2024 _Annual Report

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adolphe merkle institute
excellence in pure and applied nanoscience

About the
Adolphe Merkle Institute

The Adolphe Merkle Institute (AMI) is an independent competence center at the University of Fribourg that focuses on research and education in soft nanomaterials.

We owe our existence to Dr. Adolphe Merkle, a successful local entrepreneur who established the Adolphe Merkle Foundation to strengthen research and teaching at the University of Fribourg. His CHF 100 million endowment constitutes one of Switzerland's most important private donations in favor of academic research.

Founded in 2008, AMI is, in many aspects, unique in the landscape of Switzerland's research institutions. Our focus on soft nanomaterials is unmatched in Switzerland and beyond. Our research combines fundamental and application-oriented aspects in a multidisciplinary setting. Through collaborations with industrial partners, AMI aims to stimulate innovation, foster industrial competitiveness, and improve the quality of life.

Our researchers are currently organized into five primary and one junior research groups, which offer complementary expertise and interests in strategically important areas: BioNanomaterials, Polymer Chemistry and Materials, Soft Matter Physics, Biophysics, Food Science and Technology, and Mechanoresponsive Materials. Interdisciplinary collaborations between our researchers are the basis for the successful and efficient execution of complex research projects that transcend the boundaries of traditional scientific disciplines. This environment and world-class research facilities make AMI a desirable destination for master's and PhD students, postdocs, and senior researchers.

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Expanding our horizons
_ A message from the Director

Prof. Ullrich Steiner

Dear reader,

The Adolphe Merkle Institute can proudly reflect on a transformative year marked by groundbreaking scientific discoveries, innovative collaborations, and strategic expansion. Most notably, we were thrilled to announce in 2024 the appointment of Prof. Hans Jörg 'Hanjo' Limbach as our new Chair of Food Science and Technology, representing a pivotal expansion of AMI's research horizon. A special thanks to the Adolphe Merkle Foundation, our University, and the Canton of Fribourg for making this possible. With his extensive industry experience at Nestlé and research background, Prof. Limbach brings a unique perspective that bridges fundamental nanoscience with consumer-driven food applications.

This year's research stories exemplify the breadth of our scientific endeavors. Our BioNanomaterials group has made remarkable strides in understanding how diesel exhaust particles interact with our lungs and has developed an improved method for studying how nutrients survive their journey through our digestive system. The Polymer Chemistry and Materials group followed the path of more sustainable materials, creating cellulose-based nanocomposites that could impact packaging applications. Our Smart Energy Materials team achieved a breakthrough in solar technology by engineering perovskite solar cells with adaptive photochromic layers, a potential shift toward dynamic interfaces that automatically adjust to environmental conditions. The BioPhysics group led investigations into nature-inspired ultra-thin membranes with potential applications spanning domains such as water treatment and medical devices. And our Soft Matter Physics team delved into the structural coloration of slime molds, expanding our understanding of biological photonic structures.

The NanoARTS program exemplified our commitment to transdisciplinary innovation, fostering unprecedented collaboration between Swiss artists and our scientists. Through carefully structured "tandem" partnerships, we witnessed the emergence of hybrid creations building on shared knowledge. Finally, with our new Knowledge and Technology Transfer manager, Dr. Ana Marques, AMI has reinforced its innovation framework, ensuring rapid translation of discoveries into real-world applications.

You will find more coverage of some of the achievements of our researchers in our "In Brief" section, with highlights from the last year that range from significant nominations to new collaborations and student achievements.

We hope you enjoy reading this report, and thank you for your interest in our institute, our team, and our activities.

Prof. Ullrich Steiner
Director, Adolphe Merkle Institute

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Pursuing excellence

NanoARTS

_ Arts meet science in the lab and in the studio

Artist Pedro Wirz's creations with Prof. Christoph Weder questioned perceptions of materials

The NanoARTS program, launched in 2022 as a collaboration between the Swiss Arts Council Pro Helvetia and the Adolphe Merkle Institute (AMI), marked a new milestone in transdisciplinary innovation for the Institute. By providing a unique framework, extended timeframes, and dedicated support, NanoARTS enabled the emergence of new forms of shared knowledge and creativity.

