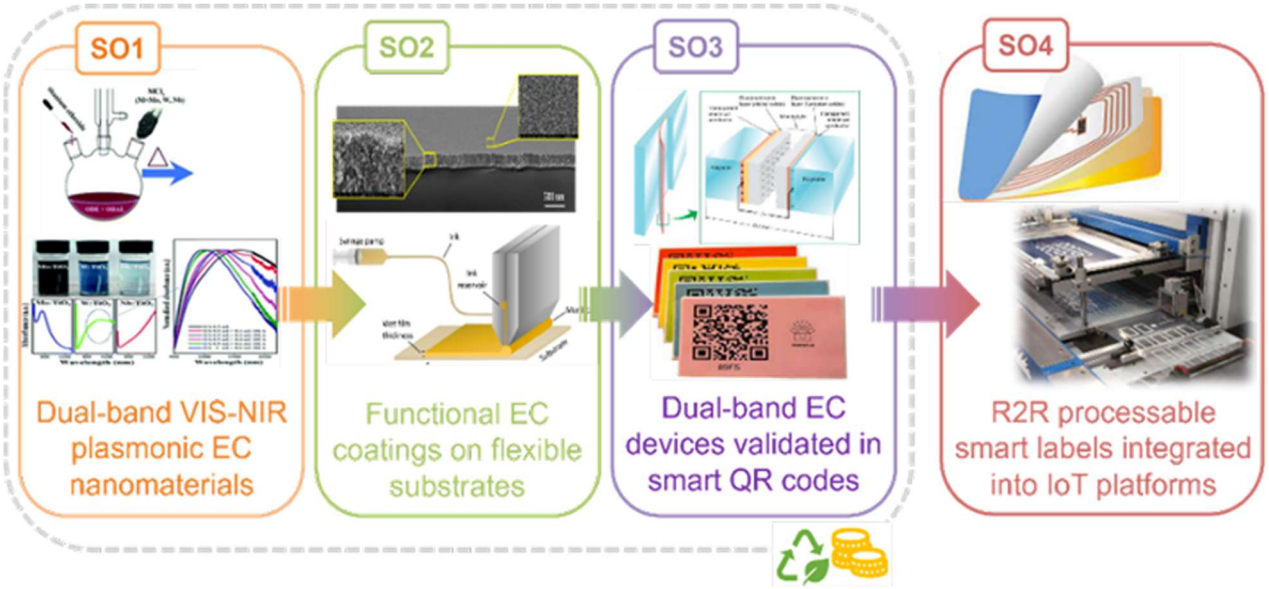
Newsletter #1, May 2026

PECLABEL

Plasmonic ElectroChromic Materials for Dual-Band VIS-NIR Smart LABELing



The PECLABEL project (2023-2026) aims to develop an **innovative technology of smart electrochromic labelling for intelligent packaging** based on **inorganic metal oxide nanomaterials**. PECLABEL relies on strongly innovative and ambitious concepts and approaches, sustaining responsible research, designing and characterising novel functional materials for smart energy- and electronics-related applications. Therefore, PECLABEL builds on a new generation of metal-oxide-based plasmonic nanomaterials for the **conceptual design of VIS-NIR dual-band, spectrally selective electrochromic (EC) display and labelling** materials, surfaces and devices. This first newsletter presents the objectives and methodology of PECLABEL, along with the initial results achieved by the different partners.

Synthesis of plasmonic electrochromic nanostructures

GREEnMat (https://www.greenmat.uliege.be) is a front-edge chemistry research laboratory at the University of Liège, specialising in the development and characterisation of functional inorganic and hybrid materials in the form of powders, bulk materials or coatings, targeting key societal challenges in **energy** (new generation solar cells, Li/Na/K ion batteries; electrochromic materials and devices; etc.), **environment** (recycling of silicon-based PV cells, battery waste and metals scraps; development of photocatalytic oxides for water/air treatment; etc.) and **health** (excipients for dry powder inhalers; osseous and dental implants materials and shaping by additive manufacturing; sweat biosensors; etc.).

