Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
NEST NETWORK FOR ENERGY SUSTAINABLE TRANSITION

ALLEGATO B

PE00000021
"PNRR MUR - M4C2 – NEST - Extended Partnership Network 4 Energy Sustainable Transition"

SPOKE N. 4

CUP D33C22001330002

Research proposal

Topic addressed by the project
(with reference to Allegato 2)

6. Innovazione per lo stoccaggio di idrogeno allo stato solido

f. Innovation for Solid State Hydrogen Storage

HyStoVal
Hydride-based hydrogen Storage Value chain

- Name of the PIs' host institution for the project: Department of Chemistry – University of Turin
- Name of the Principal Investigators (PIs): Marcello BARICCO – Paola RIZZI
- 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)	*Marcello*	*BARICCO*	*University of Turin /Department of Chemistry*	*Full Professor*	*NO*	*M*
co-Principal Investigator (PI)	*Paola*	*RIZZI*	*University of Turin /Department of Chemistry*	*Full Professor*	*NO*	*F*
Component of the Research Team	*Mauro*	*PALUMBO*	*University of Turin /Department of Chemistry*	*Associate Professor*	*NO*	*M*
Component of the Research Team	*Abhishek*	*PATEL*	*University of Turin /Department of Chemistry*	*Post doc*	*YES*	*M*
Component of the Research Team	*Valentina*	*FIUME*	*University of Turin /Department of Chemistry*	*PhD student*	*YES*	*F*
Component of the Research Team	*Francesca*	*GARELLI*	*University of Turin /Department of Chemistry*	*PhD student*	*YES*	*F*

ABSTRACT

Hydrogen is conventionally stored in high pressure gas cylinders and, as a liquid phase, in suitable tanks. These methods present several economic and security problems. So, hydrogen storage in solid carriers is a promising method for future applications. Materials to be used as solid-state hydrogen carriers require high gravimetric and volumetric capacity, coupled with a fast kinetics of gas uptake and release. In addition, the reversible hydrogenation reaction should take place close to ambient pressures and temperatures. These properties can be reached when appropriate thermodynamic properties are combined with a suitable microstructure. In addition, the use of hydride-polymer composites can be considered to improve the management of the hydrogen carrier. In order to set up hydrogen tanks based on hydrides, the development of a suitable system is necessary. The main goal of the project is to reach a full value chain for the introduction of hydride-based hydrogen storage systems into the market.

RESEARCH PROPOSAL

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

Hydrogen is a clean energy vector, which can be produced from renewable sources and has only water as the by-product of its reaction with oxygen[1]. However, a significant challenge to establish an economy based on

hydrogen is to develop effective and safe ways to transport and store it[2]. Generally, hydrogen can be stored following different approaches, mainly in the gaseous state (at the high-pressure condition) and in liquid form (at cryogenic condition)[3]. As an alternative, hydrogen can be chemisorbed in solid compounds. In some cases, after suitable activation, these compounds can reversibly absorb and desorb hydrogen close to ambient conditions of pressure and temperature[4]. Hydrogen has the highest energy density per unit mass of any fuel; however, its low volumetric density at ambient temperature and pressures correspondingly results in a rather low energy density per unit volume. Metal hydride materials research focuses on improving both the volumetric and gravimetric capacities, hydrogen absorption/desorption kinetics and reaction thermodynamics of potential material candidates. Furthermore, long-term cycling effects must be taken into account for the development of hydrogen-based technologies. **HyStoVal project aims to develop a full value chain for the hydrogen storage technology using metal hydrides as carriers.**

The powder materials are typically intermetallic compounds of general formula AB_n, which are commonly named metallic hydrides, from the facts that both hydrogen-metal bonding and electronic structure have a metallic character[5]. A is an element that forms very stable metallic hydrides and B an element that only forms hydrides at very high pressure[4]. Out of all transition elements, TiFe compound is one of the most suitable for hydrogen storage applications, but its activation is always challenging, as it requires high temperature and Ti is highly sensitive towards gaseous impurities like oxygen. If an oxide layer is formed on the surface of the material, the activation is suppressed, and it is difficult to remove it. The substitution of Fe with Mn in TiFe is known to significantly improve the activation conditions, without affecting hydrogen storage capacity, and to prove resistance to impure elemental gases during the activation[6]. The **first goal of the HyStoVal project** is to identify an **optimized composition** of TiFe-based alloys and to develop **suitable processes for their preparation**. The developed process must have the potentiality for an up-scaling, in order to be used at an industrial scale. For this reason, the following parameters will be taken into account: selection of raw materials, recyclability, simple process and low cost of the final product.

