real IIHS ratings, with a confidence level of 85%. The methodology's accuracy suggests that changing the vehicle model can study the performance of the lighting headlamp system effectively.

In conclusion, as the automotive industry continues to innovate, the importance of clear, comprehensive, and forward-looking regulations and ratings cannot be overstated. These papers shed light on the ongoing efforts to ensure that automotive lighting systems are not only advanced but also safe and compliant with the necessary standards.

Sustainability and System Approach

The automotive industry is undergoing a significant transformation, with sustainability at the forefront of its evolution. As the world grapples with environmental challenges, there's a growing emphasis on creating products that are not only efficient but also environmentally friendly. In the realm of automotive lighting, this translates to the development of systems that are energy-efficient, made from sustainable materials, and designed for longevity and recyclability. The "Sustainability & System Approach" section of the ISAL 2023 proceedings delves into this topic, exploring innovative solutions that aim to reduce the carbon footprint of automotive lighting systems while ensuring optimal performance.

One of the standout papers in this category is titled "Sustainable headlamps contributing to carbon neutrality" by Kazuki Honda, Shota Nishimura, Takehiro Matsumoto, and Yoshihiro Fujiyama from Stanley Electric Co., Ltd., Japan. The paper introduces the "E-thi-caL" headlamp unit, a groundbreaking development in sustainable automotive lighting. This headlamp is characterized by its low power consumption and lightweight design. Remarkably, the "E-thi-caL" headlamp consumes significantly less power than conventional headlamps, registering a power consumption of just 10.9 W. Additionally, its weight is a mere 100 grams, making it one of the lightest in its category.

ISELED technology is based on the integration of several LEDs – RGB, white/white or combinations thereof – and controller chip within one single common package in the form of a SiP (System in Package). The LED manufacturer performs the optical calibration of the individual LEDs during the final test of the SiP. During this process, the characteristic data of the LEDs are stored into a non-volatile memory, which is embedded in the controller chip. This precisely adjusts the LEDs during operation; using a sensor integrated in the controller it also takes the ambient temperature into account eliminating the need for both time-consuming calibration at tier-1 suppliers and extensive external control during operation. ISELED is therefore also referred to as a „digital LED", because only the address of the respective SiP module, the color and brightness values are required for controlling. This is done in the form of the „lean" ISELED protocol, which enables light sequences at video speed despite the low data rate of 2 Mbit/s – conventional systems use the SPI bus which is clocked at frequencies in the range of 20 to 30 MHz.

The unique features of the "E-thi-caL" headlamp are attributed to its highly efficient and straightforward optical system. The system is designed to identify the "really necessary light distribution" based on accident analysis. This approach ensures that the light distribution is optimized for safety, reducing the likelihood of accidents. Furthermore, the headlamp's design incorporates a mechanism where certain LED light sources designated for the low beam are turned off when the high beam is activated. This design choice further reduces power consumption without compromising the driver's comfort or visibility.

The paper emphasizes that replacing conventional halogen headlamps with the "E-thi-caL" unit can significantly contribute to global environmental efforts. Given that a large proportion of vehicles worldwide still use halogen headlamps, transitioning to the "E-thi-caL" headlamp can lead to substantial reductions in power consumption, pushing the automotive industry closer to its carbon neutrality goals.

In the quest for sustainability, the automotive lighting industry is considering the re-use of lighting products, particularly in major markets as presented in the paper "Local Approach for Major Markets Minimizes Logistic Costs". This approach is driven by the aim to reduce logistic costs, efforts, and CO_2 emissions associated with the second life of these products. The paper emphasizes the importance of common mechanical and electronical interfaces, along with assembly and disassembly strategies. These strategies, if implemented effectively, can offer a higher degree of flexibility within the sustainability scale-up.

The paper suggests that bold and visionary decisions are required to initiate this sustainable path. Starting with small profitable pilot lines is a recommended approach. The ultimate goal is to harmonize the lighting module designs, ensuring a smoother transition towards this sustainable vision. However, it's crucial that this sustainable path does not compromise the styling attractiveness and light performance, both of which are essential for safe driving.

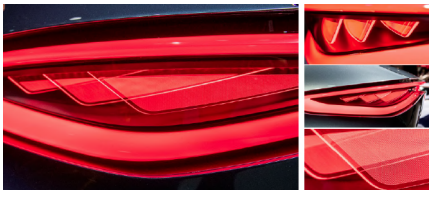
The future of lighting products, as outlined in the paper, is rooted in digital safety-enhancing high-resolution light functions. These functions are expected to be introduced to the market by the SSL|HD technology. Additionally, the paper mentions the significance of high-efficiency and homogeneity-based signal functions, which will be realized by Flat Light optics. Digital projections are anticipated to extend the safety space around vehicles, and displays will play a pivotal role in enhancing the styling aspects of these products.

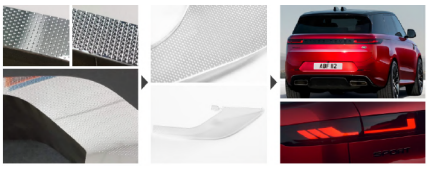
In essence, the paper underscores the importance of a sustainable approach in the automotive lighting sector. By minimizing logistic costs and focusing on re-use, the industry can make significant strides towards a more environmentally-friendly future, without compromising on performance or aesthetics.

In conclusion, as the automotive industry continues its journey towards sustainability, innovations like the "E-thi-caL" headlamp are pivotal. They not only represent technological advancement but also underscore the industry's commitment to creating products that are in harmony with the environment. The papers in the "Sustainability & System Approach" section highlight the ongoing efforts in this direction, showcasing solutions that are both innovative and eco-friendly.

Car Interior and Ambient Lighting

The transformation of vehicles into autonomous entities is reshaping the very essence of car interiors. No longer just spaces for driving, these interiors are evolving into environments where a myriad of activities such as relaxation, conversation, work, and entertainment take place. This shift necessitates a reimagining of automotive interior lighting to create a comfortable ambiance for diverse in-vehicle activities. Moreover, the advanced convergence in automotive interior lighting should be adept at adjusting the lighting environment based on the occupant's emotional states, ensuring a holistic and user-centric experience.





