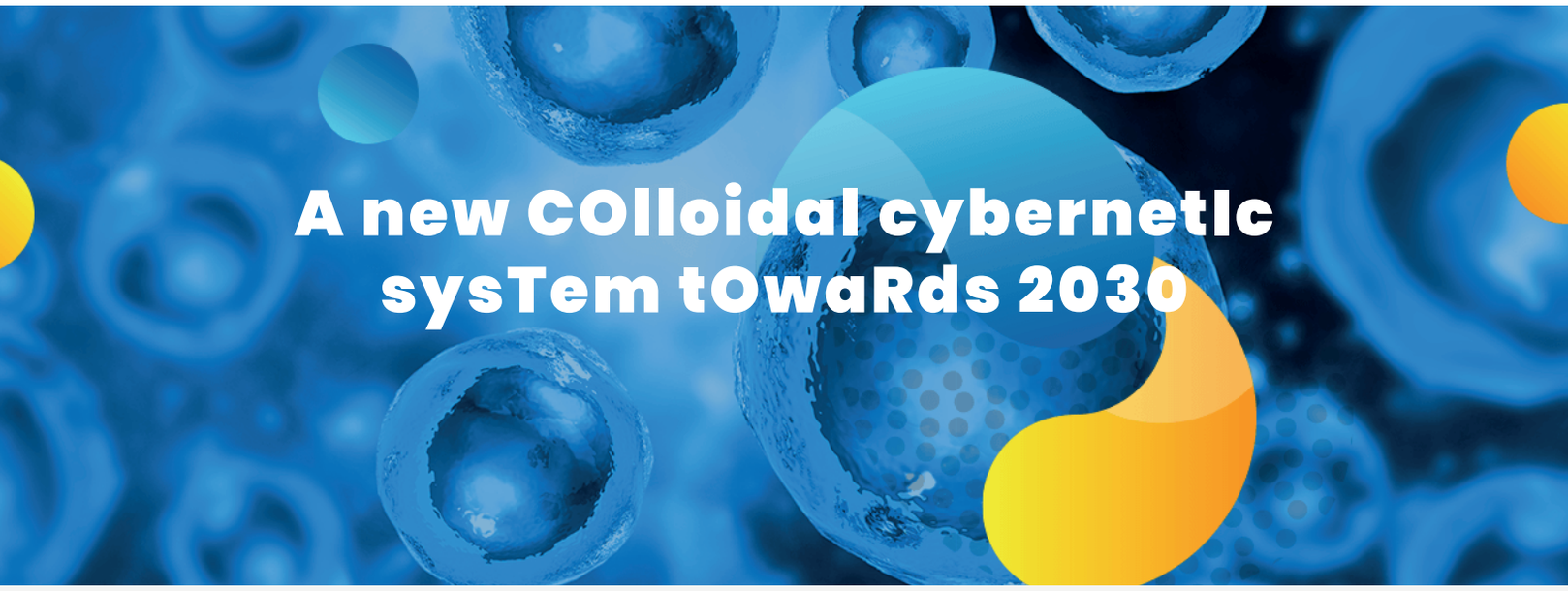
COgITOR



A new COlloidal cybernetIc sysTem tOwaRds 2030

LETS' FIND OUT MORE ABOUT COGITOR ACHIEVEMENTS!

COgITOR is a project funded under the topic H2020-FETOPEN-2018-2020 / H2020-FETOPEN-2018-2019-2020-01 programme, aiming at developing a liquid state cybernetic system prototype. Holonomic memory and computing, pressure sensing, and energy harvesting from thermal gradients will be achieved using colloids. The prototype will be tested in extreme environments for potential space applications.

The COgITOR project has reached a level of maturity which is particularly relevant in the field of computing with colloids. Never before the COgITOR project we could think about using a liquid to perform any sort of calculus, and now after opening such new route, the entire consortium is exploring the unprecedented possibilities of building logical gates, systems that can learn and remember, sensors and switches.