NanoARTS' goal was to tear down the walls between art and nanoscience by fostering collaborations between Swiss artists and scientists and conceived as a space for sustained and meaningful exchanges. The program's structure was based on the "tandem" model developed by Pro Helvetia. The first stage saw a variety of Swiss artists and AMI scientists form pairs after a workshop in early 2022, submitting joint proposals that articulated a shared vision for exploring the interface of art and nanoscience. These proposals were then evaluated by a transdisciplinary jury, ensuring that each partnership was grounded in mutual interest and complementary expertise.

The three selected tandems were given 12 to 18 months to develop their projects. This extended period enabled deep relationship-building, iterative creative development, and genuine knowledge exchange – key ingredients for those collaborations. The program's process-focused approach also highlighted that the connection established between the creative duos was as important as the final product.

Three projects

Each of the tandems chose a different approach to bridging art and nanoscience. For example, Claudia Christen, a visual artist, and Prof. Jessica Clough, head of the Mechanoresponsive Materials group, collaborated on "Painting with Light: The Darkroom of Nature." Their project explored the connections between nanoscience and photography, combining expertise in light, optics, and mechanochemical processes. Clough and Christen sought to develop innovative photography techniques merging science and art by incorporating their professional backgrounds to create a multi-layered project. Christen photographed AMI scientists and printed the images using an older alternative process called “platinum palladium printing.” Adding another layer illustrating the subject’s work added more depth to them as a person. According to Christen, this process also provided a contrast between high-tech lab work and the lower technology print process. Another experiment sought to print Christen’s photographs onto mechanochromic plastic screens prepared by Clough. The idea was to allow an observer to “write” without ink on the photograph, to share their own reflections, and to edit the memory depicted in the photograph.

Designer Yvo Goette and Prof. Alke Fink, the Co-Chair of BioNanomaterials, focused on the spatial visualization of crystalline micro- and nanostructures and their transitions. Their project, “Bigger Picture,” began with scientific imaging methods to visualize the micro- and nanostructure of materials. They then used a parametric computer-aided design approach to translate scientific data into 3D models, employing artistic design processes to reinterpret digital structures through various media such as holograms and virtual reality. This approach blurred the lines between technical analysis and creative expression, demonstrating how computational tools can serve both scientific and artistic purposes. The most imposing result of this collaboration was the Nano-Space, a large cubic spatial installation in which visitors could interact with and walk through 3D-visualizations of different nanostructures.

Finally, visual artist Pedro Wirz and Prof. Christoph Weder, the Chair of Polymer Chemistry and Materials, engaged in a dialogue about sustainability, technology, and nature. Their project, “Material Changes,” questioned the boundaries between natural and artificial materials, exploring themes such as recycling, reuse, and the role of nanostructures in both the natural world and technology. Through their evolving conversation, they created objects that documented their dialogue, suggesting that sustainability is not just a technical challenge but also a cultural one. The result was a series of artworks produced by Wirz, combining elements such as clay, found objects, recycled plastics, and Weder's shape-memory polymers. The works went on display in Zurich in the summer of 2024.

Science and art

NanoARTS revealed that both artists and scientists are driven by curiosity, creativity, and a desire to explore the unknown. By integrating empirical, quantitative scientific methods with the interpretive, qualitative approaches of art, the tandems produced hybrid research practices that neither discipline could achieve alone. For example, Christen and Clough’s project highlighted how both fields deal with light, optical signals, and mechanical processes, revealing shared conceptual foundations.