Microrelleus specializes in laser microstructuring, texturing, and industrial engraving. In 2016, they became world pioneers by offering femtosecond laser services in 5-axis configurations. By 2022, they further established their pioneering status by adapting this technology for large and heavy tools and parts. The femtosecond laser allows them to engrave both standard tools and direct prototypes in ways previously deemed impossible. Image: Tool microstructuring > Injected parts > Final product (tail lamp).

A notable study titled "Development of a Mixed-Reality Vehicle Interior Lighting Testbed" delves deep into this paradigm shift. The research, conducted by a team from Yeungnam University in Daegu, Republic of Korea, introduces a mixed-reality automotive indoor environment tailored for evaluating autonomous interior lighting across various scenarios. The study leverages Virtual Reality (VR) to rapidly explore and design lighting scenarios. Using the Unity platform, the researchers developed

a VR-based interior lighting environment that mirrored a Propose Built Vehicle (PBV) buck, designed specifically for autonomous vehicles. This environment simulated realistic driving scenarios with multiple surrounding screens and short-throw projectors.

The lighting module design for this testbed was intricate. Eight directional lights were strategically placed on the ceiling, capable of basic color adjustments and alterations in color temperature and illuminance via the HDRP rendering engine. The design also incorporated ambient lighting samples in the form of lines and bulbs, allowing for easy integration of ambient lighting from the buck environment as needed. To enhance the immersive driving experience, 360-degree videos and HDRP light maps of daytime road driving scenarios were incorporated.

The buck, donated by a company referred to as 'Company H' in the study, was equipped with prototype lighting and equipment. It served as a testbed to analyze passenger activities from various scenarios in autonomous vehicles and evaluate lighting environments implemented by prototype lighting and surroundings. The buck was designed to recognize and respond to passenger activities and emotions, ensuring a personalized lighting experience.

In conclusion, the study underscores the potential of mixed-reality environments in shaping the future of automotive interior lighting. By bridging the gap between virtual designs and real-world implementations, such testbeds can pave the way for lighting scenarios that are both innovative and user-centric, enhancing the in-vehicle experience in the age of autonomy.

Conclusion

The ISAL 2023 conference showcased the multifaceted evolution of automotive lighting, emphasizing its pivotal role in the rapidly transforming automotive landscape. One of the standout themes was the emphasis on visual performance, with research underscoring the significance of adaptive systems like the "Adaptive Driving Beam" that dynamically adjust to on-road conditions, ensuring optimal visibility while minimizing glare for oncoming drivers. The future lighting section highlighted innovations like the "DIGITAL LIGHT" system, which, after years of series production, has proven its capability in enhancing safety through high-resolution adaptive beam functions. As vehicles edge closer to full autonomy, AV Communication has emerged as a crucial domain, with lighting systems serving as communication tools between vehicles and other road users. The "ADS Marker Lamps" study, for instance, emphasized the need for universally recognizable lighting cues to indicate a vehicle's autonomous status, ensuring safety and clarity on roads.

HD Headlamps represent the zenith of technological advancement in lighting, with systems capable of projecting intricate patterns and symbols on roads, extending their role beyond mere illumination. The push for sustainability was evident, with innovations like the "E-thi-caL" headlamp emphasizing low power consumption and lightweight design, marking a significant stride towards carbon neutrality in automotive lighting. The Rating & Regulations section underscored the industry's commitment to ensuring that these innovations align with safety standards, with research focusing on predicting IIHS headlamp ratings to promote nighttime driving safety. The Sustainability & System Approach highlighted the industry's eco-conscious direction, emphasizing the re-use of lighting products to minimize logistic costs and CO_2 emissions. Lastly, the transformation of Car Interior and Ambient Lighting was evident, with mixed-reality testbeds being developed to evaluate and design lighting scenarios for autonomous vehicles, ensuring a holistic in-car experience.

In conclusion, the future of automotive lighting is poised at the intersection of technology, safety, and sustainability. As vehicles become more autonomous and interconnected, lighting will transcend its traditional role, serving as a communication tool, safety enhancer, and a symbol of eco-consciousness. The industry is gearing towards a future where lighting systems are not just about illumination but about enhancing the overall driving and in-car experience, ensuring safety, sustainability, and seamless vehicle-to-environment communication. ■

Tristimulus-filtered Imaging Spectral Colorimeter

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SphereOptics

Westboro Photonics' WP525 is an all-in-one tristimulus-filtered imaging colorimeter with integrated spot spectroradiometer. Calibrated and paired with Westboro's Photometrica™ software, the equipment is suited for measuring displays, lighting, and backlit graphics in development and production. The 25-megapixel color and luminance measurements are corrected via a spot spectral measurement in the center of the image.

Westboro Photonics' WP525 is an all-in-one tristimulus-filtered imaging colorimeter.

A key component of the WP525 is a high-speed linear translation stage. It has multiple positions for imaging light with the spectroradiometer or with the XRed, XBlue, Y and Z tristimulus filters and camera. In addition, there is standard filtering up to ND2 in the spectrometer path. Conveniently, the moving stage provides positions where the imager or spectrometer is shuttered from illumination.
The system thus supports fully automated shuttering and dark measurements to correct detector noise. Thirteen interchangeable lenses can be calibrated with the system, including a conoscopic lens for viewing angle testing and a near-to-eye-display lens for AR/VR display analysis. With the help of the associated Photometrica™ software and optional application-oriented software addons, comprehensive tests are available to support customers in various automotive interior and exterior applications.

For more information, please contact SphereOptics on www.sphereoptics.de or email us info@sphereoptics.de. ■

OLED Lighting Technology Brings Beauty and Safety to the Road

OLEDWorks

Founded in 2010, OLEDWorks is the world leader in manufacturing Organic Light Emitting Diode (OLED) lighting technology. Since its founding, OLEDWorks has expanded globally, facilitated by the purchase of the Philips OLED division in 2015, which included their intellectual property, state-of-the-art production facility in Aachen, Germany, and a core team of OLED engineers, business experts, and technicians. This unique combination of American entrepreneurship and German precision engineering has allowed OLEDWorks to produce world-class OLED lighting technology, with the thinnest and brightest OLED lighting panels on the road in the redesigned Audi A8, announced in 2021. Today, OLEDWorks continues to expand its production capabilities and work toward increasing the number of automotive solutions that capitalize on the beauty and safety capabilities of this technology.

