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"PNRR MUR - M4C2 – NEST - Extended Partnership Network 4 Energy Sustainable Transition"

SPOKE N. 4

CUP D33C22001330002

Research proposal

Innovation for green hydrogen production from biomass

PER2H – Development of High Entropy Perovskite Oxide-Based Photocatalysts for Green Hydrogen Production from Biomass

- Università degli Studi di Pavia
- Lorenzo Malavasi, Andrea Speltini
- Proposal duration in months: 12

ROLE IN THE PROJECT	*NAME*	*SURNAME*	*INSTITUTION/ DEPARTMENT*	*QUALIFICATION*	*YOUNG (under 40 al 31.12.2023)*	*F/M*
Principal Investigator (PI)	*Lorenzo*	*Malavasi*	*University of Pavia/Chemistry*	*Full Professor*		*M*
Co-Principal Investigator (co-PI)	*Andrea*	*Speltini*	*University of Pavia/Chemistry*	*Associate Professor*	*Yes*	*M*
Investigator	*Costanza*	*Tedesco*	*University of Pavia/Chemistry*	*PhD Student*	*Yes*	*F*
Investigator	*Luca*	*Betti*	*University of Pavia/Chemistry*	*PhD Student*	*Yes*	*M*
Investigator	*Francesca*	*Merlo*	*University of Pavia/Chemistry*	*PostDoc*	*Yes*	*F*

ABSTRACT

PER2H project is addressed to develop new photoactive materials with improved efficiency for the solar light-driven photocatalytic production of hydrogen gas from biomass in aqueous solution, to meet the increasing demand for massive clean H_2 production. This will be achieved by new heterojunctions, simply and quickly prepared by spray-pyrolysis coupling P25 titanium dioxide and g-C_3N_4 with high-entropy perovskite oxides (HEPOs), namely La(B)O_3 (B=Ni, Fe, Mn, Co, Zn). The composites will benefit from the high oxidation capability of titania combined with the enlarged visible light absorption and longer lifetime of the charge carriers involved by the coupling with the HEPOs. Similarly, HEPOs composites with graphitic carbon nitride, which will be synthesized in laboratory by a consolidated route from low-cost precursors (i.e., dicyandiamide), will be prepared. All materials will undergo full characterization by several techniques XRD, HR-SEM, XRF, TGA, BET, Uv-VIS and PL spectroscopies. After a preliminary screening of the catalytic activity of the hybrid semiconductors under simulated solar light, evaluated based on the H_2 evolution from glucose aqueous solution, the work will be devoted to develop new photocatalytic systems directly in food industry wastewater, i.e., from beer and rice production. An investigation on the operational factors involved in the photocatalytic process will be studied to maximize H_2 production under sustainable conditions, that is using waste biomass, under natural sunlight. A prototype lab-scale photoreactor will be set up for continuous H_2 production using the best performing heterojunction, which will be directly immobilized by spray-pyrolysis onto glass supports for a facile catalyst recovery and recycling, further improving the sustainability of the process.

