Holland High Tech Roadmap

Lighting

2024 - 2027

Version 2.0 | January 22, 2024 | PUBLIC

Holland High Tech
Global Challenges, Smart Solutions

Visiting address
Winthontlaan 2
3526 KV Utrecht
+31 (0)30 6001 328

Postal address
PO Box 3021
3502 GA Utrecht
The Netherlands

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Authors:
Ronald Maandonks (Signify), Berry Vetjens (TNO), Ingrid Heynderickx (TU/e), Wilbert IJzerman (Signify)

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1.1. Introduction

Today, lighting accounts for about 12% of our global electricity consumption a year. By moving to more energy-efficient LED lighting, we can drop this to 8% by 2030, even while the total number of light points continues to rise. Only by embarking in advanced Solid-State Lighting (SSL) component solutions, by using intelligent lighting systems based on SSL and by using natural daylight as an integral part of these intelligent lighting systems, will we be able to cope with this demand and reduce the energy use further. Next to its impact on energy efficiency, the transition to SSL has enabled much more efficient use of scarce materials (e.g. rare earth in fluorescent). Further research must enable innovative technologies, modular designs, and business models to implement cradle-to-cradle product chains in the Lighting industry.

With the advent of the 24/7 economy, human activity is no longer limited to the daytime. By mimicking daylight and (individually) tuning light spectra and the light distribution, we can better address perceptual, psychological, and biological needs, and as such create more healthful and effective illumination conditions. Such human centric lighting will positively impact people's health, well-being, and performance. Light can also play an important role to fight virus outbreak, reduce bacteria and mold growth. In the last decades, plant factory (or vertical farm) technology has been introduced for growing vegetables and soft fruits. With a well-controlled environment, new health benefits, food safety, optimized nutrients and increased shelf-life can be offered to consumers.

Lighting is increasingly becoming connected, both the lighting system itself and in connection with other systems in the built environment. Its ubiquitous presence offers the perfect infrastructure for internet access anytime, anywhere. Currently, lighting is an integral part of the Internet of Things (IoT), enabling inclusive, innovative, and reflective societies which will further unlock the added value of lighting beyond illumination.

1.2. Societal challenges addressed in this roadmap

The innovations in lighting will contribute to each of the following KIAs (Kennis en Innovatie Agenda's/Knowledge and Innovation Agendas):

KIA Energietransitie en Duurzaamheid / Energy Transition and Sustainability

Developments in SSL technology still allow the energy usage of current state-of-the-art LED lighting to be reduced significantly. In a second phase, SMARTification will further drive the energy consumption down by selectively switching off the lighting without compromising performance. To make circular economy for lighting come through new technical interfaces that affordably allow easy maintenance and upgradeability as well as new business models that support circular models and reuse of products, components and used materials need to be developed. In addition, additive manufacturing will help to build circular products by reusing printed material and reduce transportation by allowing economically affordable local manufacturing.

KIA Gezondheid & Zorg / Health & Care

Large-scale migration to cities, increased time spent indoors, and our 24-hour economy have impacted our light exposure. Such aberrant, unnatural light dark cycles impact human physiology and functioning and can result in sleep, mood, and circadian rhythm disturbances, in fatigue and cognitive failure, and they even may aggravate certain cancer pathologies. With light for health & wellbeing lives can be improved: e.g. human-centric lighting in indoor environments where people work together, like offices, schools, factories etc., may help prevent or relieve burnout and mood and anxiety related ill-being and disorders; patients recover faster in hospitals and psychiatric care with the right light and health related cost can be reduced; improved light settings at home can help to relax.

Due to the global Covid-19 pandemic, the interest in disinfection with light has increased significantly. Using UV-C and far-UV viruses in air and on surfaces can be reduced significantly. UVB can be used to increase the vitamin D levels that have a positive impact on the immune system.

Finally, we remark that light pollution has also impact on the life and health of people, plants and animals. Solutions to reduce this pollution are in scope.

KIA Landbouw, Water en Voedsel / Agriculture, Water and Food

With light for Horticulture, animal farming and vertical farming (also known as indoor farming) the quality and quantity of products and the health of animals can be improved, while at the same time the usage of pesticides, water and fertilizers can be decreased. In the case of vertical farming water usage is reduced more than 90 % compared to open field production. This is a strong contribution to a solution for the worldwide food challenge. Vertical farming will also result in local production, shorter food chains, fresher products, higher shelf-life, less waste, and less transport, generating additional environmental benefits.