The material has to retain its performances in terms of kinetics and total hydrogen capacity, even after cycling. The reaction of the material with hydrogen must be reversible even after repeated absorption and desorption runs, but in practice powders tend to pack and sinter after long term cycling, reducing the efficiency of the system. One possible solution, which was proven successful more than once, is compacting the powder into high-density pellets[4]. The problem of oxide formation can be mitigated mixing the alloy within a polymer matrix that is resistant to impure gases, making it easier and more effective to activate TiFe. Despite being a promising approach, only a few works studied polymer-TiFe systems. Compact cylinders of PTFE and TiFe were prepared by ball milling, but this mechanical treatment was not adequate to activate the TiFe alloy, because PTFE could not be evaluated as a coating that would remove the need to reactivate the material[7]. In another study[8], cold-rolling was explored for the mechanical activation of the alloy, and PTFE and PE were used for the composite. Even though cold-rolling was effective for activating the TiFe, it was not effective to promote a homogeneous polymer coating, observing a poor adhesion between the components. The polymer to be selected must therefore be compatible with the powder and homogeneously coat it, making an effective activation of the alloy. The developed process must allow the preparation of pellets with suitable dimensions, to be tested in a real system. The **second goal of the HyStoVal project** is to **find a polymer** that can homogeneously coat the selected compound, making its activation effective. The polymer must also be permeable to hydrogen and impermeable to oxygen, thus reducing the possibility of oxide formation and it must be elastic to allow the volume change of the powder due to hydrogen adsorption and desorption over multiple cycles without breaking and without going to deform the metal tube container. Finally, the availability of pellets can definitely **optimize the powder management** during the hydrogen tank production.

The thermal conductivity of hydrogen storage material is fundamental, since the hydride formation reaction is an exothermic reaction, and the heat must be easily released to the outside of the material. Adding the polymer to the metal powder does not improve the already low conductivity of the powder. Since the heat

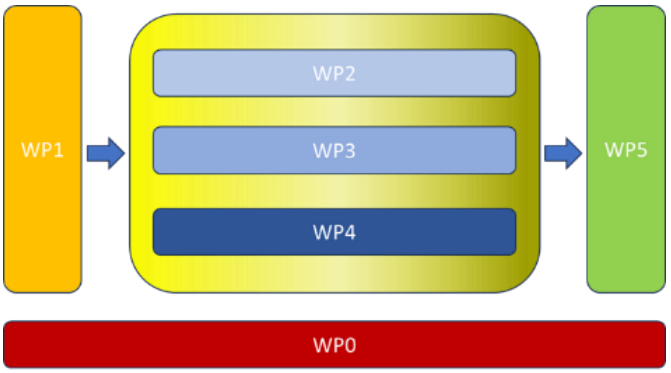
management is challenging because of MH low thermal conductivity, heat-conductive matrices can be used to improve and homogenize the heat exchange. Therefore, additives, e.g. natural graphite (ENG), can be considered to increase the thermal conductivity of the powder and pellets, also having benefits on the kinetics of the hydrogen sorption reactions. The **third goal of the HyStoVal project** is to **optimize the thermal conductivity** of developed composite material, in order to be exploited in real systems at pre-industrial scale. Suitable solutions aimed to the management of heat exchanges in hydrogen storage tanks will be developed.

The demonstration of hydrogen storage properties at a pre-industrial scale is considered an added value for the project, so the validation of the developed solution in a small-scale prototype is required. In **last part of the HyStoVal project**, a **small-scale demonstration prototype** will be developed, together with an industrial partner. It will consist in a set of metal hydrides tanks, filled with developed pellets. A testing activity will be carried out, monitoring hydrogen sorption and thermal exchanges.

Section b. Methodology

Research activities will follow three phases:

PHASE 1: Analysis of the technological challenges (within M3)
PHASE 2: Innovation development (within M9)
PHASE 3: Pototyping/validation and testing (within M12 – end of project)



The project will be organized in work packages (WP) according to the reported scheme.

The following actions are planned for the project:

WP0 - Project management The Principal Investigator (PI) will manage the whole project. Connections with the supporting team and connected companies will be maintained along the project. All expenses procedures will be managed by the administrative offices of the Department of Chemistry of the University of Turin. Suitable dissemination activities (i.e. meeting, workshops, etc) will be performed.

WP1 - Literature survey At the beginning of the project, a literature survey will investigate viewpoints, methodological solutions and research results related to the field of hydrogen storage by hydrides. The existing information will be critically analysed, so that contradicting and differing results will be highlighted. Only material that is relevant and directly related to the research will be selected in the survey.