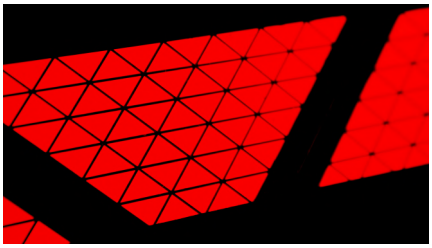
www.OLEDWorks.com

What is OLED Technology?

First invented in Rochester, New York, in 1987 by the researchers at Eastman Kodak, OLED technology is a solid-state lighting (SSL) composed of thin layers of organic material that emit light from the entire surface of the panel. This unique characteristic allows for a homogeneous and diffuse light source that does not require diffusors or optical elements necessary in other lighting technologies. Without these additional components, OLEDs can be made with a profile of 1mm or less in total thickness, reducing weight and space requirements.

In addition to an ultra-thin homogenous light source, benefits of OLED lighting include:

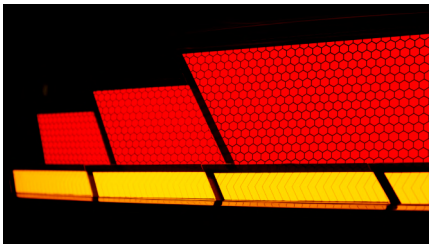
- Comparable lifetime, reliability, and energy efficiency as traditional LED solutions.
- Custom design within the panel itself (color, size, and segmentation).
- High-contrast segmentation for communication capabilities.
- Dynamic animations and crisp logos.



High segmentation allows for clear dynamic communication and symbology.

OLED Lighting in the Automotive Industry

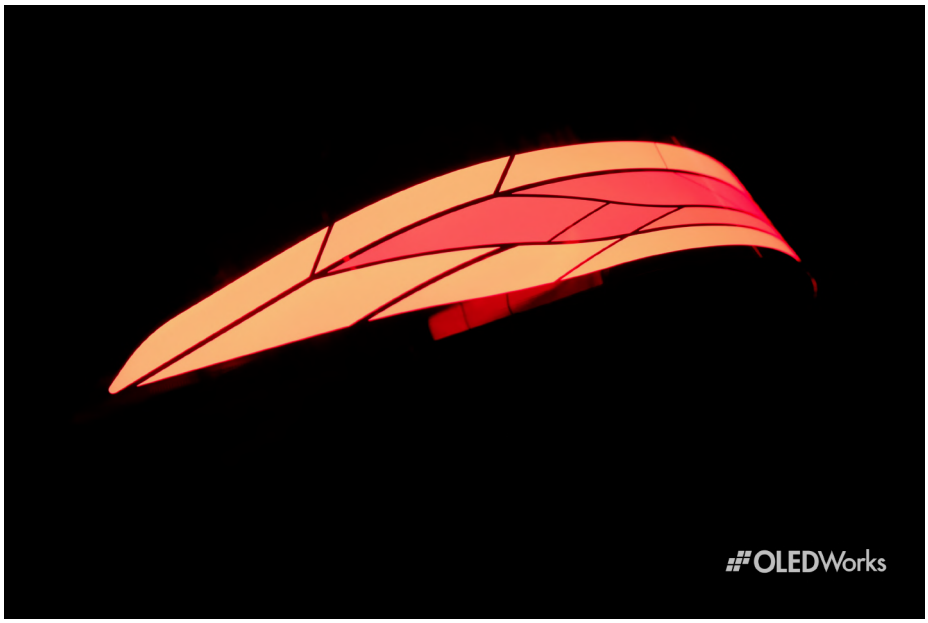
The high-contrast segmentation of OLED lighting is particularly exciting in the automotive industry, as it enables superior branding and communication capabilities. By using dynamic animations and symbols, vehicles can communicate upcoming hazards with other drivers like icy conditions, sudden braking, or other safety information in a clear and attention-grabbing manner. OEMs can also use high-contrast OLEDs to illuminate the manufacturer's badge or model name or add custom rear lighting animations to distinguish their brand from competitors.



OLEDWorks rigid automotive panels with hundreds of individually addressable segments.

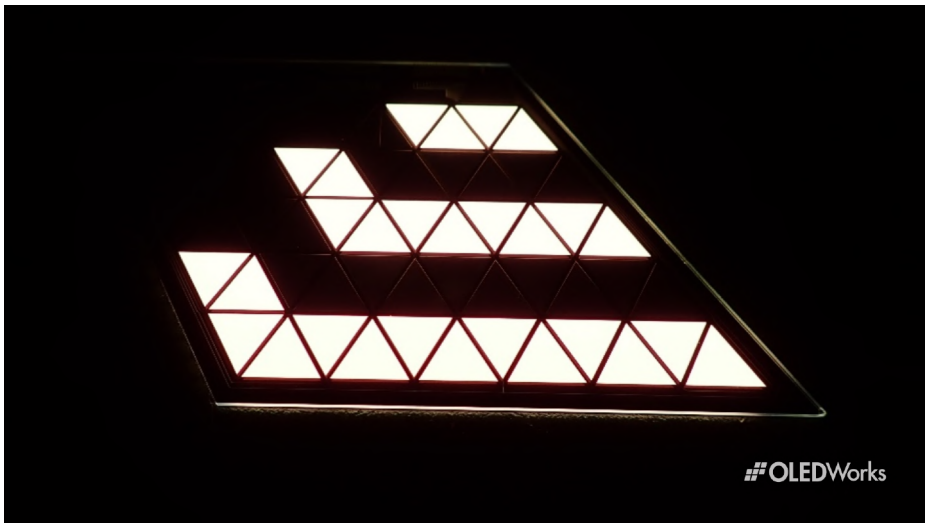
When OLEDWorks entered the automotive industry, safety was its top priority, and it knew that this would require even more rigorous technology performance and stringent reliability testing than previous ventures. OLEDWorks technology is designed to last the lifetime of the vehicle and has passed thousands of hours of reliability tests like the AEC-Q-102 standards for high heat, humidity, shock, and vibration. Additionally, OLEDWorks' commitment to quality is seen through its IATF 16949 and ISO 9001, 14001, 45001 certified manufacturing facility.