KIA Veiligheid / Safety

Lighting plays a crucial role to improve road safety and the perception of safety in the street. Using innovations in light spectrum and distribution, these safety aspects can be further enhanced, while safeguarding plant and animal ecology. New optical solutions will reduce light pollution and improve wildlife due to special light that does not disturb certain species. Moreover, lighting can be used for proactive crowd management to enhance safety and security in large scale public environments and events. Finally, lighting can be used for communication (Light Fidelity) in high bandwidth and high-security applications which is more cost effective than wired solutions.

1.3. World-wide market for this roadmap, now and in 2025

The global LED lighting market is projected to grow from $85.02 billion in 2022 to $264.08 billion by 2029, at a CAGR of 17.6% during this period, https://www.fortunebusinessinsights.com/led-lighting-market-106832. While LEDs accounted for more than 85% of the turnover of the leading lighting companies in 2022, this transformation will be quickly followed by the introduction of IoT based, connected, lighting solutions and LiFi (Light Fidelity) solutions.

1.4. Competitive position of the NL ecosystem (market and know-how)

The Netherlands has a unique position of strength in the lighting market. The largest global player in lighting is based in the Netherlands, its 2022 turnover equaling more than 200% of the second global player. Signify (formerly Philips Lighting) is the world leader in lighting products and services with a market share of around 10% and the only global player in both professional and consumer luminaires. Next to this around 350 SMEs, e.g. lighting designers, installers, distributors and shops, active in the lighting domain are registered with the Dutch Chamber of Commerce, while a substantial knowledge base in solid state technology, optics, embedded software and lighting is found with academia and research institutes, opening access to all competences needed for the future. By becoming the motor of intelligent lighting, the Dutch lighting ecosystem will be able to consolidate its number one position in lighting, both in terms of economic growth and of employment, despite the advent of Asian players that are currently driving the cost roadmap of LEDs and LED retrofit lamps. Because the Dutch government owns a substantial part of the lighting infrastructure, i.e.: outdoor lighting and public buildings, it is in a perfect position to take the lead in the validation of the R&D results under real life conditions.

The research in this roadmap has links to several other Holland High Tech roadmaps: semiconductor equipment, photonics and electronics and some activities have touch-points with other top sectors (e.g. Top sector Chemistry and Top sector Agri & Food for photochemistry and horticulture).

The activities in this roadmap have some links to a number of current Nationaal Groeifonds/National Growthfund (NGF) programmes. There is some commonality to the development of free shape optical communications in the NXTGEN Hightech NGF programme for LiFi technology as well as the development of optical chips in the PhotonDelta NGF. We also participate in the NGF programme Luchtvaart in Transitie (LIT) with LiFI in airplanes and in the NGF programme 6G Future Network Services (FNS).

The optical technologies mentioned in this roadmap relate to the prioritized technology Optical Systems and Integrated Photonics as defined in the Dutch National Technology Strategy.

2. Technology roadmap

The Lighting technology roadmap consists of four main directions:

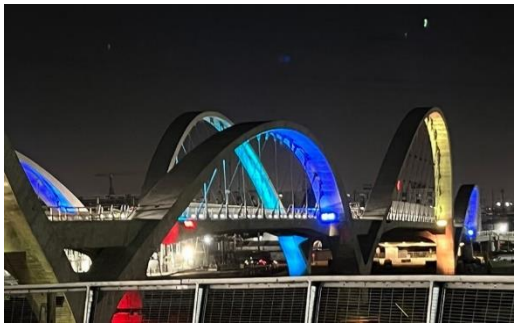
- Lighting applications: the application of light.
- Lighting technology: the technology behind light sources and luminaires.
- Sensing and Connectivity technology: the sensor and connectivity technology used in lighting systems.
- Artificial intelligence and industry 5.0: methods used to improve the design and manufacturing of lighting products and services.

2.1. Lighting applications

Light plays a crucial role in many aspects of society. It can influence humans, visually and non-visually, plants and animals.

- *Effect on humans*: Next to the image forming effect of light via the eye, there are also a non-image forming effects, such as circadian entrainment, alerting and vitalizing effects. These non-image forming effects have been established as crucially important for mental and physical health. Yet much more insight is needed, before these can be implemented in intelligent, personalized, and/or human-centric systems and services. But also new challenges in visual, image forming aspects of light have shown up: visual performance, visual comfort (glare) and light sensitivity have gained in relevance with the introduction and large-scale implementation of new light sources and requirements for high light levels for non-image forming effects.