WP2 - Alloy production Starting from the UNITO expertise in metal hydrides sector, in identifying the most relevant materials, characterizing performances at laboratory level and designing metal hydrides for hydrogen storages, WP2 will identify the most suitable composition for hydrogen storage solutions. First, a benchmark search on the commercial ferrous and Ti based alloys to be used to produce bcc Ti-based hydrides will be carried out. Possible commercial alloys that will be considered are: Ti6Al4V, FeMn, FeV, FeNb. On this basis, the selected alloys will be arc melted to obtain the selected composition: Samples will be characterized both from a structural and microstructural point of view and hydrogen sorption properties will be determined. XRD (X-Ray Diffraction), SEM (scanning electron microscopy) and FESEM (field emission SEM) are the main characterization techniques used for determining the elemental and phase composition of the alloys. Moreover, PCI (Pressure-Composition Isotherms) and HPDSC (high pressure differential scanning calorimeter) measurements will be performed to determine thermodynamic and kinetic properties of hydrogen sorption.

WP3 - Pellet production In WP3, there will be the polymer selection. The polymer chosen must have all the properties listed before. The samples with and without the powder will then be characterized quantitatively

by thermogravimetric analysis and qualitatively by FTIR-ATR analysis and morphological analysis. These analyses will be used to verify that the chosen polymer is compatible with the powder and homogeneously coats it. Subsequently, the samples will be subjected to mechanical tests to evaluate possible changes of the elasticity of the material due to the presence of the powder.

WP4 - Thermal exchange optimisation In WP4, the thermal conductivity of developed composite material will be optimized, in order to be exploited in real systems at industrial scale. Suitable solutions aimed to the management of heat exchanges in hydrogen storage tanks will be evaluated. Since the heat management is challenging because of MH low thermal conductivity, heat-conductive matrices will be considered to improve and homogenize the heat exchange. The use of additives should not change the possible environmental impact of the composite material, which should be as low as possible.

WP5 - Testing activity In WP5, an in-house setup will be developed, in collaboration with an industrial partner. It will mimic a Sievert apparatus but using a mass-flow controller. Argon will be employed for a preliminary leak test and for sample washing. A suitable activation procedure will be established. Following that, cycling experiments will be carried out at room temperature, with hydrogen kept at a pressure of 30 bar for absorption and of 2 bar for desorption. The testing system will be equipped with thermocouples for monitoring heat effects in different sections of the prototype tank. Hydrogen sorption processes will be followed as a function of time, and the gravimetric and volumetric density of pellets will be monitored as a function of the cycle number. Finally, a manufacturing value chain, as well as an eco and cost assessment of identified hydrogen storage process, will be performed.

References

1 G. Rodrigues de Almeida Neto, C. A. G. Beatrice, D. R. Leiva, L. A. Pessan, *International journal of hydrogen energy,* 2020, vol. 45, pp. 14017-14027, doi: 10.1016/j.ijhydene.2020.03.069
2 T. Sinigaglia, F. Lewiski, ME Santos Martins, JC Mairesse Siluk, *International journal of hydrogen energy,* 2017, vol- 42, pp. 24597, doi: 10.1016/ j.ijhydene.2017.08.063
3 A. Thangarasu, G. Palanisamy, Y. Min Im, T. Hwan Oh, *International journal of hydrogen energy,* 2023, vol. 48, pp. 21428-21450, doi: 10.1016/j.ijhydene.2022.02.115
4 E. M. Dematteis, N. Berti, F. Cuevas, M. Latroche, M. Baricco, *Royal society of chemistry,* 2021, vol. 2, pp. 2524-2560, doi: 10.1039/D1MA00101A
5 F. Cuevas, J.-M. Joubert, M. Latroche and A. Percheron, *Applied Physics A- Materials Science & Processing*, 2001, vol. 72, pp. 225–238, doi: 10.1007/s003390100775
6 A. Kumar, P. Muthukumar, P. Sharma, E. A. Kumar, *Sustainable Energy Technologies and Assessments,* 2022, vol. 52, pp. 102204, doi: 10.1016/j.seta.2022.102204
7 G. Rodrigues de Almeida Neto, F. H. Matheus, C. A. G. Beatrice, D. R. Leiva, L. A. Pessan, *International journal of hydrogen energy,* 2022, vol. 47, pp. 34139-34164, doi: 10.1016/j.ijhydene.2022.08.004
8 B. Sakintuna, F. Lamari-Darkrim, M. Hirscher, *International journal of hydrogen energy,* 2007, vol. 32, pp.1121-1140, doi: 10.1016/ j.ijhydene.2006.11.022.

Section c. Available instrumentations and resources

The research activities will be carried out in the frame of the Metallic Materials Group (MET) at the Department of Chemistry and at the Interdepartmental Center NIS of the University of Turin. The research activity focuses on topics related to materials for manufacturing and for energy applications.
In detail, experience in the following topics has been developed:

- Physical metallurgy of solidification and solid-state phase transformations.