Different self-healing skins have been developed, focusing on combining soft polymers and nanoclay (Figure 1.1). These systems are designed to respond to external stimuli, such as heat, by introducing dynamic bonds into the molecular chains of the polymer (thermoplastic polyurethane), facilitating thermally activated reversibility. This means that when a polymer like this is damaged, it can easily recover its full shape and properties after being "healed" with a source of heat. Tests showed that as the healing temperature increased, the reaction rate of the reversible bond exchange also gradually increased, resulting in a faster healing process (Figure 1.2). This allowed the materials to regenerate and maintain their structural properties after damage. Additionally, the interaction between the nanoclay and thermoplastic polyurethane polymer matrix demonstrated enhanced thermal resistance and robust mechanical properties for the skins (Figure 1.3). For our robot skin, we need to find a strong material that survives also in harsh conditions, yet maintaining its softness. These skins were strategically developed to be 3D printed, enabling the creation of complex objects, such as a soccer ball composed by hexagonal and pentagonal tiles, to protect functional colloids.

Thanks to this combination of self-healing, thermal resistance, and mechanical strength, the useful life of these systems can be extended, and the range of conditions where the COgITOR prototype will survive will be consequently broad. Simultaneously, other composites based on thermoplastic polyurethane and plasmonic nanoparticles are being developed to enhance the self-healing process further: our idea is to use light instead of heat to induce the healing, once the polymer has been damaged. This will be a fast and cheap healing method, featuring important fall-outs in the real world applications: imagine to heal scratches on your car by shining a laser pointer in a few seconds!

Figure 1.1. Self-healing skins

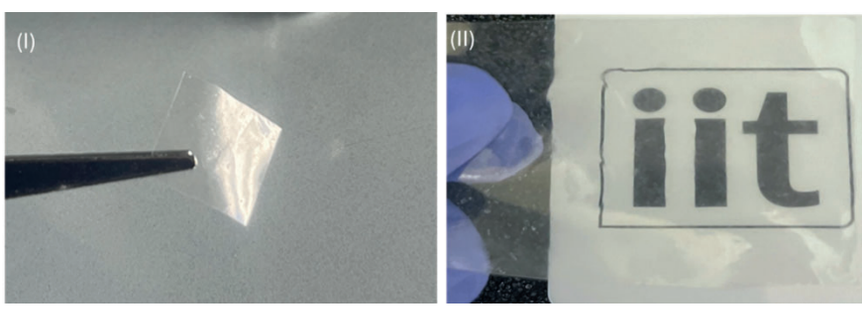
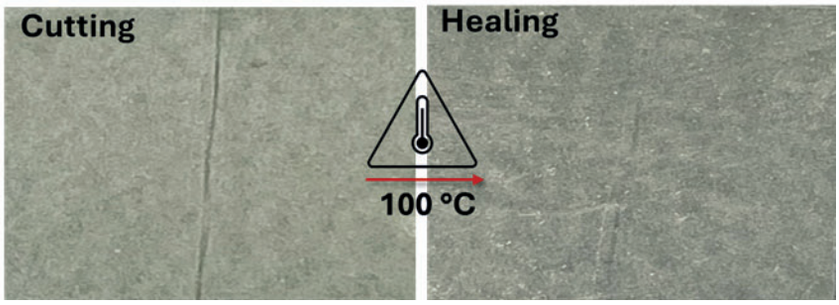
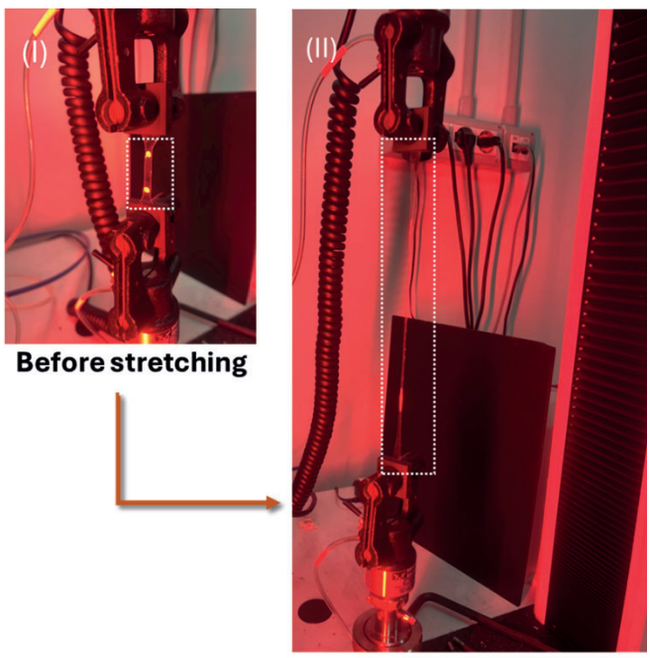