The program treated materials and scientific instruments not as passive objects or tools, but as active elements in the creative process. Polymers, for instance, served as both scientific subjects and artistic media, challenging the distinction between passive scientific specimens and active artistic materials. Advanced scientific imaging techniques were repurposed for the Bigger Picture project, questioning the traditional division between scientific visualization for data analysis and artistic visualization for aesthetic experience.

The Wirz-Weder collaboration challenged the conventional boundary between “natural” and “artificial” materials by examining how nanotechnology reveals structural similarities across these categories. This approach suggests that sustainability requires both technical solutions and cultural innovation, rather than relegating it to one domain or the other.

By emphasizing hands-on collaboration in laboratories and studios, the program also broke down the wall separating scientific investigation and artistic creation. Participants experienced firsthand how knowledge production in both domains involves embodied practices and tacit understanding that cannot be fully captured through written documentation.

Institutional support

The partnership between Pro Helvetia and AMI provided crucial institutional support, both legitimizing the interdisciplinary work and challenging the traditional separation of arts and sciences in academia and funding. Each tandem was supported by experts in art-science mediation mandated by Pro Helvetia, who provided contextualizing workshops, common activities, and coaching throughout the process. The mediator played a crucial role in helping participants develop a shared language and navigate differences in professional cultures. This support system, developed by Pro Helvetia, acknowledges that art-science collaboration is both an art and a science, with participants needing help to understand each other’s perspectives. The program’s funding structure also ensured that artists could par-

Focusing on the Bigger Picture: Prof. Alke Fink and Yvo Goette

ticipate without financial burden, removing a practical barrier.

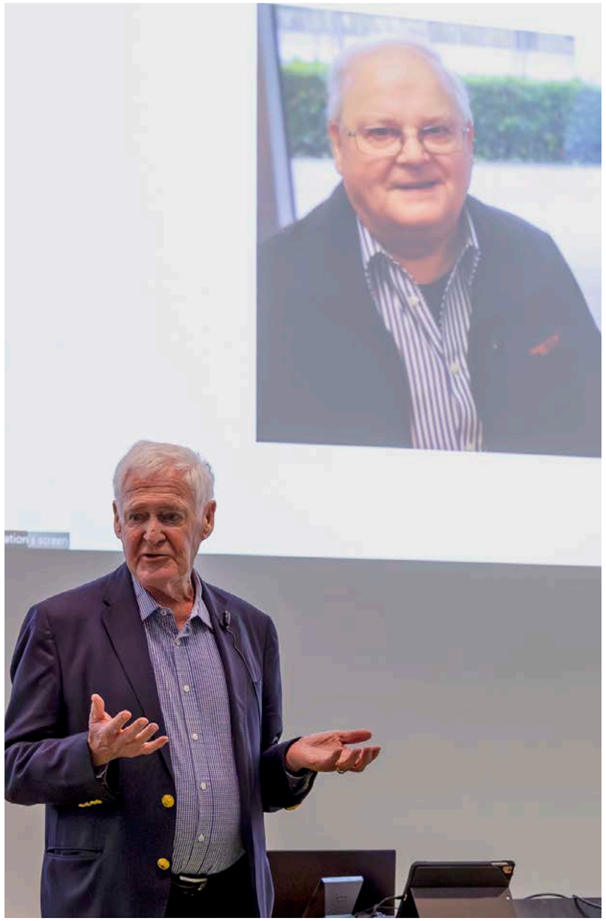
Most notably, the workshop and coaching elements helped participants translate between the empirical, quantitative approaches of science and the interpretive approaches of contemporary art, leading to genuine knowledge co-production.

Outreach

Public engagement was central to NanoARTS. In December 2023, the three tandems presented their ongoing projects at the NanoART Revolution Symposium in Timișoara, Romania, offering a glimpse into the collaborative process for an international audience. The program concluded with a final exhibition at AMI in November 2024, where the completed artworks were unveiled and the public was invited to interact with the tandems. These events underscored the program's commitment to treating both artistic and scientific outcomes as valuable forms of knowledge. The Institute has since purchased several of the artworks for public display.