RESEARCH PROPOSAL

Section a. State-of-the-art and objectives

Nowadays, the increasing global crisis of energy shortage and environmental issues are becoming serious threats to the long-term development of human society. Governments and scientists are trying to find out green technologies to address such concerns. Among the potential solutions, semiconductor-based photocatalysis has emerged predominantly as it is considered a costless, renewable, clean, and safe technology, which requires only the inexhaustible solar light as a driving force, and a suitable semiconductor as a photocatalyst to conduct catalytic reactions for a variety of applications, including H_2 production from water.[1] H_2 is an appealing storable energy source because its conversion in fuel cells efficiently generates energy, releasing water as the only by-product. To date, most of the produced H_2 derives from natural gas through steam-methane reforming, and only ~ 5% is obtained from renewable resources, mostly via water electrolysis. However, producing H_2 from natural gas poses some concerns like the restricted availability of fossil fuels and large amount of released CO_2. In light of this scenario, the development of innovative procedures both to produce H_2 from renewable materials, such as biomass and water, and to store the same fuel in a safe and efficient way in cheap and convenient materials, is strongly required and constitutes hot research topics. With reference to the photocatalytic route for hydrogen gas retrieving, presently the keywords are greenness, safety, renewability, efficiency, circular economy and sustainability. Of course, combining all these aspects really represents the big challenge the scientific community still faces, but, at the same time, it is highly exciting and inspiring for researchers. Many semiconductors have been identified as potential photocatalysts under UV or visible light, such as ZnO, CdS, TiO_2, SnO_2, $BiVO_4$, Cu_2O, Fe_2O_3 etc., and more recently also organic materials as graphitic carbon nitride, and perovskites.[2–6] Among these, TiO_2 is still used as the benchmark due to its chemical stability, low cost and non-toxicity. However, a serious drawback of all those photocatalysts is the low efficiency caused by the fast recombination of the charge carriers. Improving charge carriers separation is thus the **first key point**, and a way is to develop semiconductor composites that assure the opposite migration of electrons and holes by conduction-band (CB) and valence-band (VB) offsets. Strategies to improve charge carrier dynamics most employed to date are: rational design of heterojunctions; deposition of co-catalysts (e.g. noble metals) onto the catalytic surface (favouring also the surface reaction by reducing the activation energy); and control over particle size to shorten the diffusion pathway of the charge carriers.[2–4,7,8] A **second key point** for a more rewarding and sustainable photocatalysis is to shift light absorption to the visible region. As a matter of fact, regardless of the advances achieved on titania-based photocatalysis for solar energy conversion, the practical application of TiO_2 is drastically limited because of the poor harvesting of natural sunlight. In fact, TiO_2 absorbs mainly the UV component of solar light (< 387 nm), that represents only 4-5% of the solar radiation spectrum. Finally, relating to H_2 evolution from water, several photocatalytic systems have been improved by addition of organic additives as the sacrificial agents that, undergoing oxidation, are able to enhance water reduction to give gas phase H_2. In this context, the **third key point** for a sustainable photocatalysis is the reuse of waste biomass. Beside fine chemicals such as triethanolamine, glycerol, alcohols etc., also insoluble polysaccharides and industrial wastewaters rich in organic sacrificial matter were proved (also by present PI and co-PI) to be applicable for this purpose.[9–14] Considering the actual state-of-the-art, it is clear that **a fundamental caveat for a concrete development of all these technologies is still related to materials characteristics enabling photoreactions.** In the past 12 years, the proponents focused their research on sustainable systems and innovative photocatalysts for H_2 production. Among other results, we provided a series of novel stable perovskites with high visible-light absorption which have been used for hydrogen photogeneration both from water and biomasses and whose properties have been enhanced through the creation of suitable heterojunctions with g-C_3N_4.[5,6,12,13] Carbon nitride was also important object of the members of the present project in terms of modulation of its properties through chemical modification and rationalization of photocatalytic properties.[15–17]

Aim of **PER2H project is to develop new photoactive materials with improved efficiency for the solar light-driven photocatalytic production of hydrogen gas from biomass substrates, to meet the demand for massive clean H_2 production.** Photocatalysis is indeed a viable alternative to the high energyconsuming approaches as the thermochemical, electrochemical and biochemical ones, thus it deserves much more investigation. In this respect, the project will exploit the use of innovative High Entropy Perovskite Oxides (HEPO) photocatalysts as highly efficient and light-absorbing materials for hydrogen photogeneration. Nanometric HEPOs, characterized by structural heterogeneity and cation diversity, show promise in a wide range of applications. They demonstrate catalytic capabilities in complex chemical reactions, serve as energy storage devices for lithium-ion battery systems, and contribute to advances in fuel cell technologies. The focus on oxygen vacancies is crucial in this context, as these defects, which result from a lack of oxygen atoms, significantly influence the electronic and catalytic properties of the materials. Harnessing and controlling these defects can improve system performance, particularly in photocatalysis. The high entropy of nanometric perovskite oxides is particularly advantageous, giving the material considerable flexibility in both physical and chemical properties. The formation of a heterojunction with HEPOs is a particularly fascinating and under-explored area of research. The nanomorphology allows close contact and homogeneous integration of the perovskite into the heterojunction. In addition, the oxygen vacancies resulting from the chemical structure would act as active sites for photocatalysis. Creating a heterojunction with another semiconductor as proposed in this project (namely with TiO_2 and g-C_3N_4), and using these materials, constitute an innovative perspective to enhance the efficiency and stability of the photocatalysis process, overcoming current limitations. Specifically, we will focus on the structural and photocatalytic study of HEPOs with general formula $La_{1-x}A_x(B)O_3$ (B=Ni, Fe, Mn, Co, Zn) and alkaline-earth dopants on the A-site (Ca, Mg and Sr). We aim to correlate the presence of oxygen vacancies with the type and quantity of dopant, investigating both the band alignment and the electronic schema type in the heterojunction. Additionally, the project aims to examine the effect and quantity of vacancies on hydrogen production from biomass solutions. In conclusion, exploring this heterojunction, through the utilization of nanometric HEPOs, represents an advanced, promising, and innovative approach to boost the photocatalytic hydrogen production.