  Human-centric lighting is enabled by smaller sized light sources, fast switching of these light sources and new spectra, all allowing the industry to make light that supports biorhythms, improves concentration, is visually more pleasing and has other health effects. The impact of certain wavelengths on hormone levels (for humans and animals) and its relation to the health and effectiveness of the immune system needs further research.



The Sixth Street Viaduct in Los Angeles known as 'The Ribbon of Light,' has transformed the urban landscape and become an inspiring iconic landmark.

The largest vertical farm in the world in Bustanica, Dubai, ensures the cultivation of hygienic and tasty food using 96% less water than conventional agriculture.

- *Effect on Animals*: For animals, tuneable lighting can offer improved animal wellbeing in combination with more efficient feed conversion. To understand these relations more investigations are needed.

- *Effect on Plants*: In horticulture, lighting concepts allow a vertical farm that guarantees quantity and quality of production of fresh vegetables every day of the year, completely independent of weather, climate change, or location on earth (urban versus rural area, arctic versus tropical climates). Taste, aroma, appearance, shelf life, and nutritional value can be substantially improved (>20% improvement of the most relevant quality parameters), while there is no pesticide use, no nutrient emission, only 2-4 litres water used per kg product, at least twentyfold less land usage, and less energy usage than greenhouse production per unit product. Light is essential to produce food and essential for the quality of the crop. Achieving a successful production of vegetables from a vertical farm cannot be achieved without a smart way of using light.

- *Other*: For disinfection new applications are possible with the recent advancement in sources, optical components (filters) and other technologies (disinfection robots e.g.). More insight, however, is needed to underpin the application, safety, and effectiveness of different wavelength regimes (405nm, UV-B, UV-C, far UV) in relation to disinfection. Furthermore, we need optical components for these wavelengths and ways to solve the related material degradation challenges.

Finally, there are other applications of light that need further investigation, like photochemistry, water purification, etc.

2.2. Lighting technology

The core of the lighting industry products consists of LED lighting. We foresee three main challenges:

- *Efficiency and sustainability*: to further reduce the energy usage of artificial lighting, there is a need to develop high efficacy and low standby power for lamps, spots, and luminaires, e.g., based on high frequency drivers that combine good dimmability and compatibility with the available electronic infrastructure in buildings or direct current lighting systems.

  Furthermore, efficient sources and conversion technologies are needed to boost the lm/W performance. Utilization improvements, bringing the light where it is needed and avoid light spill and light pollution can further improve the efficiency. This can be achieved with advanced optical solutions and simulation tools.

  In addition, to reduce the footprint of lighting products research on the usage of bio-based, bio-degradable, and recycled materials (plastics, metals, etc.) is needed to understand the impact on product architecture and business models. In addition, alternative solutions for PCBs, like printed electronics, and alternative electronic components need to be investigated.

- *New architecture and new products*: the introduction of new types of light sources has traditionally resulted in new products. The potential contenders of LED are laser and OLED. Research is needed to improve these sources, their efficacy, color rendering and cost as well as to understand where these sources are optimally used.

  3D printing technology will allow the creation of low volume products and new printing technologies for plastics, metals, and ceramics among others will allow the creation of new products. 3D printing can also allow optics to be printed, allowing for a tailormade luminaire business.

- *New features, product quality and lifetime*: to create new features, new optical solutions and optical components (a.o., GRIN lenses, metalenses) are needed to improve color mixing and create low glare solutions and allow beam steering. To allow further miniaturization and to allow high power lighting, solutions for thermal management are needed. For high-efficacy and miniaturization, also new electronic components are needed based on, for example GaN, new battery technology and solar components. In addition, new features as disinfection, horticulture, data communication and health require the need to develop new LEDs for special lighting (i.e., UV, infra-red).

  The reliability models for electronic components and LEDs need updates to underpin the lifetime claims made in the lighting industry.

Innovative full colored bulb based on a lightguide for high quality color and white.

The city Tampere in Finland has the aspiration to become the most sustainable city. They have opted for a wireless gigabit network in their luminaires.

2.3. Sensing and Connectivity technology

Both in the consumer and in the professional space connected lighting systems are on the rise and the added value of such IoT systems is ever more appreciated. To create these connected lighting systems that harvest data, the lighting industry needs access to sensor technology that is cost-effective, reliable and application specific while being safe and secure at the same time.