The NanoARTS program's success suggests that the boundaries between art and science are not natural or inevitable but constructed divisions that can be productively challenged and transformed. By providing intentional design, comprehensive support systems, institutional backing, and recognition that knowledge production can benefit from the integration of multiple ways of knowing and creating, NanoARTS created the conditions for genuine transdisciplinary collaboration.

Scholarship
_ Funding for international internships



Dr. Richards Greaves presented Werner Kurth's donation

The Adolphe Merkle Institute received a significant donation from the late Werner Kurth. The donation was announced during AMI's 2024 Alumni Day in July. The Institute will establish scholarships for international students with the funds.

Mr. Kurth, a former employee of Vibro-Meter (now Parker Meggitt) during Dr. Adolphe Merkle's company ownership, passed away in 2023. He worked for the company for 50 years, notably as Director of Quality Assurance and as a management board member. In this capacity, he was responsible for establishing quality systems and controls to guarantee the airworthiness of the company's products, most of which are installed in commercial aircraft. His philanthropic decision was to donate a generous gift of CHF 147,000.

Dr. Richard Greaves, Meggitt's former Chief Technology Officer, was on hand to present the donation, as well as the Adolphe Merkle Foundation's president, Peter Huber. A number of current and former Meggitt employees were in attendance.

Greaves said that Mr. Kurth expressed a heartfelt wish for students to benefit from these funds. In response, AMI, which is deeply grateful for Mr. Kurth's donation, will establish scholarships for international students, allowing them to participate in short-term internships at our institute. The Adolphe Merkle Foundation will oversee the administration of these funds.

Alumni Day

The Alumni Day brought together former PhD students and researchers to celebrate the Institute's cutting-edge work in soft nanomaterials and materials science. It was an opportunity to present to the alumni five of AMI's research groups. AMI Director Prof. Ullrich Steiner welcomed attendees and provided insights into his Soft Matter Physics group's latest research. Mechanoresponsive Materials was represented by Prof. Jessica Clough, BioPhysics by Prof. Michael Mayer, BioNanomaterials by Profs. Barbara Rothen-Rutishauser and Alke Fink, and Polymer Chemistry and Materials by Prof. Chris Weder.

The program also featured talks by four accomplished alumni: Corinne Jud (BioNanomaterials), Ahu Dumanli-Parry (Soft Matter Physics), Matthieu Ayer (Polymer Chemistry and Materials), and Anirvan (Gogol) Guha (BioPhysics), who shared their post-AMI career journeys and research achievements.

The Meggitt attendees received a comprehensive tour of AMI's state-of-the-art facilities, gaining further insights into the cutting-edge research methodologies and scientific innovations driving the Institute's work. Following the tour, attendees gathered for lunch in gardens, creating an ideal setting for meaningful networking conversations and the opportunity to reconnect with former colleagues and guests. The day was rounded out with further social activities with AMI staff and alumni.

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NATIONALITIES

PRESENT AT AMI WITH REPRESENTATIVES FROM EVERY INHABITED CONTINENT.

7

PROFESSORS

WORKING ACROSS THE FIELDS OF POLYMER SCIENCE, MATERIALS, PHYSICS, CHEMISTRY, AND BIOLOGY.

64%

OF ALL RESEARCH EXPENDITURES

WERE COVERED BY THIRD-PARTY FUNDING.
SOURCES INCLUDED THE SWISS NATIONAL SCIENCE FOUNDATION, THE EUROPEAN UNION, INNOSUISSE, AND INDUSTRIAL PARTNERS.

OVER

6,599

CITATIONS

OF AMI PUBLICATIONS IN THE SCIENTIFIC LITERATURE IN 2023.

4

APPLICATION-ORIENTED

PROJECTS

FINANCED BY INNOSUISSE, THE SWISS INNOVATION AGENCY, AND OTHER PARTNERS.