Based on the above considerations, the main objects of the project are:

- Provide innovative photoactive materials based on HEPOs of general formulas $La(B)O_3$ (B=Ni, Fe, Mn, Co, Zn) for H_2 production from aqueous biomass substrates covering a wide light absorption spectrum (from UV to NIR), showing long-lived photogenerated charges (>500 ns), high quantum efficiencies (50%), ease of fabrication, low-cost, and based on earth-abundant elements;
- Fabrication of HEPO-based composites to further improve the catalytic properties and to power the overall reactions involving both oxidation and reduction under visible light illumination. Such composites will see the combination of tailored HEPOs with TiO_2 and g-C_3N_4;
- Manufacture a lab-scale photoreactor with the best performing photocatalysts developed in the project. To validate the proposed technology, a continuous reactor for hydrogen photogeneration will be manufactured (see details in section b)).

The principles of green chemistry and sustainability will guide the experimental work and final objectives of the plan. Indeed, the catalytic composites will be first tested in model biomass derivatives solution, then directly in wastewaters from the agri-food sectors under natural sunlight, with the intention to combine biomass recovery/valorisation with H_2 evolution. Last but not least, a significant advancement of the present project will be the use of supported HEPOs composites, providing an appealing strategy to overcome the main drawbacks of slurry reactors, such as nanoparticle separation from water and toxicity concerns due to their release in the environment. To conclude, **PER2H project spans a TRL from 1 to 4, and has a significant focus in developing novel devices/technologies for effective H_2 photogeneration from biomasses through the development of innovative and efficient catalytic systems.** We believe that the results achieved in the project will have the potential for future exploitation of the results towards the market, in a medium-to-long term vision, providing efficient devices and industry substitutes to fossil fuels. In addition, the solution proposed in the project art stands alone and can provide solar fuels in a decentralized way.

Section b. Methodology

PER2H project is composed of distinct sequential stages, namely the analysis of the technical-scientific aspects involved in the process under study in the framework of the actual knowledges, the development of the proposed innovation, and the experimental testing, evaluation and validation of the proposed solutions, which will be accomplished through the following Work-Packages (WPs). These are reported hereafter together with the expected duration in months (M).

WP1: **Analysis of the state-of-the-art and of the actual technologies/approaches to identify the innovation level of the proposed solution (M01-03)**

In this WP we will perform an accurate review of the current state-of-the-art. In particular, we will focus on the analysis of the reference process and of the technological challenge to be addressed and of its complexity. In addition, the actually existing technologies/approaches will be fully reviewed in order to identify the innovation level of the proposed solution.

WP2: **Design of innovative photoactive catalysts based on HEPO heterojunctions (M02-06)**

T2.1: Synthesis of mixed nanometric HEPOs. We plan to synthesize nanometric HEPOs by spray-pyrolysis method. This method involves spraying a nitrate solution of the precursor cations, in precise concentrations and stoichiometric proportions, after which the aerosol passes through a high-temperature chamber (1000°C) where oxidation takes place and the formation of the perovskite oxide occurs. Stoichiometries that will be considered are: $La_{1-x}A_x(Mn_{0.25}Zn_{0.25}Co_{0.25}Fe_{0.25})O_3$ and $La_{1-x}A_x(Mn_{0.25}Ni_{0.25}Co_{0.25}Fe_{0.25})O_3$ with A=Ca, Mg and Sr and x= 0, 0.20, and 0.40. Samples will be fully characterized by x-ray powder diffraction (XRD), high-resolution scanning electron microscopy (HR-SEM, with elemental analysis), X-ray fluorescence spectroscopy (XRF), surface area measurement (BET method) and thermo-gravimetric analysis (TGA). Optical properties will be investigated by Uv-VIS and photoluminescence (PL) spectroscopies.

T2.2: Synthesis of heterojunction based on nanometric HEPOs. In this task, we will couple the prepared nanometric HEPOs with TiO_2 (Evonik AEROXIDE® P25) and nanosheets of g-C_3N_4. These last will be prepared from dicyandiamide according to methods already optimized by the UNIPV group.[7] Heterojunctions will be obtained by suspending appropriate stoichiometric amounts of HEPO and the second semiconductor in water-methanol mixtures, the suspensions will be sonicated for 5 min, then mixed and placed on heating plate (60°C) under vigorous stirring until dry powder is obtained. Then, we will prepare heterojunction with different ratios between the HEPO and the second semiconductor (TiO_2 and g-C_3N_4). A full characterization of the prepared heterojunctions will be performed as for the samples of T1.1.