- Processing of metallic materials from the melt (arc-melting, rapid solidification and copper mould casting) and in the solid state (mechanical alloying).
- Additive manufacturing of alloys: study of the influence of processing conditions on phase selection (non-equilibrium phase diagram calculation), microstructure and mechanical properties.
- Characterization of the thermal stability, thermophysical properties and phase transformations in equilibrium and metastable metallic systems, by means of thermal analysis, X-ray diffraction and microscopy techniques.
- Development of thermodynamic and kinetic models for phase transformations in metallic systems (e.g. Calphad). Calculation of phase diagrams and thermodynamic properties using ab initio techniques.
- High entropy alloys: prediction of single-phase stability, synthesis and characterization.
- De-alloying as a route for the synthesis of functional nanoporous metals.
- Materials and systems for solid-state hydrogen storage and compression.
- Electrolytes for all solid-state batteries.
- Ab initio calculations of thermophysical properties of materials for batteries and hydrogen storage.
- Thermoelectric materials for waste heat harvesting: synthesis and characterization.
- Materials for radiation shielding in the space.
- Life Cycle Assessment of materials and processes.

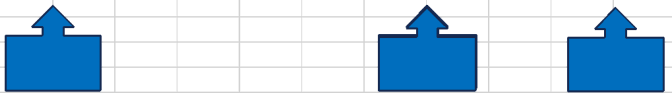
Conventional synthesis and characterization techniques (arc-melting, induction melting, X-ray diffraction, calorimetry, optical microscopy, scanning and transmission electron microscopy, microindentation, nanoindentation) are available in the laboratory, allowing experimental study of structural, microstructural, thermal, chemical, physical and mechanical properties of materials.
In recent years, the research has been focused on the study of materials for hydrogen storage in the solid state. It includes intermetallic compounds and complex hydrides with high potential for hydrogen storage applications. The gravimetric and volumetric capacity, cyclability, thermodynamic and kinetic properties of these materials are experimentally characterized by means of PCI and high-pressure DSC facilities, coupled with standard structural characterisation. The integration of solid-state hydrogen tanks with fuel cells for stationary and transport applications have been developed. More recently, metal hydrides are studied for solid-state hydrogen compression. Life Cycle Assessment (LCA) studies are running on various processes, including hydrogen-based technologies and recycling of materials.

The MET group developed several collaborations in the frame of national and European projects, as well as together with industrial partners on topics related to hydrogen storage materials. In particular, the MET group has recently coordinated the HyCARE European project (https://hycare-project.eu/) financed by the Fuel Cell and Hydrogen Joint Undertaking (now Clean Hydrogen Partnership). The HyCARE project has demonstrated the suitability of hydrogen storage by metal hydride at industrial scale. The MET group was already involved in European projects on solid-state hydrogen storage (e.g. SSH2S, FLYHY, BOR4STORE, ECOSTORE). At regional level, projects have been also developed in collaboration with industries. The MET group is currently supporting the activities of Methydor (https://methydor.com/), a spin-off company aimed to introduce the solid-state hydrogen storage in the market.

A short introduction on running activities and available equipment at MET group can be found at:
https://www.met.unito.it
https://www.chimica.unito.it/do/gruppi.pl/Show?_id=cpcf
https://www.chimica.unito.it/do/home.pl/View?doc=/ricerca/Materiali_avanzati.html
https://www.nis.unito.it/

Section d. GANTT diagram

Phase	Activity	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
	WP0 - Management												
1	WP1 - Literature survey												
2	WP2 - Alloy production												
	WP3 - Pellet production												
	WP4 – Thermal exchange optimisation												
3	WP5 – Testing activity												



Section e. Milestones, Deliverables, Oututs and KPIs

Milestones
M1. Phase 1. Selection of alloy composition [M3]
M2. Phase 2. Pellets design and production [M9]
M3. Phase 3. Final testing [M12]

Deliverables
D1. Low-cost hydrogen storage material developed [M7]
D2. Pellets based on metal hydride-polymer composites developed [M9]
D3. Thermal exchange in pellets optimized [M10]
D4. Demonstration prototype tested [M12]

Outputs
O1. Report of phase 1 [M3]
O2. Final report [M12]

KPIs
Available hydrogen gravimetric density of the carrier between 30 bar and 2 bar: > 1.2 wt%
Available hydrogen volumetric density of the carrier between 30 bar and 2 bar: > 100 kgH_2 m^{-3}
Cycling between 30 bar and 2 bar: > 50 cycles
Temperature for absorption at 30 bar: > 20 °C
Temperature for desorption at 2 bar: < 70 °C

Annexes: Curriculum vitae research team

Curriculum vitae PI

PERSONAL INFORMATION

Family name, First name: **Baricco Marcello**

Researcher unique identifier(s): ORCID: 0000-0002-2856-9894, ResearchID: B-4075-2013

Date of birth:

Nationality:

URL for web site: https://www.chemistry.unito.it/do/docenti.pl/Show?_id=mbaricco#tab-profilo

- **EDUCATION**

He obtained the **Master Degree in Chemistry** in 1982 (cum laude) and the **PhD in Chemistry** in 1987, both at the University of Turin.