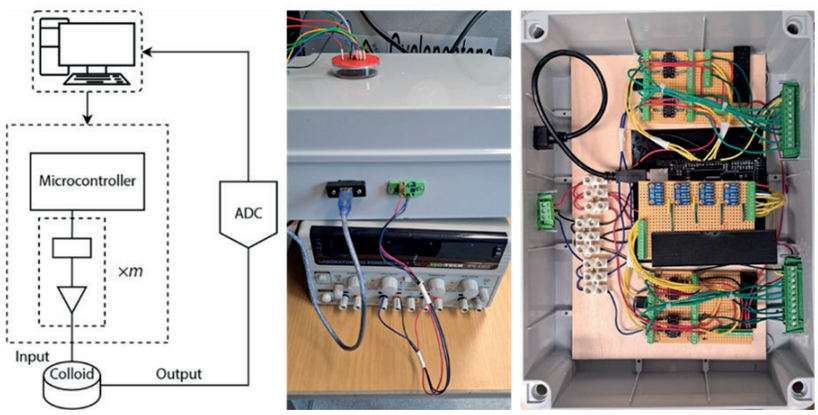
Figure 1.2. Image showing the self-healing process of a crack in the nanoclay/polyurethane composite skin



1.3. Nanoclay/polyurethane composite skin under tensile test

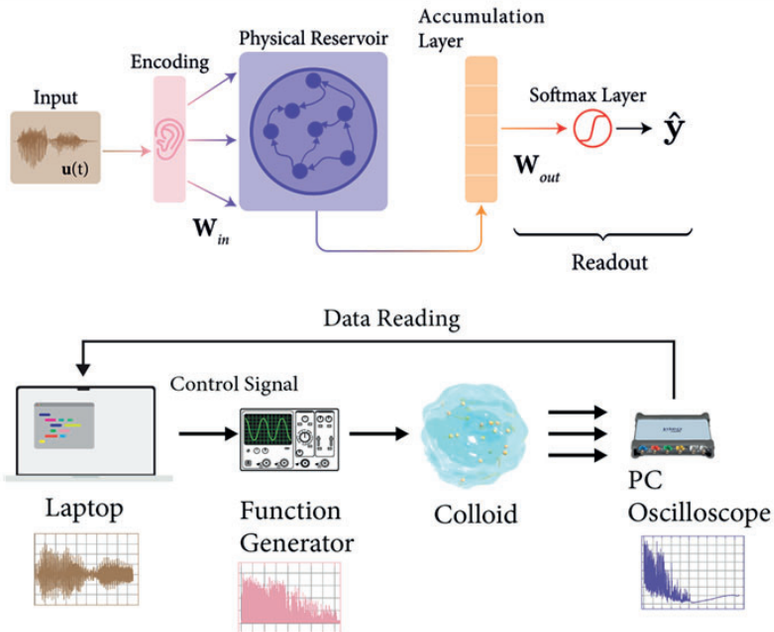


Fault Tolerant Boolean Functions in Proteinoids-ZnO Colloid



We proposed an approach to construct adaptable and fault-tolerant logic gates with 2,4 and 8-bit input strings in a mixture of ZnO colloids and proteinoids (P-ZnO).