WP3: Photoactivity of engineered materials (M06-09)

T3.1: Preliminary photocatalytic tests. In the first part of this WP, the prepared heterojunctions will be tested for H_2 production from water and their photocatalytic activity will be compared to that of the commercial Evonik AEROXIDE® P25 TiO_2 (77.1% anatase, 15.9% rutile, 7% amorphous TiO_2, particle size 10-50 nm, surface area 60.8 m^2/g), the benchmark catalyst in the control trials, to assess the role of the high-entropy oxides deposited on the titania particles.[18] A series of lab-scale photoproduction tests will be performed in triplicate to evaluate the H_2 evolution rates (HERs) under standard test conditions, that is working in aqueous solutions of probes sacrificial agents (0.1 M glucose), using platinum as the conventional, reference co-catalyst (0.5 wt%). Samples will be irradiated (4 h, 500 W/m^2, magnetic stirring) in Pyrex glass containers (30 mL capacity) equipped with sleeve stopper septa. After addition of the catalyst (1 g/L) and deoxygenation by N_2 bubbling (20 min), irradiation will be done by a Solar Box, equipped with a UV outdoor filter of soda lime glass IR treated, will be used as the solar light simulator. The evolved gas will be determined by gas chromatography (GC) through injection of proper volumes of the vessel headspace in a GC system equipped with a thermal conductivity detector (TCD).

T3.2: Hydrogen production from biomasses. On the basis of the HERs obtained in T3.1, the best catalyst will be selected for H_2 photogeneration from (waste)biomass, in particular sugar-rich wastewaters from the agri-food sector will be tested, as brewery and rice industry wastewaters. The photoreaction will be optimized by a chemometric approach (factorial experimental design) taking into account in a multivariate way the main variables affecting the photocatalytic system, *viz.* biomass amount (waste dilution), catalyst concentration (0.1-2 g/L) and co-catalyst amount (0-3 wt%). Experimental conditions for irradiation will be analogous to T3.1.

WP4: Lab-scale prototype photoreactor for continuous H_2 production (M02-12)

T4.1: <u>Deposition of photocatalyst</u>. As a noteworthy technical advancement, to streamline the experimental workflow, in this task the best performing heterojunction resulting from WP3 will be deposited onto glass substrates, fully eliminating the time-consuming and expensive procedures for the catalyst recovery after irradiation. Deposition will be realized by means of spray deposition starting from an aerosol of the precursor mixture made of powdered semiconductor (TiO_2 or g-C_3N_4) and metals nitrates. Annealing of the substrate will provide the requested continuous film, with no need for binders. The film of the heterojunction will be fully characterized as in WP1. However, the surface morphology will be further investigated by atomic force microscopy (AFM).

T4.2: <u>Photocatalytic test in the prototype photoreactor</u>. The films prepared and optimized in T4.1 will be placed into an *ad hoc* manufactured photoreactor, schematically shown in Fig. 1, where a continuous flow of water containing biomass will pass in contact with the photocatalytic bed, and the produced hydrogen will be collected as well in continuous mode through a dedicated injection switch valve in the GC instrument. Design of the photoreactor has been already devised and its manufacture will be started soon after the start of the project. We already secured two potential providers which will deliver the photoreactor in 30-45 days after order. We will look for the most rewarding experimental conditions (geometry, exposed surface area of the supported catalyst, amount of photoactive composite per substrate) by in-laboratory irradiation and after that, the performance of the system will be explored under natural solar light (outdoor conditions), and catalyst reusability tests will be performed as well, aiming at a further improvement of the sustainability of the process.