- **CURRENT POSITION**

He is **Full Professor in Materials Science and Technology** (SSD ING-IND/22) at the University of Turin since 2004.

- **PREVIOUS POSITIONS**

He worked as researcher at the **Istituto Elettrotecnico Nazionale Galileo Ferraris** of Turin (now **INRIM**) in 1987-1990 and then moved to the **Department of Chemistry of the University of Turin** to work as a **Researcher** in Physical Chemistry (1990-1998). He then reached the position of **Associate Professor** in Metallurgy at the University of Turin (1998).

He spent short **research stages** at the Brunel University, Uxbridge (U.K.) (1986), University of Cambridge (U.K.) (1993), Slovack Academy of Science (Slovakia) (1995), University of Birmingham (U.K.) (1997 and 1998), ESRF - Grenoble (F) (2000), University of Campinas (BR) (2003).

- **FELLOWSHIPS AND AWARDS**

He has been awarded of the **Senior Scientist Award** of **ISMANAM** in 2018. One of his papers has been awarded of the **IJHE David Sanborn Scott Award** for the **most cited paper** in the Hydrogen storage & compression category of the year 2019. In 2021 the HyCARE contribution has been awarded for the **second prize** for the **Poster Competition on Materials Science**. In 2021, the Dolphins project with CNH Industrial has been awarded by **National Association of Manufacturers** (NAM) of the United States.

- **RESEARCH ACTIVITY**

The **research activity** is mainly based on materials science and technology. The scientific contributions have been presented since 1984 in **more than 400 papers**, published in international and national journals, and in several invited talk in international and national meetings.

The **main research topics** may be classified as follow:
1) Microstructure and kinetics of phase transformations in materials: magnetic, mechanical and chemical properties of amorphous and nanocrystalline materials.
2) Thermodynamic properties and phase diagrams: experiments and modelling.
3) Hydrogen storage: hydrogen carriers, hydrogen tanks development, integration with fuel cells systems.
4) Energy storage: hydrides for solid electrolytes in batteries, LCA analysis of energy storage systems.

Results of the scientific activities can be found in
- ORCID: www.orcid.org/0000-0002-2856-9894 (Documents: 319)
- ResearchID: www.researcherid.com/rid/B-4075-2013 (Documents: 315, Citations: 6567, h-index: 40)

- Scopus: www.scopus.com/authid/detail.uri?authorId=7005039660 (Documents: 343, Citations: 6908, h-index: 40)
- Web of Science: apps.webofknowledge.com (Documents: 328, Citations: 6525, h-index: 40)
- Research Gate: www.researchgate.net/profile/Marcello_Baricco (Research Items: 424, Citations: 7631, h-index: 42, Research Interest Score: 3900)
- Google Scholar: scholar.google.it/citations?user=DJZg4vcAAAAJ&hl=en (Documents: 541, Citations: 8620, h-index all: 46, h-index since 2019: 27)

He has been responsible for the University of Torino in more than 50 national and international **research projects** with research institutions and industrial partners.

Specific activities on **technological transfer** have been carried out, aiming to apply knowledges developed at the University labs in industrial processes. He contributed in 2010 to the development of a spin-off (Compumat) inside the Incubator of the University of Turin (2I3T). The spin-off company was aimed to the support by modelling (thermodynamic, kinetic and FEM based) to industrial products and processes. He has been vice-president of the CIM 4.0 Competence Center, developed in Turin in the frame of the "Piano Industria 4.0".

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

He is involved in **teaching activities** on various subjects, namely Metallurgy, Chemical Plants and Materials Science. Since 1995, he has been **supervisor** of about 70 Master Degree thesis and of 23 Ph.D. thesis.

- **ORGANISATION OF SCIENTIFIC MEETINGS**

He organized **International Schools** on Bulk Metallic Glasses and Complex Hydrides and **National Schools** on Metallurgy. He was member of the **organizing and scientific committee** of various international meetings on amorphous alloys and hydrides (e.g. ISMANAM2013, MH2024). In 2022, he organized the **International Summer School** on "Renewable energy for the mountain territories" in the frame of the UNITA European University Alliance.