56

SCIENTIFIC PUBLICATIONS

IN TOP-RANKED JOURNALS SUCH AS NATURE, NATURE CHEMISTRY, ANGEWANDTE CHEMIE, SMALL, ACS NANO, PARTICLE AND FIBRE TOXICOLOGY, NATURE NANOTECHNOLOGY, CURRENT RESEARCH IN FOOD SCIENCE, JOURNAL OF THE AMERICAN CHEMICAL SOCIETY.

500+

ALUMNI

INCLUDING POSTDOCTORAL RESEARCHERS, PHD STUDENTS AND INTERNS.


Applying research
_ Moving from bench to business

Dr. Ana Marques's career has straddled academia and innovation

Dr. Ana Marques joined AMI in January 2024 as Knowledge and Technology Transfer manager. She brings experience in research and start-ups with expertise in intellectual property, innovation strategy, and collaboration.

How do you position innovation within AMI's mission?

Ana Marques: At the Adolphe Merkle Institute (AMI), innovation is inseparable from our core mission of advancing fundamental research. By pushing the boundaries of scientific knowledge in fields ranging from soft matter physics to nanoscale imaging, we lay the groundwork for new technologies and applications. Our role is to recognize when discoveries have potential applications beyond the laboratory and help our researchers turn them into real-world solutions, We work with our researchers to protect their results, increase market readiness of these promising technologies, and support them in attracting third-party funding, creating start-ups from within AMI, or building partnerships with external stakeholders such as industry, government agencies, and non-profit organizations. For us, innovation is not an add-on, but part of the research journey, and we make it a priority to train the next generation of scientists, instilling in them the mindset and skill set required to recognize the societal relevance of their work and to navigate the path from the bench to practical applications.

How does your technology-transfer framework operate?

Over the past decade, we've established a flexible framework that adapts to the needs of the projects and leading researchers. We match expertise in areas such as biomimetic adhesives or photonics with industrial and public-sector partners to ensure our research translates into real-world value. Our framework brings together innovation training, invention harvesting, and protection and support for partnership and commercialization, both through partnering or start-up creation. By working collaboratively, we strive to provide timely and relevant support that allows rapid translation decisions on promising results, ensuring that neither research dissemination nor partner engagement are delayed.

How do you balance academic objectives with commercial goals?

At the heart of our approach is the conviction that the value of AMI's fundamental research increases when discoveries are connected to real-world needs, and that the best way to achieve this is by training our researchers. Together with local partners, we provide courses on IP and innovation and promote regular exchanges with industry. I also encourage early discussions with researchers to help plan dissemination in ways that respect academic goals while opening doors to future applications. In addition, our IP board, which brings together technical and business expertise, reviews invention disclosures rapidly, ensuring that protection and publication can advance in parallel. We firmly believe that academic excellence and commercialization are complementary rather than conflicting.

How do you promote innovation among students and researchers?

We promote innovation by giving our students and researchers a range of opportunities to present and explore their work. This can be as simple as meeting visitors to AMI to present their research, or attending in-house seminars and talks given by R&D leaders and successful entrepreneurs. We encourage our early-stage researchers to join pitching competitions, such as the Falling Walls Lab, the University of Fribourg's Science Slam, and Three-Minute Thesis events. We provide coaching and feedback for these events, helping researchers refine their messages, elaborate value propositions, and think about the market potential of their research and ideas. Alongside these, we provide the aforementioned opportunities to attend workshops covering subjects such as patent drafting and regulatory pathways. These are valuable soft skills that they can implement as they pursue their career paths in academia or industry.

What are some recent achievements and future ambitions?