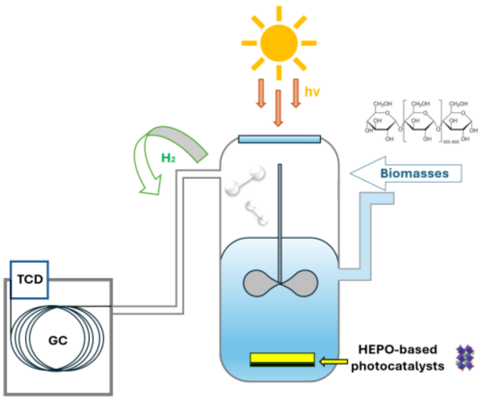

Fig. 1 – Schematic representation of the prototype photoreactor

WP5: Communication and Dissemination (M01-12)

Even though the project has a limited duration of 12 months, we expect to provide an active communication and dissemination of the project results through audience-centred activities, including seminars for academics and participation in national/international conferences. In particular, we expect to publish at least 3 papers based on the projects results. Publications resulting from this project will be published in open access journals. In accordance to the FAIR policy, scientific articles will be deposited in online institutional repositories, immediately after their publication. Sensitive data will be considered for IPR protection and, where and if pertinent, part of the results could also be object of patenting. As requested by the call, technical reporting will be delivered at the end of WP 1 (M03) and at the end of the project (M12).

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Section c. Available instrumentations and resources

Analytical tools: HPLC-MS/MS, HPLC-UV, HPLC-FD, GC-TCD, GC-FID, GC-MS, ICP-OES, ICP-MS, UV-vis spectrophotometers, COD/TOC analyzer, solar box, XRD diffractometers (Cu and Mo radiation), High resolution SEM, TGA, DSC, AFM, XRF, profilometer, Uv-VIS and PL spectrometers.

Section d. GANTT diagram

		Months											
WP	Task	1	2	3	4	5	6	7	8	9	10	11	12
1													
	T2.1												
2	T2.2												
	T3.1												
3	T3.2												
	T4.1												
4	T4.2												
5													

Section e. Milestones, Deliverables and KPI

List of Deliverables

Number	Deliverable name	Short description	WP number	Delivery date (in months)
1	Literature review	Document describing state-of-the-art to identify innovation of proposed solutions	1	03
2	HEPOs	Synthesis of innovative HEPOs	2	05
3	Heterojunctions	Optimization of HEPO-based heterojunctions	2	07
4	H_2 photoproduction	Optimization of H_2 photogeneration from biomass by application of the heterojunctions	3	09
5	Catalyst	Optimization of the photocatalyst deposition on solid substrate	4	08
5	Photoreactor	Manufacture of the photoreactor	4	04
6	Experimental set-up	Optimization of the best experimental conditions for efficient photocatalysis inside the photoreactor	4	08

List of Milestone

Milestone N°	Milestone name	Related WP(s)	Due date (in months)	Means of verification
1	Report Step 1	1	03	Availability of report on Step 1
2	HEPO-based heterojunctions	2	07	Chemical/structural analysis, experimental results of basic characterization
3	Optimized photoactive heterojunctions	3	09	H_2 photogeneration by biomasses against KPIs
4	Photoreactor	4	12	Optimized H_2 photogeneration from biomasses in the photoreactor

List of KPIs

Objective	Results	KPI	Measure
Provide innovative photoactive materials based on HEPOs	Optimize synthetic strategy, chemical composition, particle morphology, heterojunction creation	Improving preparation routes and nanometric morphology vs state-of-the-art	Select the input materials to be investigated for photocatalytic hydrogen production
Performing a successful H_2 production from biomasses	Optimize photocatalysts deposition, photoreactor configuration	Obtain hydrogen evolution rates (HER) from recovered biomasses above state-of-the art values (>10 mmol/h/g)	Measurement of HER values and apparent quantum efficiency

Annexes: Curriculum vitae research team

Curriculum vitae PI

PERSONAL INFORMATION

Family name, First name: Malavasi, Lorenzo
Researcher unique identifier (ORCID): 0000-0003-4724-2376
Date of birth:

URL for web site: malavasi.unipv.it

- **EDUCATION**

2003	PhD Department of Chemistry, University of Pavia, Italy Supervisor: Prof. Giorgio Flor
1999	Master Department of Chemistry, University of Pavia, Italy

- **CURRENT POSITION**

2021 –	Full Professor Department of Chemistry, University of Pavia, Italy

- **PREVIOUS POSITIONS**

2015 – 2021	Associate Professor Department of Chemistry, University of Pavia, Italy
2009 – 2015	Assistant Professor Department of Chemistry, University of Pavia, Italy

- **FELLOWSHIPS AND AWARDS**

2008	Alfredo di Braccio" per la Chimica dell'Accademia Nazionale dei Lincei, Roma.
2005	Young Scientist Award" dell'"International Conference on Perovskites", EMPA, Dubendorf, Swiss