The technology challenges that we see are focused on connectivity, cloud, security, and sensing:

- *Connectivity*: more and more RF spectrum or radios are shared between different protocols or concurrently running applications. E.g., connected lamps needs to be controllable by a mobile app, while at the same time need to download new firmware or sense whether someone is present in the room. Scheduling techniques are needed for optimal performance.

- *Cloud*: a topic of investigation where the services and signal processing take place, in the cloud or edge. Further cloud integration is to be foreseen as well.

- *Security*: optimally secured systems are typically hard to install and manage over time; trade-offs between security and user-friendliness need to be analysed and tested. Existing security software is often not usable due to low memory and low processing capabilities of lighting devices. Software needs to be developed to fit in resource-constrained devices.

- *Sensing*: the most information can be extracted from a space when using very granular sensors (e.g. in every lamp/luminaire) and very frequent readouts (e.g. every second). However, very often this is not feasible due to the limited (wireless) bandwidth available, the limited range of the wireless technology, the cost of sending large amounts of data to the internet, or not desired in view of privacy. Low-cost sensing hardware creates noisy signals, and signal processing technology or ML algorithms need to be developed to turn raw data into actionable information.

  Artificial intelligence and machine-learning strategies will need to be harnessed to create personalized services, e.g. for healthy light exposure, navigation, and safety purposes. Practical local (edge) data acquisition, processing and management need to be developed such that the real-time requirements of (lighting) applications can be satisfied, as well as the security and privacy requirements. Next to that, sensors are often battery-powered, and battery lifetime and technology is also a key trade-off to consider when designing sensor readout frequencies. A relatively recent and straightforward method of sensing involves detecting interference from signals used for communication between various devices, such as WIFI or Zigbee signals. Given the high noise levels in these signals, detection is challenging. Therefore, the development of new AI-based algorithms is essential to develop solutions suitable for critical applications, such as monitoring the elderly and detecting falls.

2.4. Artificial intelligence and Industry 5.0

All major professional- and consumer-lighting products and systems are designed, engineered, and manufactured with software tools. To improve these tasks and to create new value there is a need for:

- Creation of Digital Twins for new Products and Manufacturing processes: new product architectures will be based on modularity allowing of highly customizable luminaries and systems for office, retail, and home environment. This might result in fully automated novel workflows.

- Customer interaction platforms (i.e. AR, VR): The Digital Twins will allow the creation of rendering algorithms that allow visualization of the products to customers. Combined with 3D printing technologies, this will allow maximum flexibility.
- New algorithms to design optical, mechanical, thermal, and electrical components and modules are needed to improve engineering efficiency. Machine learning, artificial intelligence (e.g. deep learning algorithms) will allow this.

3. Priorities and implementation

3.1. Priorities of this roadmap in public-private partnerships and ecosystems

In the recent years, fruitful collaborations in the Dutch lighting innovation ecosystem were initiated, resulting in many collaborations established in public-private partnership projects like (not exhaustive):

- European Training Network Marie Skłodowska-Curie projects: LightCap, ArcInTex, VisIoN, ROMSOC, ENLIGHTEM and MIRELAI.
- NWO TTW Perspectief project: Freeshape Scattering Optics and OPTILIGHT TKI HTSM Phase space ray tracing.
- TKI HTSM Intellight/Eindhoven Engine Intellight+ and Mini-Impuls program.
- European Horizon 2020/Horizon Europe project OpenAIS, InScope, IOF2020, SpotLight, 1D-Neon, SynchroniCity, Create-IOT, ELIOT, DIMAP, Ecotron and PhotoLED.
- European Joint Undertaking Artemis/ECSEL/KDT program: DEWI, SCOTT, Delphi4LED, IoSense, iReL40, DIMAP, Productive4.0, Sustronics, LoLiPoP, PowerizeD, R-Podid, Aims5.0 and ALL2GaN.
- Eureka clusters ITEA/Penta/XECS: GaNEXT, PS-Crimson, Explain, HYBMAN, HyperStripes and Ampere.
- FOM_IPP (Fundamenteel Onderzoek der Materie) on “Improved Solid State Light Sources”.
- Additionally, the H2020 / KIC / EIT Digital projects BrightAgeing, “Elevators & Lighting”, ALIGRE and LumiPark explored the requirements for market introduction of connected lighting applications.

As shown above The Eureka clusters ITEA3 and XECS (formerly known as Penta), as well as the KDT JU (formerly known as ECSEL)– most relevant to HTSM – have experienced prominent Dutch participation in the recent past, including active participation in defining the SRIA (Strategic Research Innovation Agenda). Hence, the Dutch lighting ecosystem wants to continue this extensive collaboration, also with the European players in the lighting field that are established through these projects, with a continuous involvement of the Dutch SMEs, widening the scope to also include systems and services.

