Photonics, the kernel of light
in the environmental transition

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***Abstract*:**
Photonics, the kernel of light in the environmental transition, is reinventing our lives: smart, sustainable cities (the production of renewable energy and optimization of energy consumption, above all in telecommunications), factories of the future (precise and cleaner processes consuming fewer raw materials), etc. Photonic inventions (such as enhanced virtual reality and optical sensors) push in the same direction — toward the production of ecofriendly products in environmentally friendly factories. However they might prove to be disruptive as individualized production methods replace mass production.

Photonics refers to the technology for generating, emitting, transmitting, modulating, amplifying, and detecting a part or all of a light signal.[1] To simplify, it can be separated into three major components: the light bearing colors and hues (*i.e.*, images and thus our perception of reality); the light conveying (original?) energy of which the forms and signals can be modulated; and the light transmitting a force that, if controlled, can be used to interact with matter (modulate, assemble or destroy it), such as lasers for medical care or 3D-printing. In other words, photonics has penetrated all aspects of our lives. Since 2009, the European Commission has backed this science not just as a key technology but as *"the key enabling technology*",[2] owing to its potential for innovations, for responding to current challenges in our society.[3]

Light as such — the original, fundamental form of energy in our universe — is closely related to sustainable development.[4] After all, what makes less pollution than light? What is more precise than a photon? Photonic innovations provide solutions for producing energy from renewable sources and reducing energy consumption, in particular the energy guzzled by the storage of data by information and communication technology (henceforth ICT). Based on a network of optical fibers and sensors for detecting environmental risks or traveling more safely, the "smart" city will be sustainable. The most important link between photonics and the environmental transition is its modification of our tools for design (enhanced reality, virtual simulations) and production (lasers, spectroscopy, sensors). It is not surprising that, in 2008, the growth rate of "green photonics" was estimated at more than 500% over the period from 2008 to 2020.[5]

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[1] Pierre Aigrain's definition of photonics in 1970.
[2] Communication from the European Commission, "A European strategy for Key Enabling Technologies – A bridge to growth and jobs" COM(2012) 341 final, 26 June 2012 available at:
http://ec.europa.eu/transparency/regdoc/rep/1/2012/EN/1-2012-341-EN-F1-1.Pdf.
[3] This article has been translated from French by Noal Mellott (Omaha Beach, France). The translation into English has, with the editor's approval, completed or updated a few references.
[4] According to Gro Harlem Bruntland's definition of sustainable development in 1987.
[5] Berit Wessler & Ursula Tober, "Green Photonics — the role of photonics in sustainable product design", 20 April 2011 available via:
https://www.spiedigitallibrary.org/conference-proceedings-of-spie/8065/806515/Green-photonics-the-role-of-photonics-in-sustainable-product/10.1117/12.882979.full.

Given its societal impact, photonics, along with the environmental and digital transitions, is stimulating a creative, entrepreneurial revival. From thirty to forty startups in this technology are being created each year in the Île-de-France region, which includes Paris. The high-tech cluster Opticsvalley, located in Île-de-France, has the role of boosting these start-ups and identifying the photonic solutions for responding to the challenge of becoming a more sustainable, more connected society.[6] I shall mention some of their products to show how photonics helps us switch toward a more sustainable economic and industrial rationale. The variety of its technological solutions and approaches illustrates quite well how diverse photonics is.

Apart from its technical feats and beyond the expected sectors of depollution and energy production, photonics improves performance in terms of sustainability. In a conventional setting, this improvement is considerable: an energy reduction of 40% (in lighting and ICT).[7] Photonics is, by definition, relevant to lighting, which accounts for an average 7% of a household's energy bill, and from 15% to 35% of a city's. As proposed by the startup EFFILUX,[8] LED and OLED are more efficient sources of a better quality of light, which, when associated with sensors (as Nexperium has done)[9] can be used for an autonomous public lighting system. Echy[10)] offers still other solutions based on natural light in buildings, while Glowee[11] has focused on bioluminescent sources. Cascade[12] works on natural light to help agriculture adapt the spectrum to crop needs and thus reduce inputs while using less space.