AMI's innovation efforts have yielded tangible successes. For collaboration with the local cheese industry, we are applying our expertise in photonics to develop advanced markers that help prevent counterfeiting. In another case, our work on reversible adhesives inspired by natural shellac has grown into an Innosuisse-supported partnership with industry, with the potential to change how electronics, cars, and even robots are manufactured and recycled. We are also looking ahead: a new AMI Chair has been created, strategically positioned to work with local industry in ways that will also strengthen our global impact. And through events such as our Industry Day in January 2024, we continue to build strong links with partners. All of these efforts point to the same goal – ensuring that discoveries made at AMI can bring real benefits to society.

Industry Day 2024

This half-day event was designed to connect with potential external partners. AMI welcomed over 20 industry representatives to the institute's facilities. It followed a format aimed at maximizing networking opportunities and knowledge transfer.

The event included presentations from AMI's professors showcasing their research portfolios. These presentations highlighted research areas such as structural color alternatives to dyes and pigments, soft implantable batteries, and single molecule detection technologies.

A distinctive feature of the day was the three-minute project presentations by PhD students and postdocs, specifically designed to assist local employment opportunities. This was designed to allow emerging researchers to showcase their work while providing industry partners direct access to highly qualified talent.

The event concluded with structured networking and brainstorming sessions where participants could discuss collaboration ideas with AMI professors and their teams, explore current innovation projects from the University of Fribourg, and meet students interested in employment opportunities.

The AMI Industry Day was an opportunity to meet potential partners

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ACTIVE RESEARCH PROJECTS

IN FIELDS SUCH AS BIO-INSPIRED MATERIALS, PEROVSKITE SOLAR CELLS, PHOTONIC STRUCTURAL MATERIALS, MECHANOCHEMISTRY, SUPRAMOLECULAR POLYMERS, DETECTION AND CHARACTERIZATION OF NANOPARTICLES, NANOPORE FABRICATION, SINGLE-MOLECULE DETECTION.

CHF 9.43 M

SPENT OVERALL IN 2024

RESEARCH EXPENDITURES REACHED CHF 8 MILLION, A SLIGHT INCREASE OVER 2023.

47%

OF STAFF AT AMI ARE WOMEN

36

SEMINARS

INCLUDING 4 GIVEN BY AMI PHD STUDENTS.

99

PEOPLE

WORKED AT AMI AT THE END OF 2024 INCLUDING PHD STUDENTS, POSTDOCTORAL RESEARCHERS, PROFESSORS, SUPPORT STAFF, AND INTERNS.

50%

OF OUR RESEARCHERS

ARE DOCTORAL STUDENTS.

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_Research at AMI

Sustainability

_ Advancing bio-based materials to reduce plastic pollution

Researchers from the Adolphe Merkle Institute's Polymer Chemistry and Materials group are working to reduce reliance on fossil-based plastics by creating advanced materials from cellulose, a renewable, plant-derived polymer. Two recent studies from the group demonstrate how cellulose-based materials can be tailored for either short-lived, biodegradable packaging or durable, high-performance applications.

Cellulose is the most abundant natural polymer on Earth. It forms the structural framework of plants and is found in wood, cotton, and agricultural waste. Industrially, cellulose is extracted from these sources using well-established pulping and chemical processes. While raw cellulose pulp is primarily used to produce paper, it can also be converted into plastic-like derivatives such as cellulose acetate or hydroxypropyl cellulose (HPC), which the AMI researchers used in one of their studies. Alternatively, cellulose pulp can be disintegrated into cellulose nanocrystals (CNCs). These tiny, rod-shaped particles are only a few nanometers wide and several hundred nanometers long. These highly crystalline particles are extremely stiff and strong, making them ideal as a reinforcing component in composite materials.

With the goal of replacing conventional plastics in food packaging – a major contributor to global plastic waste – the AMI researchers developed all-cellulose nanocomposite films by blending HPC with CNCs. Since both components originate from cellulose, the resulting materials are fully bio-based. Using simple mixing and solvent-casting techniques, the team produced transparent films containing up to 90% CNCs. PhD student Chris Rader, who led both studies, explains these nanocomposites were significantly stiffer and stronger than pure HPC and exhibited a tenfold improvement in oxygen barrier performance – a key property for preserving food. Films with moderate CNC content also showed reduced water vapor permeability and retained their mechanical integrity under humid conditions. "Importantly, all of the materials readily disintegrated in water, which may help reduce their environmental persistence if discarded," he added.