- **INSTITUTIONAL RESPONSIBILITIES**

He has been **President of the courses** on Industrial Chemistry at the Faculty of Science of the University of Turin (2004-2007), **Vice-head for the Research** of the Department of Chemistry at the University of Turin (2013-2015), **Deputy Rector** of the University of Turin (2014-2019), **President of the Interdepartmental Center** for Nanomaterials for Industry and Sustainability (2022-). He has been member of many **Institutional Committees** at the University of Turin (Giunta Dipartimento, Commissione Organico, Commissione Internazionalizzazione, etc.). He is currently a member of the **Scientific Board** of the **PhD in Chemical and Materials Sciences** at the University of Turin. He has been responsible for the hub on **Renewable Energies** for the University of Turin in the frame of UNITA European University Alliance (2020-2023).

- **REVIEWING ACTIVITIES**

He plays as a **referee for several international journals** (e.g. J.Phys.Chem C, Int. J.Hydr. Ener., J. Alloys and Compd.) and for international research institutions. He is an **expert** for the **Ministry of the University**

and Research for the evaluation of national projects. He has been **reviewers** of several projects for the **European Commission** (e.g. EIC, FCG JU) and for **Italian Regions**.

- **MEMBERSHIPS OF SCIENTIFIC SOCIETIES**

Since 2010, he is the **Italian Representative** expert in **International Energy Agency**-Hydrogen Implemetation Agreement-TCP Hydrogen (Task 22-32-40) (IEA-HIA, ieahydrogen.org).

He has been member of the **Scientific Committee** of **Fuel Cell and Hydrogen Joint Undertaking** (FCH JU) (2017-2021). He is the representative of the University of Turin in Clean Hydrogen Partnership - **Hydrogen Europe Research**, where he coordinated the activities of the **Working Group and Hydrogen Storage** in FCH-JU N.ERGHY. He is now member of **Working Group CT3** at Hydrogen Europe Research. He has been **Road Map leader** of RM6 on **Hydrogen Carriers** and RM14 on Rail for Hydrogen Europe and Hydrogen Europe Research.

He is **coordinator** of SP7 on **Hydrogen Handling** of JP on **Fuel Cells and Hydrogen** of **European Energy Research Alliance** (EERA, www.eera-set.eu). He represents the activities of the University of Turin in the **Scientific Committee** of the **Italian Association for Hydrogen Technologies** (H2IT, www.h2it.org), where he coordinated the working group on Hydrogen Storage. He follows, for the University of Turin, activities in the frame of the **National Technology Cluster on Energy**.

In the frame of activities related to **energy at the University of Turin**, he developed and internal group aimed to improve energy efficiency at university buildings. The group now is included in the activities of the University of Turin **Green Office** (UniToGO, www.green.unito.it). He collaborates for the University of Turin to the RUS (Rete delle Università per la Sostenibilità).

- **MAJOR COLLABORATIONS**

Since the beginning of the scientific activity, several **national and international collaborations** have been developed.

Appendix: Previous and current grants related to the subject of hydrogen storage:

Project Title	*Funding source*	*Amount*	*Period*	*Role of the PI*	*Relation to current proposal*
Innovative Materials for Hydrogen Storage	Regione Piemonte	560 k€	2004	PI for UNITO	Study on materials for solid-state hydrogen storage
Complex Metallic Alloys (CMA)	EU FP6 Network of Excellence		2006	PI for UNITO	Activities in the working group on "Materials for hydrogen storage"
Tank production for hydrogen storage (HYSYVISION)	Regione Piemonte	82 k€	2007	PI for UNITO	Development of a tank for solid-state hydrogen storage
Complex Solid State Reactions for Energy Efficient Hydrogen	EU FP6 MCRTN	140 k€	2006-2008	PI for UNITO	Development of complex hydrides for hydrogen storage

Storage (COSY)	project				
Fluorine Substituted High Capacity Hydrides for Hydrogen Storage at Low Working Temperatures (FLYHY)	EU FP7	345 k€	2009	PI for UNITO	Investigations on fluorine substitutions in complex hydrides for hydrogen storage
Solid State Hydrogen Storage Tank (SSH2S)	EU FP7 FCH JU	1.6 M€ (whole project) 450 k€ (UNITO)	2011	Project coordinator	Development of a solid-state hydrogen storage tank based on a combination of metal and complex hydrides for application as auxiliary power unit
Hydrogen storage tank based on metal hydrides (H2FC)	Regione Piemonte	132 k€	2012	PI for UNITO	Test and FEM simulation for solid-state hydrogen tanks
Boron based hydrogen storage materials (BOR4STORE)	EU FP7 FCH JU	254 k€	2012	PI for UNITO	Study of boron-based complex hydrides for hydrogen storage
Energy storage by hydrogen (STERIN)	Regione Piemonte	15 k€	2013	PI for UNITO	Analysis of energy storage solutions, comparing batteries with hydrogen
Metal hydrides hydrogen storage tanks for naval applications (FAH2FC)	Regione Piemonte	33 k€	2013	PI for UNITO	Analysis of metal hydrides hydrogen storage tanks for naval applications
Hydrogen absorption in alloys	ENEL	30 k€	2013-2014	PI for UNITO	Study on metallic materials for hydrogen absorption
Hydrogen driven drone (DRONHy and CleanDRONHy)	Regione Piemonte	35 k€	2015-2017	PI for UNITO	Development of a hydrogen-driven drone
Hydrides for radiation shielding (ROSSINI 2-3)	ESA THALES ALENIA SPACE	85 k€	2014-2028	PI for UNITO	Study on complex hydrides for shielding of cosmic radations
Hydrogen CArrier for Renewable Energy Storage (HyCARE)	EU H2020 FCH JU	3.0 M€ (whole project) 230 k€ (UNITO)	2018-2023	Project coordinator	Development of a hydrogen storage prototype up to 40 kg of hydrogen
Metal Hydride Hydrogen Storage Materials for Maritime Applications (NAVIRIS)	FINCANTIERI	30 k€	2020-2022	PI for UNITO	Support for an investigation on possible applications of Metal Hydride Hydrogen Storage Materials for Maritime