Towards Liquid Neuromorphic Processors: Colloidal Solutions for Reservoir Computing



In this study, we presented as a physical reservoir for spoken digit recognition tasks using reservoir computing. The colloidal reservoir was able to encode temporal audio data from the dataset and was coupled with a trained readout layer for classification. In a speaker independent scenario, we achieved an average accuracy of 82.15% when trained and tested on individual speakers, demonstrating the reservoir's ability to effectively separate and classify different spoken digits.

While continuing the synthesis and assessment of polymer actuators and sensors, Empa decided to begin fabricating handy objects as deliverables. Thus, Empa has manufactured structural models of soccer-ball shaped soft robots, based on design suggestions previously made by the coordinator. See Figure 1, where the models are assembled by segments with hexagon and pentagon symmetry, with hollow compartments inside that can be filled with thermal energy harvesting liquid dispersions. The segments are 3D printed from various polymers and are connected with neighboring segments by channels and tubes.

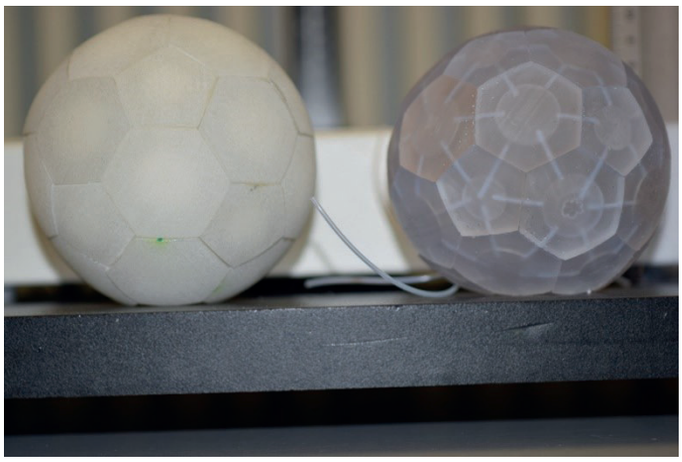


Figure 1: Soccer ball-shaped models of the COgITOR soft robot, assembled from 3d printed polymer segments with pentagon and hexagon symmetry.

Photo by Dr. Artur Braun, Empa.

Since the COgITOR robot is designed to work under extreme environments including space missions, Empa has begun testing two such models at the Sphinx Laboratory of the High Altitude Research Stations at Jungfraujoch in Switzerland, 3572 meters above sea level (Figure 2), where cosmic radiation is over 10 times stronger than at sea level.

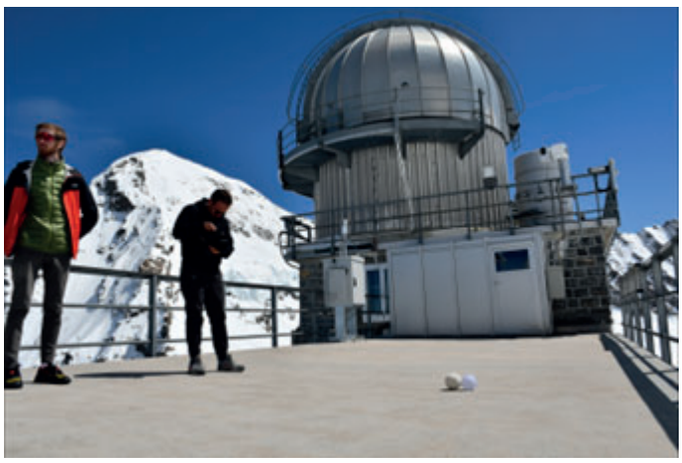


Figure 2: Empa postdocs Dr. Nikolay Ryzhkov and Dr. Alexey Rulev at the Sphinx Laboratory of the High Altitude Research Stations at Jungfraujoch in Switzerland, 3572 meters above sea level, with two soccer ball-shaped models of the COgITOR soft robot.