With the launch of the redesigned Audi A8, OLEDWorks confirmed the reliability and performance of its products. OLED lighting is offered standard in the A8, with four unique lighting signatures possible across the model range that provide a sense of customization for each driver. The OLEDWorks panels exhibit ECE/SAE-certified deep red emission color and an impressive $2000\,cd/m^2$ brightness, due, in part, to OLEDWorks' best-in-class multi-stack OLED technology, which allows more active material to be incorporated into the OLED architecture.



OLEDWorks bendable automotive panel with intrinsic segmentation.

Segmented amber panel for automotive.



Segmented white panel for automotive.

Tomorrow's Automotive OLED Solutions

While OLED lighting on the road today is impressive, available products have only scratched the surface of what is possible with OLEDs. The clear next step for OLED technology is an increased number of individually addressable segments within the panel design. OLEDWorks has demonstrated panels with over 600 segments at industry shows, which will enable greater communication and branding options for automotive manufacturers.

Another major milestone for OLEDs will be the commercialization of flexible OLED lighting that can curve with the contours of the vehicle. Flexible OLED rear lighting will allow for additional design considerations in addition to making it easier to see the lights from all angles around the vehicle to increase safety on the road. OLEDWorks has shown flexible OLED lighting concepts previously and is working vigorously with its automotive partners to move this product to the road.

In addition, OLEDs are being developed in higher brightness and additional color options such as amber and automotive white. Once commercialized, these colors can be used in full rear combination lights, including turn and brake applications, as well as Center High Mount Stop Lighting (CHMSL) and daytime running lights.

The benefits of high-performance OLED lighting solutions for the automotive industry are numerous and continue to expand with each product generation. As the manufacturer of the brightest and thinnest OLED lighting panels on the road, OLEDWorks is excited to lead the charge of high-quality OLED lighting production to usher in a more beautiful, safer tomorrow. ■

OLEDWorks

From Computers to Cars: Microchip's Ethernet Leap into Automotive Illumination

Dipl.-Phys. Martin MILLER, Director of Marketing Applications for Microchip Technology's Automotive Information Systems Business Unit

At the International Symposium for Automotive Lighting (ISAL) in Darmstadt, Microchip showed a new way of connecting LED-based lamps inside vehicles to the main computer. In this new approach, Ethernet is used to connect interior or exterior lamps directly to the vehicle's IT backbone instead of connecting them via CAN, LIN or LVDS to a central gateway. This has several key advantages, as outlined below.

Lower Cabling Cost

Ethernet in cars uses Unshielded Twisted Pair (UTP) cables. Cables and connectors are cost-effective especially for the lowest speed grade 10BASE-T1S running at 10 Mbps. Cables also will be shorter since the lamps are connected to the closest zone controller instead of routing the cable through the entire vehicle to a central point. 10BASE-T1S also supports bus topologies like CAN, allowing to connect multiple lamps to a cable or connect multiple PCBs inside a lamp via the same cable. In the example shown in **Figure 1**, head- and backlights are connected to the closest zone controller. The three backlights in the trunk lid benefit from 10BASE-T1S' support for the bus topology.

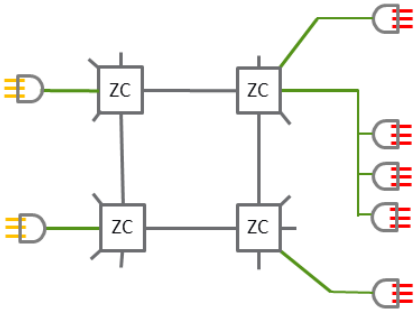


Figure 1: Exterior lighting with Zone Controllers.

Higher Bandwidth

For automotive applications Ethernet offers speed grades from 10 Mbps up to 10,000 Mbps. If an application requires more bandwidth, only the PHY is changed. Everything else (arbitration, synchronization, security, functional safety, software stacks, etc.) remains untouched. Imagine if you migrate a lamp from CAN to LVDS. Everything would change.

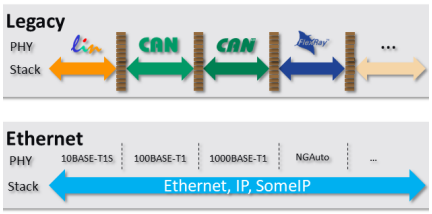


Figure 2: Communication approaches for automotive applications.

Higher Resolution

In today's lamps, LED drivers are mostly used with a CAN interface (**Figure 3** top). They are connected to a single cable. Since the maximum number of nodes on a CAN line is limited to ≈15, the total number of LEDs is limited. Let's say we are using LED drivers with 16 channels, we end up with a maximum of 15 (nodes) x 16 (channels) = 240 LEDs. This number is far below the resolution required today by many applications. Resolutions with several thousand LEDs are requested more and more.

In Microchip's new approach (**Figure 3** bottom), an Endpoint is used as a bridge from Ethernet to the local LED driver. Simpler LED drivers without a CAN transceiver can be used lowering system cost. Many LED drivers can be connected to a single digital interface of the Endpoint, e.g., SPI or UART. This architecture enables the addressing of up to 20,000 LEDs over a single 10BASE-T1S link. For higher Ethernet speed grades, the corresponding higher resolutions can be achieved.

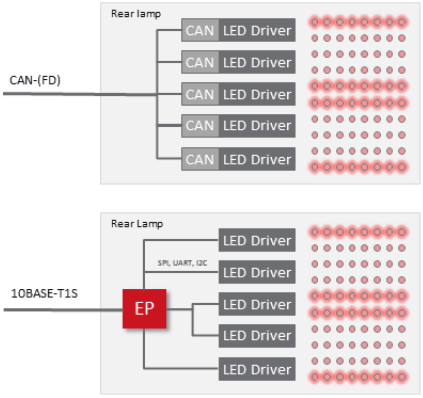


Figure 3: In today's lamps, LED drivers are mostly used with a CAN interface (top). In Microchip's new approach, an Endpoint is used as a bridge from Ethernet to the local LED driver (bottom).