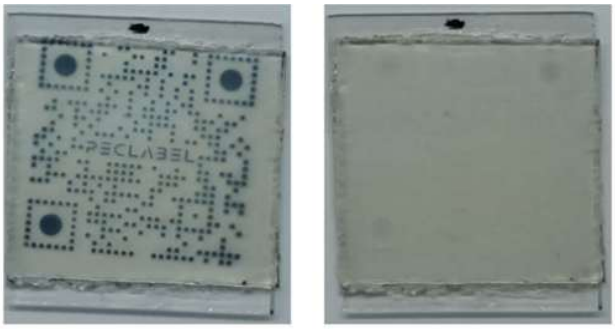
Since 2011, GREEnMat has built strong expertise in **electrochromic coatings and devices**. The laboratory develops a wide range of electrochromic materials based on inorganic metal oxides, including tungsten oxide (WO_3) and nickel oxide (NiO), as well as plasmonic highly doped oxides such as indium tin oxide (ITO), aluminium-doped zinc oxide (AZO), and mixed molybdenum–tungsten oxides ($MoWO_x$). These innovations aim to enable the **dynamic modulation of visible and infrared light**, paving the way for advanced dual-band electrochromic materials and devices.

Within the PECLABEL project, GREEnMat plays a central role by combining project coordination and scientific innovation through the development of dual-band visible–near infrared (VIS–NIR) plasmonic electrochromic nanostructures, bringing complementary expertise in advanced (nano)materials design, synthesis, and multiscale (micro)structural characterisation.

GREEnMat's research focuses on **next-generation electrochromic materials** capable of independently and dynamically regulating visible and infrared light. A key innovation lies in the optimisation of **plasmonic indium tin oxide (ITO) nanoparticles**, acting as infrared-active components, embedded within a **tungsten oxide matrix** responsible for visible light modulation. This dual-band formulation opens new pathways for **selective light and heat management**, a critical lever for energy-efficient buildings and smart optoelectronic technologies.

In parallel, the team has developed **high-performance cerium oxide (CeO_2)-based counter electrodes** using an innovative combination of **ultrasonic spray coating and molybdenum doping.**
[DOI:10.1016/j.solmat.2025.114060]

These formulations demonstrate significantly enhanced charge capacity while preserving high optical transparency. The resulting materials outperform most recent state-of-the-art solutions reported in the literature and exhibit excellent spectral compatibility with dual-band electrochromic layers, enabling the fabrication of **fully integrated, high-efficiency electrochromic smart QR code labelling.**

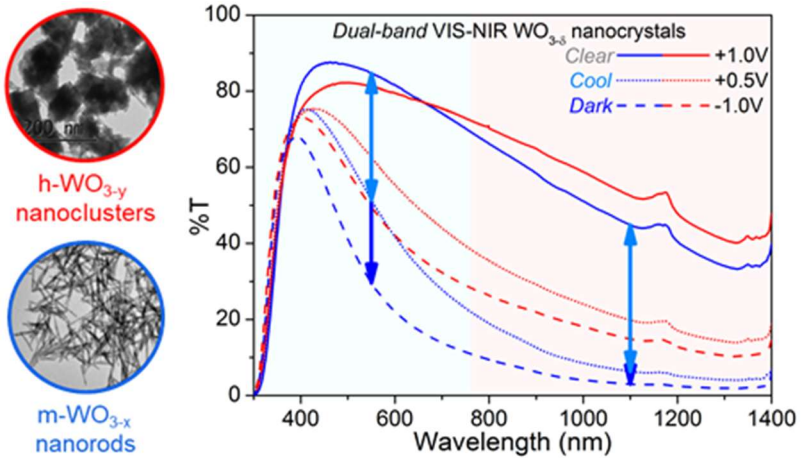


Pictures of a QR code patterned electrochromic labelling device made with tungsten oxide and cerium oxide-based electrodes, in its coloured (left) and bleached (right) states.

Nanostructured films of plasmonic materials and electrochromic devices components

The **ICMCB–CNRS** (https://www.icmcb-bordeaux.cnrs.fr/en/), located in Pessac, France, is a leading joint research institute affiliated with the CNRS, the University of Bordeaux, and Bordeaux INP. The institute specialises in solid-state chemistry, materials science, and chemical processes, with a strong focus on the design, synthesis, and characterization of advanced functional materials for applications in energy, environment, health, electronics, and photonics. ICMCB is internationally recognised for its interdisciplinary approach, effectively bridging fundamental research and technological innovation. More recently, the institute has increasingly integrated data science and artificial intelligence methodologies to accelerate materials discovery and development.