					Applications
Centro Nazionale Mobilità Sostenibile (MOST)	MUR PNRR	1.6 M€	2022-2025	PI for UNITO	Activities in the frame of Spoke 14 “Hydrogen and new fuels”
Digital and Sustainable North West Ecosystem (NODES)	MUR PNRR	150 k€	2022-2025	Member of the UNITO team	Activities in the frame of Spoke 1 “Aerospace and sustainable mobility” – Flagship Hydrogen

Curriculum vitae CO-PI

PERSONAL INFORMATION

Family name, First name: **Rizzi Paola**

Researcher unique identifier: orcid.org/0000-0002-3977-2839

Date of birth:

Nationality:

URL for web site: https://www.chimica.unito.it/do/docenti.pl/Show?_id=prizzi#tab-profilo

- **EDUCATION**

1997 PhD in Chemistry
Department of Chemistry, University of Torino, Italy
Name of PhD Supervisor: Prof. Livio Battezzati

1993 Master in Chemistry
Department of Chemistry, University of Torino, Italy

- **CURRENT POSITION(S)**

2022 – now **Full professor** in **Materials Science and Technology** (SSD ING-IND/22)
Department of Chemistry, University of Torino, Italy

- **PREVIOUS POSITIONS**

2014 – 2022 Associated professor
Department of Chemistry, University of Torino, Italy

2004 – 2014 Researcher
Department of Chemistry, University of Torino, Italy

1998 – 2044 Technician
Department of Chemistry, University of Torino, Italy

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

2004 – 2024 Number of Postdocs: 4/ PhD: 6/ Master Students: 25
Department of Chemistry, University of Torino, Italy

- **ORGANISATION OF SCIENTIFIC MEETINGS**

2013 Member of the organising committee of the **ISMANAM conference**, Torino, Italy

- **INSTITUTIONAL RESPONSIBILITIES**

1198 – now Member of the Department of Chemistry, University of Torino, Italy
2005 – 2008 Member of the Department Committee "**Department council**", Department of Chemistry, University of Torino, Italy
2015 – 2018 Member of the Department Committee "**Research committee**", Department of Chemistry, University of Torino, Italy
2018 – 2020 Member of the **Scientific Board** of the **PhD in T4C – Technologies for Cultural Heritage** University of Torino, Italy
2018 – 2020 Member of the **Scientific Board** of the **PhD in Chemical and Materials Sciences** University of Torino, Italy
2023 - now **Head of the Bachelor Course** in **Materials Science** at the University of Torino, Italy

- **REVIEWING ACTIVITIES**

2018 – 2020 Member of the **Scientific Advisory Board** of the **European Project**: BioTiNet (G.A. no. 264635)

- **MAJOR COLLABORATIONS (if applicable)**

Since the beginning of the scientific activity, several **national and international collaborations** have been developed.

Results of the scientific activities can be found in

- ORCID: https://orcid.org/0000-0002-3977-2839
- ResearchID: https://www.webofscience.com/wos/author/record/14112695
- Scopus: https://www-scopus-com.bibliopass.unito.it/authid/detail.uri?authorId=7003375786
- Research Gate: https://www.researchgate.net/profile/Paola-Rizzi
- Google Scholar: https://scholar.google.com/citations?user=519MVuIAAAAJ&hl=en

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

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current proposal*
Bioremia	H2020-MSCA-ITN-2019	248 k€	2020-2024	PI for UNITO	Ti-based metallic materials
Nerehydes	PRIN	71 k€	2023-2025	PI for UNITO	Hydrides for hydrogen storage
ENEA-UNITO	ENEA	90 k€	2023-2025	PI for UNITO	Social and environmental impacts of hydrogen technologies