Single Protocol for All Lamps

Today LEDs are typically connected via CAN or one of its derivates UART over CAN or via LIN (**Figure 4** top). The protocol used is not standardized. Animations are realized in software on the main lighting ECU. Whenever an animation needs to be changed, the software must be rewritten. If another LED driver is used inside the lamp, the software must be rewritten. But changing the software requires a requalification of the device, increasing cost and lowering time to market.

The Microchip solution uses standard video streaming (**Figure 4** bottom). Each LED is treated as a pixel. For each pixel/LED only a single byte is needed during transmission to set the brightness. The update of LEDs is synchronized with an accuracy

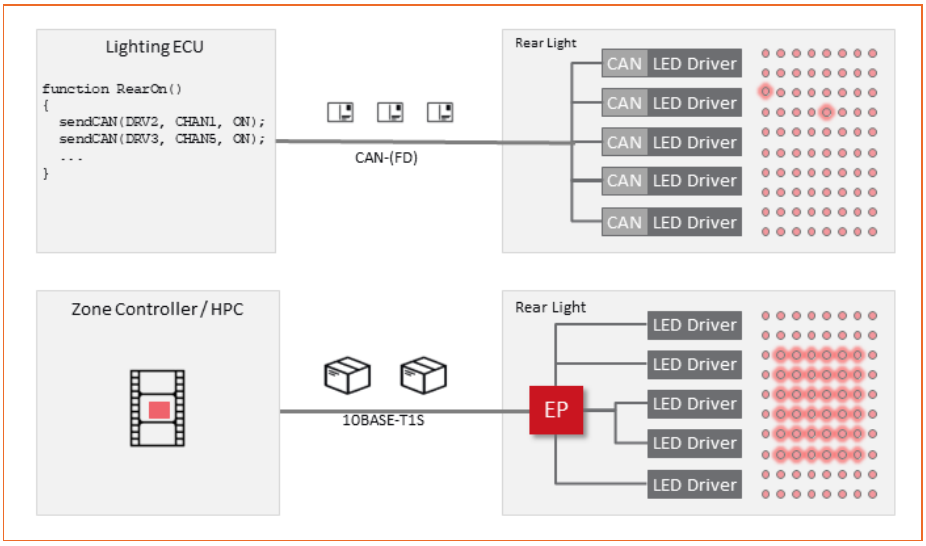


Figure 4: Today LEDs are typically connected via CAN or one of its derivates UART over CAN or via LIN (top). The Microchip solution uses standard video streaming (bottom).

of microseconds even between multiple lamps. It can be controlled from the main vehicle computer, where the video is rendered. Framerates of up to 200 frames per second are supported guaranteeing super low latencies. Especially for LED arrays or uLEDs the usage of video streaming is beneficial. To change e.g., an animation of the LED array, only a new video clip needs to be used → no software changes → no re-qualification.

Single Point for Orchestration of Light and Audio

With controlling all light sources from a single intelligence with a single protocol, the orchestration finally becomes homogeneous. The used streaming protocol is used for audio in most cars today, already. Therefore, lighting and audio can be synchronized without additional effort. This will lead to a new user experience. Projections on the road like lane highlighting for easier navigation, obstacle highlighting for increased safety, etc. will be enabled. Audio combined with video will enable animations in a welcome scenario or at vehicle startup, shutdown and more.

Lamps Without MCU

Microchip's endpoint is a bridge chip translating the streaming protocol received via Ethernet to the local LED-driver's language and interface (SPI, I2C, UART, etc.). An MCU inside a lamp is therefore obsolete, no software update capabilities are required anymore. Instead, the bridge chip is configured once at the Tier1 supplier uses a graphical configuration tool running on a PC. After configuring the tool, it provides a string, which is flashed into the endpoint end of line either via the network or a needle adaptor.
Monitoring the lamp for functional safety and the diagnosis of the lamp is done via Remote Control. Registers of LED drivers can be read, a reset can be triggered throughout the network.

Standards Only

Another key advantage of the chosen approach is that only standards are used. All Ethernet speed grades are standardized by the IEEE, the usage of Ethernet in automotive by the OPEN Alliance. Mechanisms like wake/sleep, diagnosis, synchronization and security are all available in open protocol specifications. Operating systems understand these protocols natively, no additional software stacks are needed. A huge eco-system is providing tools and services. No expert knowledge is required, as the used network know-how is taught at universities today.

Summary

Ethernet is a technology which made its way over the last 30 years from networking computers into many markets and applications including telecom, industrial, home automation and consumer. Lighting is the next area to benefit from this outstanding successful technology. Having a standard based way of controlling lamps will pave the way for automotive LED applications. ■

AUTHOR: Dipl.-Phys. Martin MILLER
Martin holds a Diploma in Physics from the esteemed Friedrich Alexander University in Erlangen, Germany. Since 2004, he has been deeply immersed in the semiconductor industry, bringing with him a wealth of experience and knowledge. Currently, Martin serves as the Director of Marketing & Applications for Automotive Networking at Microchip Technology Inc., where he plays a pivotal role in shaping the company's strategic direction and product applications.

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MICROCHIP

Future of Vehicle Lighting: The Role of Measurement Technology

Oliver ESTERL, Sales & Product Manager at Instrument Systems

Vehicle design appeals in a special way to the emotions of customers. The intention is to create a connection with the owner of the vehicle through the vehicle's unmistakable appearance and strengthen customer loyalty to a vehicle brand in the long term. Vehicle lights have always played a key role in this regard, but they do so to a much greater extent today. People have always spoken of the headlights as the "eyes" of the vehicle, but today it is impossible to imagine the central stylistic element in vehicle design without lighting technology: Lighting is the new Chrome.

Today, LED and OLED technologies offer designers possibilities they could only dream of 10 to 20 years ago. Currently we are talking about illuminated radiator grilles at the front and edge-to-edge taillights at the rear (**Figure 1**), which can reach widths of up to 180 cm. And it is difficult to say where the future will take us.

Most of the new taillights consist of three segments, two of which are located in the vehicle body and one in the trunk lid, but there are already such lights that only consist of one piece.

Figure 1: Edge-to-edge signal lamp as shown at ISAL 2023.