Within this framework, ICMCB is actively involved as a partner in the PECLABEL project and contributes to the development and characterization of electrochromic layers showing **dual-band modulation as single material components. ICMCB has developed novel formulations of sub-stoichiometric tungsten oxide** (WO_{3-x}) using hydrothermal, polyol, and colloidal synthesis methods. In particular, being able to isolate different phases with respect to the structure, composition and morphology, dual-band modulation is reported for monoclinic and novel hexagonal WO_{3-x} phases [DOI: 10.1021/acs.chemmater.5c01714] (Figure below), while NbW_xO_y are synthesised via a hydrothermal route. Successful integration of dual-band single component electrochromic layers in complete device, based on multilayer assembly, investigating in particular CeO_x and Mo-doped CeO_x as counter electrodes and various lithium-based electrolyte mixtures leads to selective modulation in both visible and IR region.



TEM image of the pristine synthesized suspension of sub-stoichiometric tungsten oxide NCs (left).
Transmittance spectra of the m-WO_{3-x} as well as h-WO_{3-y} films at varying applied potentials, showcasing the optical contrasts in cool and dark modes (right).

Dual-Band Smart Electrochromic Labels

Founded in 1906, **LEITAT** (https://leitat.org/en/) is a Spanish Technology Centre whose mission is to collaborate with companies and other entities for the creation of economic, social and sustainable value, through R&D projects and technological processes based on innovation and creativity.

SUNTEC research group gained vast experience in the development of **new materials and technologies for smart photo-electrochemical systems** within a vast range of applications, namely **from electrochromic labels to dynamic switchable windows**. LEITAT team in PECLABEL has a consolidated experience in device engineering and advanced manufacturing processes as well as in the development of electrochromic devices based on plasmonic materials, covering the whole value chain from materials preparation to device assembly and control system integration.

LEITAT has the infrastructure needed to fully characterise films and devices, including physical, chemical, and spectro-electrochemical characterization, also providing several climatic chambers coupled to potentiostat/galvanostat to study the long-term stability under different temperature, relative humidity and illumination conditions.

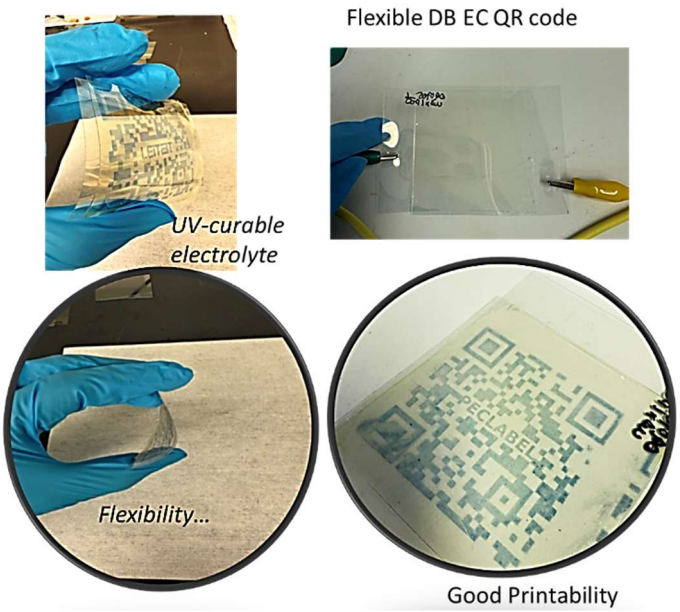
LEITAT approach is based on the implementation of its patented "plasmochromic" technology (https://patents.google.com/patent/WO2021063832A1/en) that enables **spectrally selective electrochromic devices based on plasmonic nanomaterials with synthetically adjustable chromogenic features**. This know-how has been adopted to develop low-temperature, screen-printable dual-band electrochromic inks suitable for flexible substrates.

Key achievements of the PECLABEL project include:

✓ Room-temperature processability for cost-effective manufacturing.

✓ Dual-band Near-Infrared & visible functional switching for controlled readability of QR codes.