- **SUPERVISION OF GRADUATE STUDENTS AND POSTDOCTORAL FELLOWS (if applicable)**

2008 – 2024	12 PhD Students
2014 – 2024	8 PostDocs

Department of Chemistry, University of Pavia, Italy

- **ORGANISATION OF SCIENTIFIC MEETINGS (if applicable)**

2024 MATSUS24. Symposium Organizer "Metal Halide Perovskite Photocatalysis"/Spain Please
2012 NONSTOICHIOMETRIC COMPOUNDS. Conference Chair/Italy

- **INSTITUTIONAL RESPONSIBILITIES (if applicable)**

2018 – Deputy Director of the Chemistry Department, University of Pavia/Italy
2017 – Member of the PhD School in Chemistry Board, University of Pavia/Italy
2018 – 2021 Member of Academica Senate, University of Pavia/Italy
2017 – Member of the INSTM Board and Representative of the Pavia Research Unit, INSTM/Italy

- **REVIEWING ACTIVITIES (if applicable)**

2018 – Review panel member, National Science Foundation / Poland
2020 – 2021 Review panel member, Puglia Sviluppo / Italy
2016 – 2023 Review panel member, VQR / MUR/ Italy
2020 – Reviewer, ERC/European Commision
2010- Reviewer for several international journals, among other: JACS, Nature, Science, Nature Materials, Angewandte Chemie, JPCL, Science Advances, Nature Energy, Joule.

- **MAJOR COLLABORATIONS (if applicable)**

Filippo De Angelis, Computational Modelling, Department of Chemistry, University of Perugia /Italy
Annamaria Petrozza, Advanced Spectroscopy, Optoelectronic Group, IIT/Italy
Michele Saba, Pump Probe Spectroscopy, Department of Physics, University of Cagliari/Italy

Appendix: All current grants and on-going and submitted grant applications of the PI and Co PI (Funding ID)

Mandatory information (does not count towards page limits)

Current grants (Please indicate "No funding" when applicable):

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current proposal*
A bio-inspired chemical approach for agro-industrial waste valorization (BEAGLE)	MUR/PNRR	225000	2023-2025	Principal Investigator	No direct relation

Re-Evolutionary solar fuel production envisioning water stable lead-free perovskites exploitation - REVOLUTION	MUR/PNRR	203624	2023-2025	Research Unit PI	Photocatalysis but with different materials and not on biomass
Tuning physical properties of chiral perovskite at high pressure (ProPerHP**)**	MAECI	81900	2023-2025	Principal Investigator	No relation
CHIRAL HYBRID ORGANIC-INORGANIC METAL HALIDES: A PLATFORM FOR EMERGING ELECTRONICS	Pathfinder Challenge	3900000	2023	Principal Investigator	Submitted, no relation

Curriculum vitae CO-PI

PERSONAL INFORMATION

Speltini, Andrea
Researcher unique identifier: ORCID 0000-0002-6924-7170
Date of birth:

URL for web site:
https://unipv.unifind.cineca.it/resource/person/673708
https://chimica.dip.unipv.it/it/ricerca/linee-e-gruppi-di-ricerca/chimica-analitica/studi-la-produzione-fotocatalitica-di-h2-verde

- **EDUCATION**

2011 PhD
Department of Chemistry, University of Pavia, Italy
Supervisor: Prof. Antonella Profumo

2008 Master
Department of Chemistry, University of Pavia, Italy

- **CURRENT POSITION(S)**

2022 – Associate Professor
Department of Chemistry, University of Pavia, Italy

- **PREVIOUS POSITIONS**

2018 – 2021 Assistant Professor (RTD A)
Department of Drug Sciences, University of Pavia, Italy

2011 – 2018 Post-doc Research Fellow
Department of Chemistry, University of Pavia, Italy

- **FELLOWSHIPS AND AWARDS**

2011 EUROANALYSIS XVI: Poster Prize awarded for excellent presentation of particularly significant innovative analytical research

- **SUPERVISION OF GRADUATE STUDENTS AND POSTDOCTORAL FELLOWS**

2010 –	31 Master Students (Thesis Correlator) Department of Chemistry, University of Pavia, Italy
2021 –	5 Master Students (Thesis Relator) Department of Chemistry and Department of Drug Sciences, University of Pavia, Italy
2022 –	1 Ph.D student (Thesis co-Supervisor) Department of Chemistry, University of Pavia, Italy

- **INSTITUTIONAL RESPONSIBILITIES**

2021 –	Member of the Tutoring Commission ("Commissione Tutorato"), Department of Drug Sciences, University of Pavia, Italy
2021 –	Member of the Chemistry Commission of Almo Collegio Borromeo, Pavia, Italy