In a complementary study, the team pursued a different strategy: enhancing performance and durability by chemically grafting synthetic polymer chains directly onto CNC surfaces. This strategy afforded so-called "hairy nanoparticles," where flexible and rigid polymer segments are chemically attached to the CNCs and surround the latter. These hybrid particles self-assemble into nanostructured materials that combine strength, stiffness, and toughness. Compared to similar polymers without CNCs – or to traditional nanocomposites made by simple mixing – these new materials showed markedly improved mechanical performance. The key lies in the intimate molecular integration between the reinforcing CNCs and the polymer matrix, which prevents particle aggregation and ensures efficient load transfer.

"These two approaches target different application spaces – one emphasizing biodegradability and ease of processing, the other durability and mechanical performance – but they share a common vision: replacing conventional plastics with materials derived from a renewable and industrially scalable resource," said Rader. Together, these studies highlight the versatility of cellulose and underscore the importance of combining sustainability with functionality – a critical step toward a circular materials economy.

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Rader, C.; Fritz, P. W.; Ashirov, T.; Coskun, A.; Weder, C. One-Component Nanocomposites Made from Diblock Copolymer Grafted Cellulose Nanocrystals. *Biomacromolecules* **2024**, 25 (3), 1637–1648.

Rader, C.; Grillo, L.; Weder, C. Water and Oxygen Barrier Properties of All-Cellulose Nanocomposites. *Biomacromolecules* **2024,** 25 (3), 1906–1915.

Chris Rader joined AMI's Polymer Chemistry and Materials group in 2018 after completing his Master's degree at Virginia Tech in the United States. He successfully defended his PhD in 2023, and is currently a postdoctoral researcher at Empa, the Swiss Federal Laboratories for Materials Science and Technology.

Polymers

Team

Prof. Christoph Weder, Dr. Jose Berrocal, Luca Bertossi, Veronique Buclin, Dr. Satyajit Das, Dr. Linlin Deng, Jonas Eschmann, Matilde Folkesson, Dr. Georges Formon, Luca Grillo, Dr. Manon Guivier, Dr. James Hemmer, Xueqian Hu, Derek Kiebala, Benjamin Ladet, Davide Lardani, Davide de Luca, Chaninya Mak-lad, Marta Oggioni, Ilaria Onori, Chris Rader, Anita Roulin, Shohei Shimizu, Dr. Athanasios Skandalis, Nick Zahnd

Key Publications

1. Kiebala, D.J.; Dodero, A.; Weder, C.; Schrettl, S.; Optical monitoring of supramolecular interactions in polymers. *Angew. Chem. Int. Ed.* **2024**, 63, e202405922.

2. Onori I.; Formon, G.J.M.; Weder, C.; Berrocal, J.A. Toughening Healable Supramolecular Double Polymer Networks. *Chem. Eur. J.* **2024**, e202402511.

3. Hu, X.; Rigamonti, D.; Villa, I.; Pollice, L.; Mauri, M.; Molin, A. D.; Tardocchi, M.; Meinardi, F.; Weder, C.; Monguzzi, A. Sensitized Triplet–Triplet Annihilation in Nanostructured Polymeric Scintillators Allows for Pulse Shape Discrimination. *Advanced Materials* **2024**, 36 (28), 2400443.

4. Liu, P.; Jimaja, S.; Immel, S.; Thomas, C.; Mayer, M.; Weder, C.; Bruns, N. Mechanically Triggered On-Demand Degradation of Polymers Synthesized by Radical Polymerizations. *Nat. Chem.* **2024**, 16 (7), 1184–1192.