3.2. Linkage with other innovation instruments, such as public purchasing and risk investment

Currently, LEDs are rapidly entering the market as replacement for less efficient conventional (e.g. incandescent or fluorescent) lamps (either as retrofit lamps or as new modules). The potential of digital and connected lighting has recently started to be addressed, with the extremely successful Philips HUE proposition (connected lighting for the consumer space) as an example.

Public authorities, owning a substantial fraction of the existing indoor and outdoor lighting infrastructure, can speed up the uptake of digital lighting in the Dutch market as a launching customer and through innovative purchasing. Public authorities will benefit from the additional savings offered by combining LED technology with controls, while the industry will be able to optimize its offer much faster based on the feedback obtained from the launching customer.

3.3. Collaboration in and leverage with European and multi-national policies and programs

This roadmap is closely linked with the European roadmap put together by the Photonics21 European Technology Platform in close cooperation with Lighting Europe. Signify is very active in the work group dealing with “Climate, Mobility and Energy” (working group 4). Experts from TNO, Holst Centre and Signify were deeply involved in editing of the latter roadmap in collaboration with the relevant European players from academia, research industry, start-ups, SMEs and large industry.

Through this Photonics21 innovation roadmap we do align with and define the Photonics PPP work programmes in Horizon 2020, and by mobilizing the lighting ecosystem it enables us to contribute substantially to several of the Key Enabling Technologies (KET).

4. Partners and process

4.1. Process followed in creating and maintaining this roadmap (with role of SME)

Signify (being a global market leader in lighting solutions) has led the process to come to this updated Holland High Tech Lighting roadmap document for the Netherlands in close cooperation with the Intelligent Lighting Institute of Eindhoven University of Technology and other stakeholders in the ecosystem. It reflects input gathered from various sources and includes inspiration from contacts with universities and knowledge institutes as well as industry.

On Monday 21 November 2022, the Intelligent Lighting Institute (ILI) organized a public outreach event with participants of different stakeholders which was held at the Conference Center Eindhoven. The different program lines of ILI have presented their running research activities and have shared their vision on trends and new directions relevant for the Lighting research and industry in the Netherlands. The participants contributed with new ideas in parallel sessions by brainstorming. This event was well attended by nearly 120 interested participants. The discussions in this workshop have been used as input material for this roadmap. A summary of the participating organisations and companies in this workshop is shown below:

Academia	Radboud University, University of Groningen, Eindhoven University of Technology, Delft University of Technology, Maastricht University, University Medical Center Groningen, Leiden University, University of Twente, Utrecht University, University of Amsterdam, Tilburg University, Wageningen University & Research
Institutes	AMOLF, DIMES, TNO-ESI, Holst Centre, ILI, M2i, MESA+, TNO-Snellius, TNO-B&O, TNO-D&V, TNO-I&T, TNO-ICT, VSL, Waag Society, Dekra, DPI
Industry	Applied Micro Electronics AME, Avantes, BESI-Fico, BIC Industries, Boschman Technologies, Cofely GDF Suez, DCD, Deerns, DevLab, EagleVision, Etap, Foreverlamp, Havells Sylvania, Innolumis, I-NRG, LED expert, LedNed, Lemnis, Lightronics, LuxLab, Machine Fabriek Otto Schouten, MARAS, Massive, Mat-Tech, Metatronics, Nederlandse Licht Associatie (NLA), Noldus, NXP, OCE Technologies, OTB Solar, Paleco, PeerPlus, Philips, Plugwise, Quintor, Rena Electronica, Scheuten Solar, Seher, Somfy, Tass, Trilux, Vinotion, Wittenburg, Y'All Solutions

5. Investments

Source	Total (M€ p.a.)	Already committed (M€ p.a.)	To be mobilized (M€ p.a.)
Private resources	4	3	1
PPS surcharge	0,5		0,5
TO2 resources	0		0
NWO	2		2
Universities and Universities of applied sciences	2		2
Regional resources (province, municipality)	0		0
National government resources	2		2
EU funds	3		3
Dutch regional development agencies (ROMs) and InvestNL	0		0
Other	0		0
Total amount (M€ p.a.)	**13,5**	**3,0**	**10,5**

R&D in public-private partnership, including contract research; all figures in million euro cash flow per year (cash plus in-kind contribution)