✓ Scalability for large-area, flexible applications in smart packaging, security, and IoT.

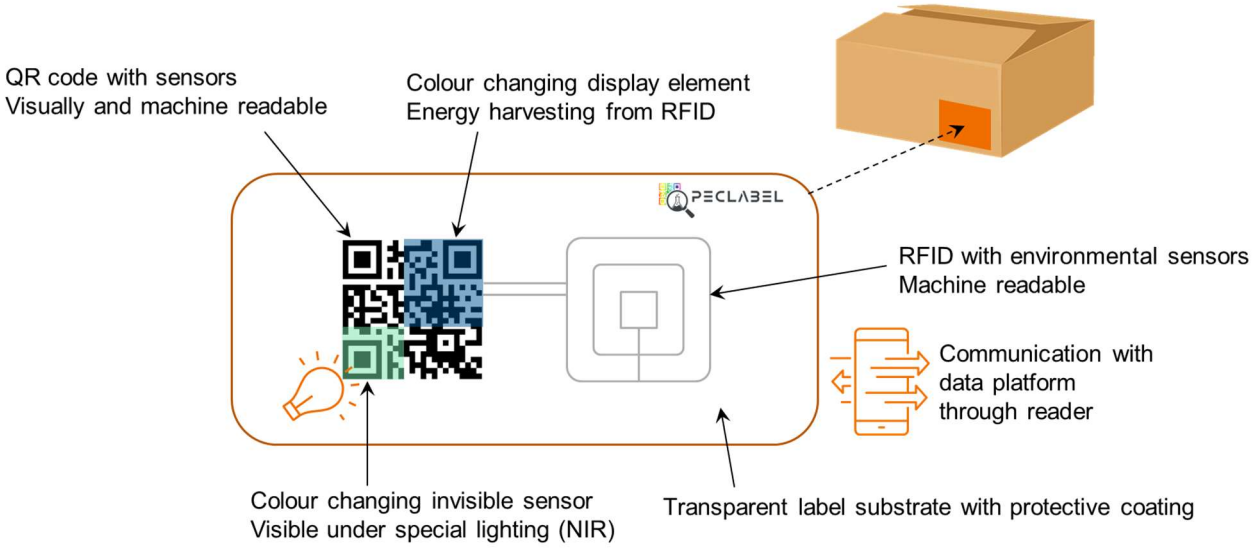


Manufacturing of smart labelling demonstrators with wireless powering

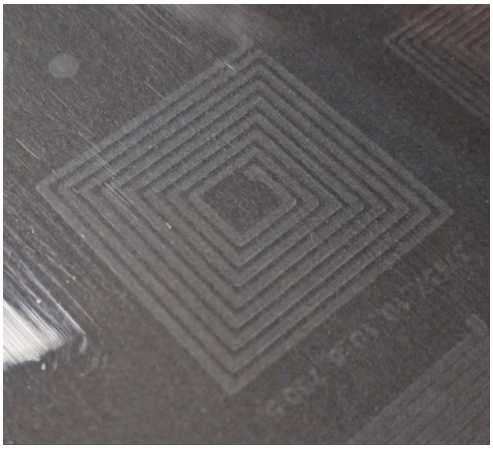
VTT (www.vttresearch.com/en) is one of Europe's leading research institutions with personnel of ca. 2300, and owned by the Finnish state. VTT has developed printed functional solutions for over 20 years with world-class expertise in materials, processing, and integration. VTT possesses a unique R2R pilot manufacturing environment for Printed Intelligence processes enabling development and manufacturing of demonstrators and prototypes on up to industrial scale.

VTT's Sensing Solutions research area designs, develops and integrates **the smart label demonstrator based on R2R (roll-to-roll) compatible manufacturing technologies**, such as printing. VTT is also in charge of testing more **sustainable alternatives for printing materials**, such as bioplastics and regenerated cellulose. Furthermore, VTT leads **stakeholder engagement activities** to gain industrial feedback for demonstrator planning.

PECLABEL demonstrator concept is presented below. It **combines multiple visual and electronic technology elements for a flexible design that can be adapted for multiple end use purposes**.