Examples of this could be admired at this year's ISAL Symposium from September 25th to 27th, 2023 in Darmstadt. ISAL is the world's most important forum for innovative vehicle lighting technology and ADAS, where international specialists exchange ideas about new technologies and designs for exterior vehicle lighting.

As a vehicle component that is essential for road safety, vehicle lights are subject to strict legal regulations for type approval testing that is required for the registration of a vehicle. These regulations can be found in UN-ECE R148 and R149 documents and primarily include photometric tests with a goniophotometer to prove compliance.

CIE publication no. 121 (the Photometry an Goniophotometry of Luminaires) distinguishes between three types of goniometers, Type A, B and C. Type A goniometers are used for the measurement of directional light sources, including vehicle headlights and signal lights. **Figure 2** shows a typical Type A goniometer.

The requirements for the goniometer mechanics for Type A machines are particularly high, especially when it comes to

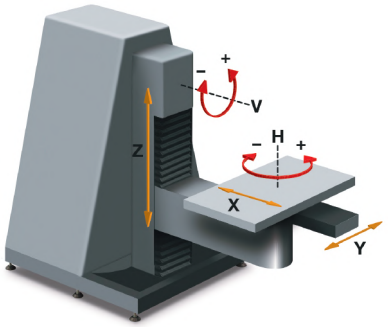

Figure 2: Motion directions type A goniometer.

repeatability, but more importantly absolute accuracy, which must be better than 0.05° for headlight measurements. However, it is immediately noticeable that the traditional Type A goniometer structure makes it difficult to align the light functions in the mounting position in the vehicle, especially if a DUT is very large and its certain optical reference points are at the extreme positions on the right or left of the DUT. There are basically different approaches to solving this problem.

It would be possible to use a conventional industrial robot. This has the advantage that there would no longer be the design-limited limitation of sample size, especially in edge-to-edge luminaires with optical reference points at extreme positions. However, it also has a number of possible serious disadvantages. First of all, the size and cost of a robot. To align a very large luminaire to extreme positions, an extremely long robot arm is necessary. The radius of action and space requirements with the safety area and room height are enormous and probably not practical in most cases. Compared to the conventional design of a goniometer, increased costs must also be expected.

Secondly, although high-precision industrial robots have good reproducibility, they do not achieve the absolute accuracy of the positioning of conventional goniometers. It is also to be expected that the absolute accuracy will continue to suffer as the size

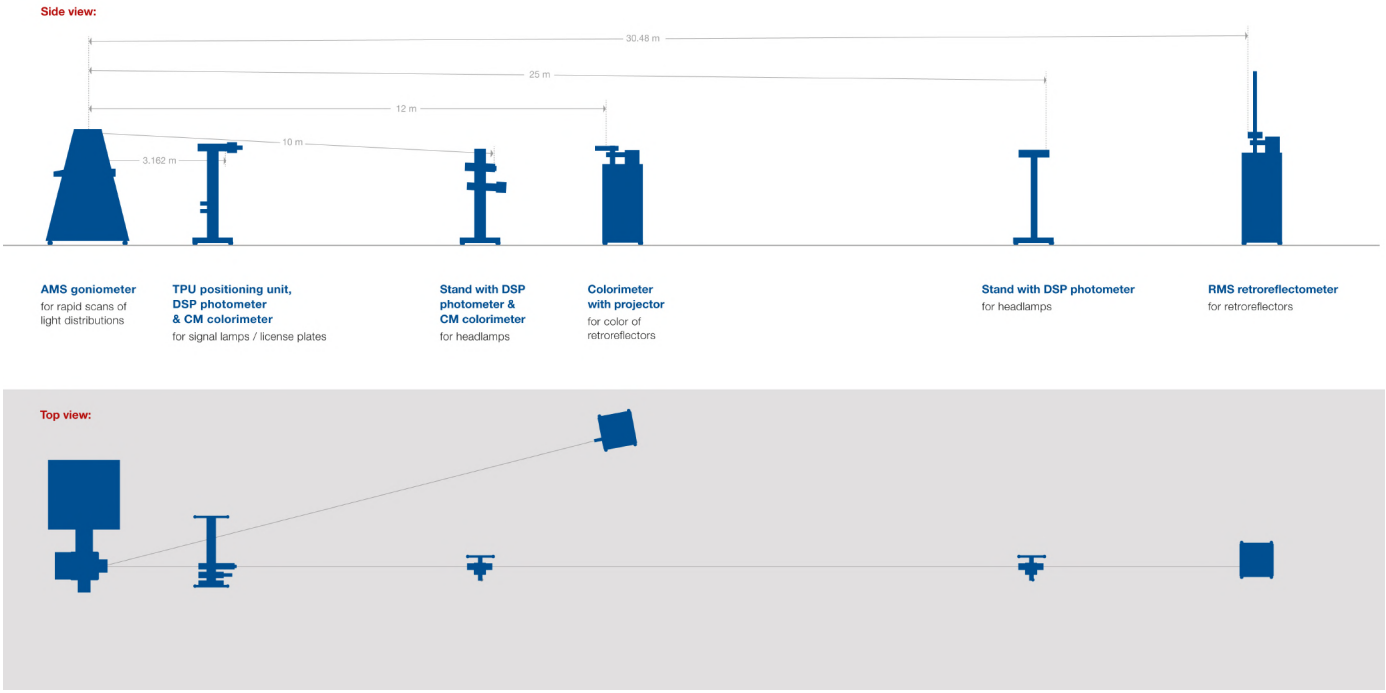

Figure 4: Schematic layout of complete lab set-up.

of the robot increases and the resulting mass increases. This means that robots may be suitable for measuring signal lights, but they do not offer the absolute accuracy for headlight measurements, where the requirements tend to increase in view of new ADB and matrix headlights.

Instrument Systems is therefore pursuing a different solution approach, namely adapting the traditional goniometer mechanics of a Type A system. It is suitable for the majority of applications, but also especially for signal light and headlight applications, since, for economic reasons an investment in two systems, i.e. one for signal lights and one for headlights, is not an option.