Photo by Dr. Artur Braun, Empa.

The polymer film stretching device, which was designed and built in 2023 for the recording of electrical impedance data of elastic films under strain [Braun 2024], is now being improved for time-saving automatic, unattended operation.

As promised in the COgITOR proposal, Empa produced a video [Braun 2023], featuring two materials scientists interviewing each other (Figure 3) and allowing a brief glimpse in the daily work of researchers.

Figure 3: Empa/ETHZ ESKAS Fellow Dr. Kwanele Kunene and former Empa COgITOR postdoc Dr. Loghman Jamilpanah in the COgITOR video.

Empa Co-PI Artur Braun organized with Minkyu Kim from Univ. of Arizona, Danielle Mai from Stanford University, and Newaye Medhin from Addis Ababa University (Ethiopia) the Symposium SB11 [Kim 2023] "Bio-based and Biomimetic Polymers in Soft Robotics" at the Materials Research Society Spring Meeting 2024 (Figure 4),

https://www.mrs.org/meetings-events/spring-meetings-exhibits/2024-mrs-spring-meeting/call-for-papers/detail/2024_mrs_spring_meeting/sb11/Symposium_SB11

2024 MRS SPRING MEETING & EXHIBIT

April 22-26, 2024 | Seattle, Washington
May 7-9, 2024 | Virtual

CALL FOR PAPERS

Abstract Submission Opens
Monday, September 25, 2023

Abstract Submission Closes
Thursday, October 26, 2023 (11:59 PM ET)

Symposium SB11: Bio-based and Biomimetic Polymers in Soft Robotics

Robots are anticipated to becoming an indispensable part of our daily lives. Traditional robots (e.g., autonomous vacuum cleaners) are expected to transform into more complex robots to care for the ill, or collaborate with human beings in difficult working environments from underwater and space operations to minimally invasive surgeries. Exoskeletal robots can enhance the physical capabilities of human body, and the components of robots can be implanted into the human as active prostheses that are controlled through human-machine interfacing. To accomplish these expected tasks, next-generation robots will require functional soft materials. Specifically, for a better robot-human interface, a soft, flexible, and dynamic outer layer is necessary to cover the rigid, stiff surface of robots, as the hard human skeletal system is covered by soft skin. The motivation for this Symposium originates from the suitability of multifunctional polymer films as artificial skins for robots, which allow for all-terrain adaptability and mobility. In the ideal case, the skin of such robot can withstand extreme environments while maintaining its functions, such as sensing, energy conversion and storage, actuating, computing information, and the self-healing - once damages and injuries occur on the skin. Furthermore, biocompatibility, including foreign body reactions, and immune responses, should be addressed for long-term contact between human skin and robot skin in the example of active prostheses. It is believed that adapting bioinspired, bio-enabled, and biomimetic polymeric materials is the approach to providing innovation for the future of robotics. Therefore, it is the aim of this Symposium is to stimulate the collaboration of scientists and engineers who are working in robotics, synthetic chemistry, biochemistry, physiology, biology, biomaterial science, and conventional materials science.

Topics will include:

- Soft robots
- Biomimetic materials
- Bio-enabled materials
- Shape-memory materials
- Protein-based polymeric materials
- Stimuli-responsive polymers
- Self-healable polymers
- Sensors and actuators
- Artificial detectors and skins
- Polymer heterostructures, laminates and composites
- Dynamics of/in polymers
- Analysis, assessment, and diagnostics of soft matter

A **tutorial** complementing this symposium is tentatively planned. Further information will be included in the MRS Program that will be available online in January.