Eco-design is addressed with **use of bioplastic substrates and decrease in process energy consumption**, specifically by finding **substitutes to ITO-coated PET** that is an essential layer in the PECLABEL concept. Direct R2R printing of **transparent conductive layers** has been investigated to decrease process steps and thus the process energy used and benchmarked against coating and etching based technologies. Experiments to analyse the performance of the material combinations with respect to print quality, electrical performance and optical properties have been carried out on plastic and bioplastic substrates. The results show that a performance, with regards to conductivity and transmission, compatible with ITO-coated PET can be achieved even on a bioplastic substrate using a transparent silver ink.



Industry partners

ColorSensing (https://www.color-sensing.com/en), Spin-off from University of Barcelona, arises as an innovative deep-tech business developing a range of applications such as **digitisation of colour-changing sensors, digital image standardisation or printed chemical-sensing technologies**. *ColorSensing is in charge of the development of a colorimetric model to automatically transform the colour of the developed materials into quantitative data.*

Optitune (https://www.optitune.com/) Oy has developed **ultra-thin nanocoatings for metal, glass and plastic surfaces** based on its proprietary polysiloxane technology. Optitune chemists and engineers are a determined team, intent on pushing the boundaries of possibility in terms of light transmission, surface management, and durability. Optitune's patent-protected product portfolio includes flexible plastic hard coats, metal and glass coatings, light management, and optoelectronic materials. The nano-engineered optical coatings are developed and produced at Optitune's facility in Oulu, Finland. Optitune's sales team is located in Asia and Europe. *Optitune is in charge of the development of coating materials and processes to improve efficiency and stabilise device performance and lifetime.*

Founded in Finland in 1986, **NordicId** (https://www.nordicid.com/) has been Europe's leading provider for **item tracking and tracing solutions** for over 30 years, serving customers worldwide. Since 2021, it has been a part of BRADY Corporation. *NordicID offers devices and software platform to collect data, from RFID/NFC based smart labels.*

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PECLABEL in conferences and publications

Gillissen, F., Colson, P., Spronck, G., Maho, A., Cloots, R., & Dewalque, J. (2026). *Development of molybdenum doped cerium oxide passive counter electrodes by surfactant-assisted ultrasonic spray pyrolysis.* Solar Energy Materials and Solar Cells, 296, 114060. doi:10.1016/j.solmat.2025.114060.

Gillissen, F., Deonikar, V., Spronck, G., Colson, P., Cloots, R., & Dewalque, J. (October 2025). *Dual-band electrochromic coatings for energy-efficient smart windows : Dynamic control of light and heat* [Oral presentation]. Nanotechnology Crossing Borders 2025, Geleen, Netherlands.

Deonikar, V., Gillissen, F., Spronck, G., Cloots, R., Colson, P., & Dewalque, J. (April 2025*). Development of Dual-Band VIS-NIR Electrochromic Materials Based on Plasmonic Metal Oxides and Their Formulations* [Oral presentation]. 2025 MRS Spring Meeting, Seattle, USA.

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Nayak, Suraj S; Sadashivamurthy, Nithin; Labrugère-Sarroste, Christine; Duttine, Mathieu; Maho, Anthony; Rougier, Aline (2025). *Selective Colloidal Synthesis of Hexagonal and Monoclinic Substoichiometric Tunsgten Oxide Nanocrystals as Dual Band Electrochromic Materials*, Chemistry of materials., 2025, Vol.37(21), p.8764-8774; doi: 10.1021/acs.chemmater.5c01714

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S Nayak, N Sadashivamurthy, A Maho, A Rougier (2024). *Posters Award - Synthetic tuning and film processing of plasmonic WO3-x nanostructures as dual band VIS-NIR electrochromic materials.* 15th International Meeting on Electrochromism-IME15, 2024.

Liisa Hakola. (2025) *Sustainable printed smart labels enabled by electrochromic display elements.* MRS Spring Meeting 2025, Seattle, USA. Invited talk.

Liisa Hakola, Elina Hakola, Henrik Sandberg, Maria Smolander. (2026) *The importance of sustainable approaches in technical feasibility and market potential of a smart label concept.* LOPEC 2026: International Exhibition and Conference for Flexible, Organic and Printed Electronics, Munich, Germany. Poster.

Funding organisations

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