Curriculum vitae

PERSONAL INFORMATION

Family name, First name: **Palumbo Mauro**
Researcher unique identifier(s): ORCID 0000-0002-0689-0839, Scopus Author ID 7102570031
Date of birth:
Nationality:
URL for web site: https://www.chemistry.unito.it/do/docenti.pl/Show?_id=mpalumbo#tab-profilo

- **EDUCATION**

2004	PhD in Materials Science Department of Chemistry, Università di Torino, Torino, Italy Name of PhD Supervisor: Prof. Livio Battezzati
2001	Master in Materials Science, cum laude Department of Chemistry, Università di Torino, Torino, Italy
2019	Master (I livello) in "Cybersecurity", Università di Pisa - CNR, Pisa, Italy

- **CURRENT POSITION(S)**

2020 –	**Associate Professor** in **Materials Science and Technology** (SSD ING-IND/22) Department of Chemistry, Università di Torino, Torino, Italy

- **PREVIOUS POSITIONS**

2018 – 2019	**Security System Engineer** Aizoon Technology Consulting, Torino, Italy
2015 – 2017	**Postdoc** researcher (Assegni di ricerca) Scuola Internazionale Superiore di Studi Avanzati (SISSA), Trieste, Italy
2009 – 2015	**Assistant researcher** ICAMS (International Centre for Advanced Materials Simulations), Ruhr University Bochum, Bochum, Germany
2008 – 2009	**Postdoc** researcher NIMS (National Institute for Materials Science), Tsukuba, Japan
2004 – 2008	**Postdoc** researcher (Assegni di ricerca) Department of Chemistry, Università di Torino, Torino, Italy

- **FELLOWSHIPS AND AWARDS**

2009	Best poster award at **CALPHAD** XXXVIII **Conference**, Prague, Czech Republic
2010 – 2015	**Invited research** at NIMS (National Institute for Materials Science), Tsukuba, Japan

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

2020 – Number of Postdocs 1 / PhD 1 / Master Students 6
Department of Chemistry, Università di Torino, Torino, Italy

- **INSTITUTIONAL RESPONSIBILITIES**

2020 – Department member, Department of Chemistry, Università di Torino, Torino, Italy
2021 – Member of the **Education Committee**, Department of Chemistry, Università di Torino, Torino, Italy
2022 – Member of the **Centro Nazionale HPC**, Big Data and Quantum Computing, Ministero dell'Università e della Ricerca, Italy
2020 – 2021 Member of the **Orientation Committee**, Department of Chemistry, Università di Torino, Torino, Italy

- **REVIEWING ACTIVITIES**

Referee for several international journals: CALPHAD, Intermetallics, Journal of Alloys and Compounds, Philosophical Magazine, International Journal of Hydrogen and Energy, Materials Science and Engineering, Journal of Metallurgy, International Journal of Materials Research, Metals, etc.

- **MEMBERSHIPS OF SCIENTIFIC SOCIETIES**

2020 – Member, **Research Network** "*Associazione Italiana Metallurgia*"
2020 – Member, **Research Network** "*Consorzio Interuniversitario Nazionale per la Scienza e Tecnologia dei Materiali*"

- **MAJOR COLLABORATIONS**

Dr. V. Stavila, Dr. M. Witman, Machine learning models for metallic hydrides, SANDIA National Laboratories, Livermore, California, USA
Dr. M. Ghidelli, High entropy alloys and hydrogen storage materials, Laboratoire des Sciences des Procédés et des Matériaux, LSPM, Paris, France
Prof. G. Cacciamani, Thermodynamic modeling of metallic alloys, Dipartimento di Chimica, Università di Genova, Italy
Dr. J.-M. Joubert, Dr. J.-C. Crivello, DFT and thermodynamic modelling of TCP phases and Ni-base superalloys, Institut de Chimie et des Matériaux, Paris-Est, ICMPE – CNRS – UPEC, France
Dr. S. G. Fries, Dr. T. Hammerschmidt, DFT and thermodynamic modelling, Ruhr University Bochum, Bochum, Germany
Dr. A. Pasturel, N. Jackse, DFT calculations, SIMAP, UGA, CNRS 5266, Saint-Martin d'Hères, France

Results of the scientific activities can be found in

- ORCID: https://orcid.org/0000-0002-0689-0839
- ResearchID: https://www.webofscience.com/wos/author/record/1093846
- Scopus: https://www-scopus-com.bibliopass.unito.it/authid/detail.uri?authorId=7102570031
- Research Gate: https://www.researchgate.net/profile/Mauro-Palumbo-3
- Google Scholar: https://scholar.google.it/citations?user=BrOCyXMAAAAJ&hl=it

IL LEGALE RAPPRESENTANTE

Il Rettore dell'Università degli Studi di Torino

Prof. Stefano Geuna

Firmato digitalmente