- **REVIEWING ACTIVITIES**

2010 –	Reviewer for international peer-reviewed journals: Analytical and Bioanalytical Chemistry, Analytica Chimica Acta, Arabian Journal of Chemistry, Analytical Methods, Analytical Chemistry, Applied Catalysis B: Environmental, ACS Applied Materials & Interfaces, Applied and Environmental Soil Science, Bioanalysis, Chemical Engineering Journal, Chemosphere, Chemical Physics Letters, Chirality, Chromatographia, Desalination and water treatment, Ecotoxicology and Environmental Safety, Environmental Technology, Environmental Science and Technology, Environments, Food Chemistry, Fuel, International Journal of Environmental Analytical Chemistry, International Journal of Environmental Research and Public Health, International Journal of Hydrogen Energy, Industrial Engineering Chemistry Research, International Journal of Analytical Chemistry, Journal of Physics and Chemistry of Solids, Journal of Chromatographic Science, Journal of Chromatography A, Journal of Food Composition and Analysis, Journal of Chemistry, Journal of Pharmaceutical and Biomedical Analysis, Microchimica Acta, Nano, Photochemical & Photobiological Sciences, Journal of Separation Science, Sensors & Actuators: B. Chemical, Separation Science Plus, Science of the Total Environment, Talanta, Water Research
2020 –	Editorial Board Member of International Journal of Environmental Research and Public Health, section "Environmental Science and Engineering"
2020 –	Editorial Board Member of Catalysts, section "Photocatalysis"
2022 –	Associate Editor of Frontiers in Environmental Chemistry
2023	Evaluator of the project "Rational design and preparation of thermo-sensitive hydrogels for the capture and preconcentration of pesticides from aqueous matrices" project N° 1240126, 2024 Regular Fondecyt National Projects Competition (Chile)

- **MEMBERSHIPS OF SCIENTIFIC SOCIETIES**

2010 –	Member of Italian Chemistry Society (SCI), Analytical Chemistry division, and

interdivisional group of Separation Science
2022 – Member of European Chemistry Society-Analytical Chemistry division (EuChemS-DAC), Sample Preparation network/Green Sample Preparation working group

- **MAJOR COLLABORATIONS**

1. Prof. Massolini and Prof. Calleri, Department of Drug Sciences, University of Pavia (Italy): design, preparation and analytical application of (modified)high internal phase emulsions polymers for drugs extraction in various matrices
2. Prof. Ferretti, Department of Chemistry and Industrial Chemistry, University of Genoa (Italy): development and evaluation of sustainable photocatalysts for hydrogen production from water
3. Prof. Anticò, Department of Chemistry, University of Girona (Spain): preparation of biochar-modified polymer films for extraction of organic compounds/contaminants in complex matrices

Appendix: All current grants and on-going and submitted grant applications <u>of the PI</u> <u>and Co PI</u> (Funding ID)

<u>Mandatory information</u> (does not count towards page limits)

Current grants:

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the co-PI*	*Relation to current proposal*
PRIN 2022 Prot. 2022HXZ3BK "Waste biomass valorisation for green H_2 production by application of new TiO_2-Carbon Dots photocatalysts supported on magnetic zeolites obtained from industrial wastes"	UE/MUR	200000	2023-2025	Principal Investigator	Photocatalysis but with different catalysts and preparation routes
PRIN 2022 PNRR Prot. P20223HSWX "A bio-inspired	MUR/PNRR	225000	2023-2025	Permanent staff member of the Pavia University research unit	No direct relation

chemical approach for agro-industrial waste valorization (BEAGLE)”					

Curriculum vitae (max. 3 pages)

PERSONAL INFORMATION

Family name, First name: Tedesco Costanza

Researcher unique identifier(s) (such as ORCID, Research ID, etc. ...): https://orcid.org/0000-0001-7378-9194

URL for web site:

- **EDUCATION**

2022-2025	PhD Material Chemistry/ Department of Chemistry, Pavia University, Italy Lorenzo Malavasi
2020	Master Chemistry/ Department of Chemistry, Pavia University, Italy

- **CURRENT POSITION(S)**

2022 –2025	PhD student Material Chemistry/ Department of Chemistry, Pavia University, Italy

- **ORGANISATION OF SCIENTIFIC MEETINGS (if applicable)**

2022	Poster contribute / MAT-SUS fall 2022 / Barcelona, Spain
2023	Oral contribute / ENERCHEM PhD school / Florence, Italy