Photonics provides solutions for the twofold challenge faced by ICT: increase the bandwidth while reducing both energy consumption and the environmental impact (3% of an energy consumption increasing 40%/year).[(7)] The rollout of optical fiber, beyond its technical performance, will help reduce our carbon footprint during not only production but also use: the electricity consumed to run an office computer will drop from 63 watts to 24 (2.5 times less).[13] This statistic takes into account neither the deployment in data centers of optical connectors such as those made by Fischer,[14] nor Almae's optoelectronic chips[15] nor the expectations from optical computing (as proposed by Lighton)[16] or quantum computers.

The smart city will be photonic. The panoply of solutions will extend to communication systems such as Li-Fi (Oledcomm),[17] the control of pollution (Blue Industry and Science)[18] and risk-management (Leosphere)[19] owing to the improved security from using biometric or heat cameras and from digitizing installations. This panoply also includes: depolluting fluids with light pulses (Agro Hall)[20] or ultraviolet rays (Abiotec),[21] sorting wastes optimally (Uzer)[22] and producing more renewable energy thanks to more efficient photovoltaics (Solems),[23] solar sources (SunR)[24] or biofuels produced by stimulating algae with light. Given the objective for solar energy — 20% of the

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[6] http://www.opticsvalley.org/

[7] I. Weir, G. Archenhold, M. Robinson, M. Williams & P. Hilton, *Photonics Technologies and Markets for a Low Carbon Economy* (Study prepared for the Photonics Unit, DG CONNECT, European Commission under reference SMART 2010/0066) report of 17 February 2012 available via https://publications.europa.eu/en/publication-detail/-/publication/629caf66-7fb2-4593-8e8f-9586d7f60ed2.

[8] http://www.effilux.fr

[9] http://www.nexperium.com

[10] www.echy.fr

[11] www.glowee.eu

[12] http://lprl.org/cascade-light-technologies.php

[13] Jean-Michel Mur "Fibres optiques et développement durable: le FTTO vert", *Photoniques*, 78, pp.20-22, 2015 available at https://www.photoniques.com/articles/photon/pdf/2015/05/photon201578p20.pdf.

[14] www.fischerconnectors.com

[15] www.almae-technologies.com

[16] www.lighton.io

[17] www.oledcom.com

[18] www.blueindustryandscience.com

[19] www.leosphere.com

[20] www.agrohall.fr

[21] www.abiotec.fr

[22] www.uzer.eu

[23] www.solems.com

[24] www.sunr.fr

electricity generated in Europe by 2020 — the challenge is to switch to organic cells and use them in isolated or hard-to-reach areas (Zephyr Solar).[25]

The factory of tomorrow, if factories still exist, will be photonic. Various uses of light will disrupt the chain of production from design to manufacturing. The introduction of advanced manufacturing processes based on spectroscopy, lithography and lasers has brought the precision of light into the action of cutting materials. Photonics helps make gains in energy and raw materials during the production process, and then gains in energy when the products are used (owing to the lighter weight of newly designed products). It is hard to quantify these effects just now, except for 3D-printing (additive manufacturing leads to a gain of more than 90% — compared with less than 35% for standard machine-finishing techniques) and for certain uses (a coating one micron too thick on an aircraft's cabin weighs as much as two passengers) (Enovasense).[26]

Photonics endows us with a new intelligence that results from a broader view of design and monitoring processes. This view results from methods reaching beyond the human spectrum of perception, methods that have drawn inspiration from, for instance, the mantis shrimp or the fly's eye dome. Depending on the type of photonic sensors used, such views can serve: to digitize a product, a piece of equipment, a building, a neighborhood, etc.; to reproduce obsolete products; to make virtual prototypes (Optis);[27] or to make simulations of complicated products and urban facilities. This is the point where the environmental and digital transitions come into an intense interaction. Any surface can be turned into a tablet computer for designing, sharing, co-designing (Adok).[28] Designing products is being affected by these changes in procedures, such as 3D-printing (Pollen AM),[29] which literally makes it possible to manufacture what used to be unthinkable, especially in the field of medicine where "production" can be personalized (and thus made more sustainable) for the patient's well-being.