A design study based on the AMS 5000 high-performance goniometer was presented at this year's ISAL Symposium: Compared to a clear diameter of 900 mm, the swivel arm was extended by 550 mm to a clear diameter of 1450 mm. This allows luminaires up to approx. 2800 mm wide to be mounted with an optical reference point in the middle. The clear width allows the measurement and alignment of samples of about 1500–1600 mm wide lights with optical reference points at the extreme right or left position. The machine with the working title AMS 5000 XXL, which was shown at ISAL, is equipped with a larger test table on which larger samples can be aligned more easily and secured stably. This sample table can be made from a high-strength carbon composite material, which also saves weight and allows the maximum sample mass specified for this goniometer to remain largely the same, compared to a standard system despite the machine's significantly longer swivel arm. **Figure 3** shows a picture of the machine taken at the ISAL Symposium 2023 in Darmstadt. The DUT was provided by courtesy of Marelli Tolmezzo.

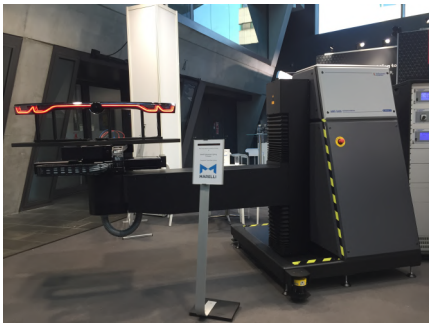

Figure 3: The AMS 5000 XXL goniometer, which was shown at ISAL, is equipped with a larger test table.

This goniometer will be available as a standard system by the end of 2023, but also serves as an example of the possibilities of adapting the goniometer mechanics to the requirements of the DUTs and of covering the widest possible range of applications with the design of the system.

The goniometer can be combined with different options: For example with ultra-fast DSP 200 photometers with sensor cooling and filter thermostatization. They are positioned at different measuring distances and enable quick measurements of light distributions on-the-fly. Or even with high-precision spectroradiometers of the CAS 140D series for determining the color locus and the most similar color temperature. Last but not least, with the RMS retroreflectometer 1200 for reflector measurement according to ECE R3, 27 and 150 as well as other accessories. Everything together forms a complete turnkey system for type testing of headlights, signal lights and reflectors (**Figure 4**).

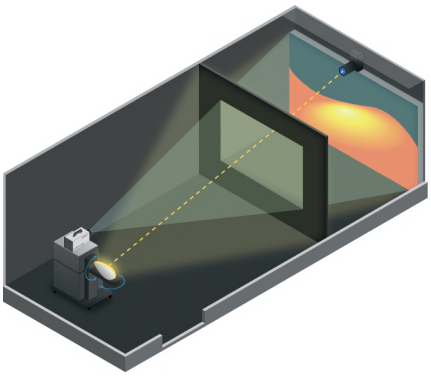

Figure 5: Schematic view of AMS Screen Imaging System.

In combination with the 2D imaging camera LumiCam 2400B/4000B and the calibration source ACS 630, the expansion to a screen photometer for the development-assisting, highly efficient, and rapid determination of ADB, Matrix, AFS headlight distributions is also possible (**Figure 5**). ■

To learn more, please visit or contact us at www.instrumentsystems.com Esterl@instrumentsystems.com.

Expert Talks on Light

Willem Sillevis Smitt, Senior Director of Strategic Marketing at Lumileds, discusses the evolution and challenges of the lighting industry.

Shedding Light on the Future: Nightscape Technology Pioneers Eco-Friendly Illumination!

In a groundbreaking LpS-Digital lecture, Willem Sillevis Smitt, Sr. Director of Strategic Marketing at Lumileds, delves deep into the transformative journey of the lighting industry, introducing the revolutionary Nightscape Technology. This innovation promises to harmonize our lighting needs with the preservation of our natural ecosystem and the dark sky initiatives.

Video at a Glance

- Presenter: Willem Sillevis Smitt
- Job Title: Sr. Director Strategic Marketing
- Organization: Lumileds
- Country: USA
- Recording: August 9, 2023
- Duration: 23:53 min

Video Links

LpS Digital YouTube

https://is.gd/zlqRSY

LpS-Digital.global

https://is.gd/c3pTx7

Content of the Talk

Historical Perspective: 15 years ago, there were concerns about LED technology, questioning its light output, lifespan, and efficiency. Regulatory measures like Energy Star, DLC, LM80, TM21, and European lighting regulations emerged to address these concerns.

Current Concerns: Recent headlines highlight the negative impacts of lighting, such as light pollution affecting humans and wildlife. Concerns about the amount of blue light and its effects on human health are prevalent. Light pollution laws are being implemented in various states in the US, with places like Maui regulating the amount of blue light in new installations.

Impact of Light at Night: Factors to consider: shielding of light, managing blue light content, timing of light, and direction of light. The lighting industry needs to focus on minimal environmental disruption in addition to efficiency and longevity.

Nightscape Technology: Lumileds introduces Nightscape, a technology aiming to produce white light with less than 2% blue content. A comparison of different light sources shows that Nightscape meets the 2% blue requirement while maintaining a higher CCT than other sources. Nightscape aims to provide a balance between pleasant light quality and minimal environmental disruption.

Conclusion: The lighting industry should address end-user concerns and view them as opportunities for improvement. Collaboration is key to creating a better end-user experience.

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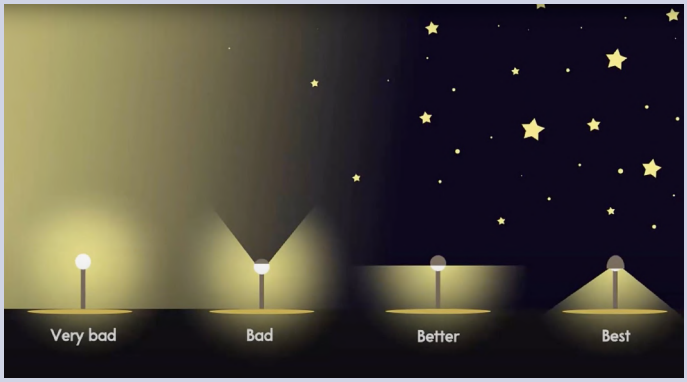