Invited speakers include:

Zhenan Bao	Stanford University, USA	**Wendimagegne Mammo**	Addis Ababa University, Ethiopia
Gurthwin Bosman	Stellenbosch University, South Africa	**Abdon Pena-Francesch**	University of Michigan, USA
Blair Brettmann	Georgia Institute of Technology, USA	**Huisheng Peng**	Fudan University, China
Qing Chen	Empa–Swiss Federal Laboratories for Materials Science and Technology, Switzerland	**Ritu Raman**	Massachusetts Institute of Technology, USA
		John A. Rogers	Northwestern University, USA
Mmantsae M. Diale	University of Pretoria, South Africa	**Stephan V. Roth**	Deutsches Elektronen-Synchrotron, Germany
Michael Dickey	North Carolina State University, USA	**Niyazi Serdar Sariciftci**	Johannes Kepler Universität Linz, Austria
Peter Fratzl	Max Planck Institute of Colloids and Interfaces, Germany	**Robert Shepherd**	Cornell University, USA
		Helen Tran	University of Toronto, Canada
David Gracias	Johns Hopkins University, USA	**Jie Xu**	Argonne National Laboratory, USA
Olle Inganas	Linköping University, Sweden	**Shu Yang**	University of Pennsylvania, USA
Christoph Keplinger	Max Planck Institute for Intelligent Systems, Germany		
Tjaart Kruger	University of Pretoria, South Africa		

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Figure 4: Call for Proposals for the Symposium on Soft Robotics at the MRS Spring Meeting 2024.

COgITOR postdoc scientist Dr. Qing Chen delivered an invited talk at the Annual Spring Meeting of the Deutsche Physikalische Gesellschaft in Berlin in the Session Responsive and Adaptive Systems II, March 22, 2024 with title "A hierarchical fabrication strategy for multi-responsive actuators with structural reconfiguration-assisted self-healing ability".

https://www.dpg-verhandlungen.de/year/2024/conference/berlin/part/cpp/session/53/contribution/1?lang=en

Dr. Qing Chen also presented (Figure 5) at the Materials Research Society Spring Meeting 2024 in Seattle, United States, on April 23rd the talk "The Design, Fabrication and Structural Modeling of Biomimetic Soft Materials for Robotic Applications" as JMR Distinguished Invited Speaker.

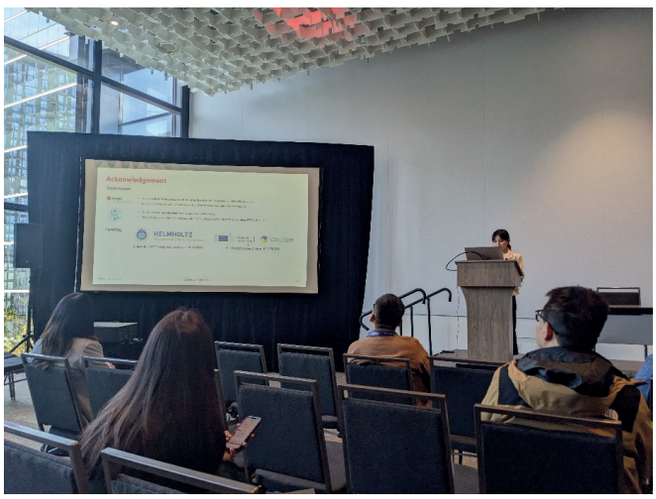

Figure 5: Dr. Qing Chen, Empa, presenting a COgITOR as JMR Distinguished Invited Speaker at the MRS Spring Meeting 2024 in Seattle, WA, United States. (Photo by Prof. Michael Dickey, North Carolina State University).

The status "JMR Distinguished Invited Speaker" has been awarded to only 11 out of the ~ 3'500 attendees of the MRS Spring Meeting 2024 (Figure 6). It is worthwhile to mention – that Empa's Dr. Qing Chen is the only non-Professor out of these 11 high profile researchers. For a postdoc, this is a noteworthy award and accomplishment.