Curriculum vitae (max. 3 pages)

PERSONAL INFORMATION

Family name, First name: Betti, Luca Angelo.
Researcher unique identifier (ORCID): 0009-0006-1537-7769
Date of birth:

- **EDUCATION**

2022 Master
Department of Chemistry, University of Pavia, Italy

- **CURRENT POSITION(S)**

2022 – On Going PhD Student
Department of Chemistry, University of Pavia, Italy
Supervisor: Prof. Lorenzo Malavasi

- **PREVIOUS POSITIONS**

2022 Research Grant
Department of Chemistry, University of Pavia, Italy
2021 Internship
Eni s.p.a., Novara, Italy

- **FELLOWSHIPS AND AWARDS**

2023 2nd FullProf School, ILL – Neutron for society, Grenoble, France
2017 Climathon, Associazione Cultura e Sviluppo, Alessandria, Italy

- **SUPERVISION OF GRADUATE STUDENTS AND POSTDOCTORAL FELLOWS (if applicable)**

2024 1 Master Student
Department of Chemistry, University of Pavia, Italy

- **ORGANISATION OF SCIENTIFIC MEETINGS (if applicable)**

2023 Poster contribute / 50th AIC Meeting/ Bologna, Italy
2023 Poster contribute / ENERCHEM PhD School/ Florence, Italy

- **MEMBERSHIPS OF SCIENTIFIC SOCIETIES (if applicable)**

2023 - 2024 Member, Research Network "*Associazione Cristallografi Italiani*"

- **MAJOR COLLABORATIONS (if applicable)**

Raffaella Biesuz, Chemometrics, Department of Chemistry, University of Pavia, Italy
Lisa Rita Magnaghi, Chemometrics, Department of Chemistry, University of Pavia, Italy

Curriculum vitae

PERSONAL INFORMATION

Family name, First name: Merlo, Francesca
Researcher unique identifiers: ORCID 0000-0003-1769-1760; Scopus Author ID 57200564914
Date of birth:

- **EDUCATION**

2021	PhD in Chemical and Pharmaceutical Sciences and Industrial Innovation Department of Chemistry, University of Pavia, Italy PhD Supervisor: Prof. Antonella Profumo
2017	Master in Chemistry (LM-54) Department of Chemistry, University of Pavia, Italy

- **CURRENT POSITION(S)**

2023 – present	Post-doc Fellow Researcher Department of Chemistry, University of Pavia, Italy

- **PREVIOUS POSITIONS**

2022 – 2023	Post-doc Fellow Researcher Department of Chemistry, University of Pavia, Italy
2020 – 2022	Post-doc Fellow Researcher Department of Chemistry, University of Pavia, Italy

- **FELLOWSHIPS AND AWARDS**

2018	Award for Master's Thesis 2018, Italian Chemical Society - Division of Environmental Chemistry and Cultural Heritage

- **CO-SUPERVISION OF GRADUATE STUDENTS AND POSTDOCTORAL FELLOWS**

2023 – 2024	1 Master Student Department of Chemistry, University of Pavia, Italy
2022 – 2023	3 Master Students Department of Chemistry, University of Pavia, Italy
2021 – 2022	1 Master Student Department of Drug Science, University of Pavia, Italy
2020 – 2021	1 Master Student Department of Chemistry, University of Pavia, Italy
2020 – 2021	1 Master Student Department of Drug Science, University of Pavia, Italy

2018 – 2019 1 Master Student
Department of Chemistry, University of Pavia, Italy

- **REVIEWING ACTIVITIES**

2020–present Peer Reviewer for Talanta
2021–present Peer Reviewer, Journal of Hazardous Materials
2023–present Peer Reviewer, Science of Total Environment
2023–present Review Editor for Frontiers in Chemistry, section Analytical Chemistry

- **MEMBERSHIPS OF SCIENTIFIC SOCIETIES**

2018 – present Member, Società Chimica Italiana
2022 – present Member, EuChemS-DAC Sample Preparation Study Group and Network

- **MAJOR COLLABORATIONS**

  - Prof. Maria Enriqueta Anticò and Prof. Claudia Fontàs, Development and application polymeric membrane for pollutants' enrichment, Department of Chemistry, University of Girona, Spain
  - Prof. Enrica Calleri, Design and synthesis of polyHIPE material for analytical methods, Department of Drug Science, University of Pavia, Italy