The intelligence gained from this new view is the very core of the technology for drones, autonomous robots and even the service-providing robots proposed by Eos,[30] which can replace human beings in high-risk operations in difficult or dangerous environments. To further this intelligence, images can be analyzed using the deep-learning of a wide variety of applications (for sorting, maintenance, etc.) and through instant interactions (Scortex).[31]

While upending practices in the phase of product design, photonics optimizes quality control and risk-detection by analyzing gases (MirSense),[32] ingredients (Greentropism)[33] or colors (Seelab),[34] by monitoring infrastructures (Cementys),[35] by performing nondestructive control procedures from any angle (for locating surface defects, etc. Holo3)[36] and even by detecting counterfeits. The advantage of using light for monitoring and control procedures is that the object being examined is not destroyed or altered as when using chemicals.

As for the phase of production, besides the already mentioned additive manufacturing, light serves not only to apply ever thinner coatings via lithography but also to reinforce materials with laser shocks or modify surfaces on a nanometric scale by using ultrabrief lasers (Amplitude).[37] Photonics thus replaces chemicals. It can be used to make smart, multifunctional skin-like surfaces (Manutech).[38] Heat via solid state lighting can modify the making and assembling of composites

[25] http://zephyr.solar/EN/
[26] www.enovasense.com
[27] www.optis-world.com
[28] www.getadok.com
[29] www.pollen.am
[30] www.eos-innovation.fr
[31] www.scortex.io
[32] www.MirSense.com
[33] http://www.greentropism.com
[34] https://seelab-spectro.com/fr/accueil/
[35] www.cementys.com
[36] http://www.holo3.com/
[37] http://www.amplitude-systemes.com/6-t-pulse-duo-double-oscillateur-laser-femtoseconde.html?lang=2
[38] http://www.manutech-usd.fr/

(Uwave).[39] Light can even make materials “grow” via self-assembly (as in nature) or literally help us invent new materials (Silsef).[40] Once again, this approach, which creates *ex nihilo*, tends to use 100% of the materials produced.

These disruptions enable all of us, via “fab labs”, to be designers and manufacturers. This boosts, in turn, the entrepreneurial potential and could disrupt factories based on the manufacturing of a standardized quality. The product singly designed and made on the spot[(5)] could come back and deeply alter our relations with the world of production and of employment under condition that insurance companies propose a coverage for risks and a warranty for the product’s reliability.

Photonics lies at the center not only of the environmental transition (risk detection, savings on raw materials and energy during manufacturing, local production, and a supply of renewables) but also of a societal trend, which is driven by changes in our modes of learning, designing and manufacturing. All this fosters an entrepreneurial spirit and takes issue with the current organization of a mass market and of firms. With photonics, the environmental transition implies human relations and raises questions about the model for society: “The barbarians are coming!”

[39] http://uwave.fr/
[40] http://www.silsef.com/

Table 1: Photonics and sustainable development, a few examples			
For:	***Seeing/ analyzing***	***Transforming/piloting***	***Interacting/ analyzing***
Basic technology	Cameras LIDAR Detection/sensing Enhanced reality Internet of things (IoT)	Photovoltaics Optical fibers LED/OLED Laser Li-Fi	Laser Spectroscopy Detection/sensing IoT
Pollution detection & risk reduction	Imagery Monitoring	Optical fibers	Sensors Monitoring Drones Maintenance
Reduction of energy consumption	Optimization in agriculture	Solid state lighting	Lighter products
especially in ICT	—	ICT Optical fibers Li-Fi Laser Connectors Quantum computers	—
Production of renewables (lighting)	—	Photovoltaics Biofuels Lighting	—
More sustainable phases of design and production (industry)	Quality control Sorting Simulations Screens	Optical components for ICT	Laser processing Additive manufacturing Smart robots Non-destructive controls
Depollution 2.0	—	—	Lasers UVs