Figure 6: List of 11 JMR Distinguished Invited Speakers at MRS Spring Meeting 2024 in Seattle, USA. Photo by Professor Bharat Yalan, University of Minnesota.

Meanwhile, the first of a series of COgITOR manuscripts from the Empa group has been published in Advanced Functional Materials, with open access [Chen 2024]. This article also appears in: Hot Topic: Robotics.

In the course of the project, several students and postdocs, unnamed here and not supported by COgITOR, have contributed to the project by assistance, experiments, and production.

Former Empa COgITOR postdoc Dr. Jamilpanah and Empa COgITOR scientist Dr. Chen left Empa in May and April 2024, as their working contracts finished on time. Co-PI Dr. Artur Braun remembers both for their fruitful contributions to the success of COgITOR.

With the funds now exhausted at Empa, pending final contributions to COgITOR will be the Sensing Report (Deliverable), and further publication of manuscripts.

[Braun 2023] Braun A, Chen Q. Braun A. Film or Broadcast. COgITOR Soft Robot.2023.Switzerland. https://youtu.be/TXSDzKzz-ZE

[Braun 2024] Braun A: Device for controlled stretching of flexible films and fibers for performing electrical impedance spectroscopy and DC conductivity. Zenodo; 2024. doi: 10.5281/zenodo.10651676.

[Chen 2024] Chen Q, Künniger T, Song Q, Zhang K, Chumakov A, Bulut Y, Harder C, Müller-Buschbaum P, Roth SV, Braun A: Hygro-dynamic and conductive actuator that heals and activates by water Advanced Functional Materials 2024.doi: 10.1002/adfm.202402924

[Kim 2023] Kim M, Mai D, Braun A, Tegegne N: Call for Papers: MRS Spring Meeting 2024 Symposium SB11: Bio-based and Biomimetic Polymers in Soft Robotics. pp. 1. Warrendale PA, United States: Materials Research Society; 2023:1. doi: 10.5281/zenodo.10719584.

PlasmaChem

“PlasmaChem is intensifying its activities in the further development of mixed oxide. Besides of successful improvement of the purity of bismuth ferrite, further activities now include doping of the material with other metals. Another representative of mixed oxide – chromium copper oxide, a wide band-gap nanomaterial has been synthesized.”

Within WP6, CTECH led the partners in the knowledge management with appropriate IPR strategy and continues with the exploitation activities. Two **Key Exploitable Results (KERs)** were analysed:

1. Liquid State In-Memory Computing System (by IIT)

- Innovative computing system using non-toxic, inexpensive raw materials.
- Capable of operating under extreme conditions and demonstrating advanced neuromorphic processing.
- Potential applications: food industry (e.g., wine), AIoT, space exploration.
- Commercialization approach: forming a spin-off company, short-term services, and long-term product sales.

2. New Computation Material – Bismuth Ferrite (by PlasmaChem)

- Advanced material included in the company's portfolio, to be sold worldwide.

The **preliminary exploitation plan** included the characterization of the 2 KERs, their risk assessments and exploitation roadmap.

- Monthly exploitation meetings ensure alignment and progress in commercialization strategies.

A focus on creating a light business plan based on preliminary and tentative commercialization potential.

Dissemination and communication activities of the projects are continuously up and running. The materials such as brochures, posters and rollups have been renewed with the latest results achieved during this project year, and partners are widely spreading information about CogITOR most important updates through social media accounts, magazines and events attended.

CONSORTIUM

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EIDGENOSSISCHE MATERIALPRUFUNGS-UND FORSCHUNGSANSTALT (EMPA)
https://www.empa.ch

PLASMACHEM PRODUKTIONS-UND HANDEL GMBH
https://www.plasmachem.com

CIAOTECH Srl
https://www.pnoconsultants.com/it

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