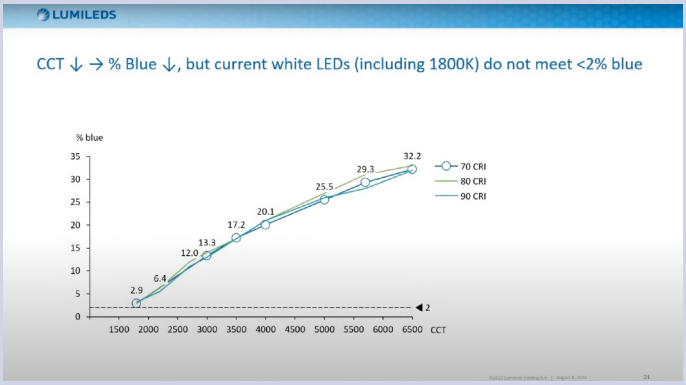

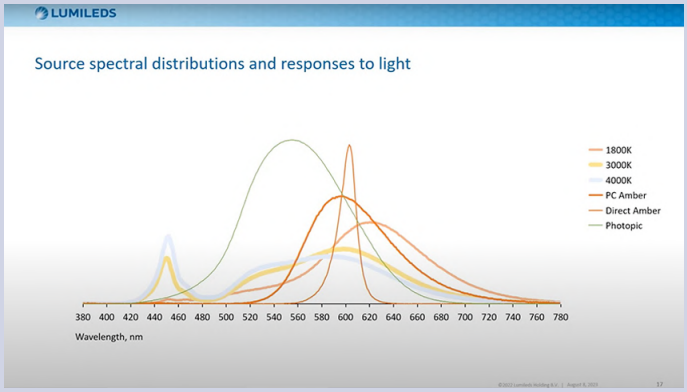

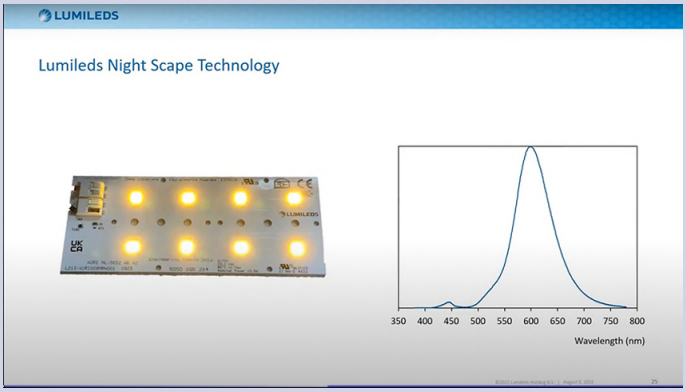

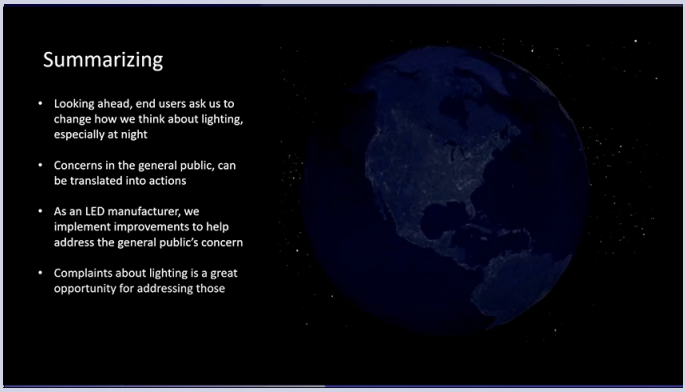

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MATERIAL DUE
January 15, 2024

DIGITAL PUBLICATION
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editors@led-professional.com
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PREVIEW*
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Light and Building SPECIAL

In the upcoming Jan/Feb 2024 issue of LpR, we present a multifaceted exploration of the **lighting** and **optics** industry. The issue commences with a captivating CEO Interview, offering profound insights from a prominent figure in the field. A thought-provoking **Commentary** sets the stage for in-depth discussions. Discover the revolutionary **"Robot that Forecasts the Product Life of LED Lightsources,"** revealing how TÜV SÜD pioneers comprehensive data provision through automated testing, promising advancements in **LED lighting quality**. Get ahead with our **Light and Building Forecast**, previewing innovations, technologies, and design trends for the March 2024 event. Explore tools enhancing **Life Cycle Assessment** processes for luminaires, promoting **sustainability**. Join us in celebrating excellence as we unveil the **LpS Digital Award** winners. Dive into a **Project Use Case Article**, spotlighting **free-form optics'** latest innovations. Our **Global Lighting Report** offers comprehensive market, energy, and cost insights. Lastly, stay updated on the Latest **LED Innovations** for the **Automotive market**. Illuminate your industry understanding with this diverse array of topics.

Questions and Comments

Please don't hesitate to send us your opinions or ask questions about articles you have read. We appreciate your feedback.
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Institute for Innovation & Technology
Moosmahdstrasse 30, A-6850 Dornbirn, Austria, Europe
info@lugerresearch.com | www.lugerresearch.com
P +43 5572 394489 | F +43 5572 394489 90

Publisher
Siegfried Luger +43 699 1133 5570 s.luger@lugerresearch.com

Editors
Dr. Günther Sejkora +43 5572 394489 70 editors@led-professional.com

Theresa König +43 5572 394489 70 editors@led-professional.com

Elio A. Farina +43 5572 394489 70 editors@led-professional.com

Art & Design
Sarah Luger +43 680 2305 445 hallo@moments-of-aha.com

Account Manager
Christine Luger +43 699 1133 5520 c.luger@lugerresearch.com

China, Hong-Kong
Lolo Young +852 9792 2081 lolo@castintl.com

Germany
Armin Wezel +49 30526 891 92 armin@eurokom-media.de

India
Priyanka Rai +91 124 4787331 priyanka.rai@binarysemantics.com

South Korea
Jung-Won Suh +82 2 78 58222 sinsegi@sinsegimedia.info

Taiwan
Leon Chen +886 2 256 81 786-10 Jeon@jkmedia.com.tw

Benelux, France, Ireland, Scandinavia, UK
Zena Coupé +44 1923 85 25 37 zena@expomedia.biz

USA & Canada
Lesley Harmoning +1 218 686 6438 lesley@lhmandco.com

Jill Thibert +1 218 280 2821 jill@lhmandco.com

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