5. Sproncken, C. C. M.; Liu, P.; Monney, J.; Fall, W. S.; Pierucci, C.; Scholten, P. B. V.; Van Bueren, B.; Penedo, M.; Fantner, G. E.; Wensink, H. H.; Steiner, U.; Weder, C.; Bruns, N.; Mayer, M.; Ianiro, A. Large-Area, Self-Healing Block Copolymer Membranes for Energy Conversion. *Nature* **2024**, 630 (8018), 866–871.

Photochromic

_ "Sunglasses for solar cells" improve their stability

The Smart Energy Materials group at the Adolphe Merkle Institute has achieved a significant breakthrough in perovskite solar cell technology by developing a strategy that can automatically adapt to changing light conditions. This could potentially solve one of the biggest challenges preventing the widespread adoption of next-generation solar devices: long-term stability.

This innovative approach uses bioinspired compounds that change their properties when exposed to sunlight, creating self-adjusting protective layers that enhance both efficiency and durability.

Prof. Jovana Milic and colleagues integrated photochromic materials into perovskite solar cells, creating devices that dynamically respond to environmental conditions. Perovskite devices have shown tremendous promise due to their exceptional efficiency and low manufacturing costs compared to traditional silicon cells. However, their tendency to degrade rapidly under real-world conditions has limited commercial deployment.

The breakthrough centers on a specialized compound termed SINO (4-(1,3,3-trimethylspiro[indoline-2,3'-naphtho[2,1-b][1][2]oxazin]-6'-yl)benzoic acid), which belongs to a class of materials known as photochromic compounds. Their response to light resembles sunglasses that become lighter or darker depending on light conditions. These materials reversibly change their molecular structure when exposed to light. When integrated into solar cells, SINO acts like a molecular switch that responds to sunlight by altering its configuration to better protect the underlying components by reversibly changing interfacial properties.

The researchers demonstrated that this photochromic layer transforms between two distinct states when exposed to light. In bright conditions, the material adopts a configuration that helps suppress unwanted ion migration within the perovskite structure while simultaneously facilitating efficient charge extraction. This dual functionality addresses two critical challenges to perovskite solar technology.

The mechanism underlying these improvements involves sophisticated molecular interactions at the interface between the perovskite layer and the photochromic material. Advanced characterization methods showed that the material helps suppress unwanted ion migration, a primary cause of perovskite degradation, while simultaneously facilitating efficient charge extraction.

Laboratory testing also revealed photovoltaic performance improvements. Solar cells incorporating the SINO layer achieved power conversion efficiencies exceeding those of reference devices. More importantly for commercial viability, stability improved. Under simulated day-night cycling conditions that mimic real-world operation, SINO-treated cells maintained over 90% of their initial performance after 800 hours of testing, while conventional perovskite cells dropped to to around 80% efficiency.

While the current laboratory devices show promise, scaling this technology requires addressing manufacturing integration challenges. The researchers estimate that industrial implementation could extend perovskite panel lifespans up to two years over the current five years in field conditions – a critical threshold for competing with silicon solar cells' 25-year durability. Ongoing work focuses on optimizing deposition techniques to maintain the photochromic layer's responsiveness at scale, with pilot production trials anticipated by late 2026.

"This innovation represents a fundamental shift from traditional approaches that rely on static protective materials to dynamic, responsive interfaces that can adapt to changing operational conditions," said Milic. "This approach, inspired by natural systems that respond to environmental stimuli, opens new possibilities for creating more resilient optoelectronic devices."

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Prof. Jovana Milic joined the Institute in 2020 as a Swiss National Science Foundation PRIMA Fellow before being promoted to Assistant Professor the following year. After being awarded in 2023 a European Research Council (ERC) Starting Grant, she took up a position last year as an Associate Professor at the University of Turku in Finland. Milic remains affiliated with AMI.

Smart Energy Materials

Team

Prof. Jovana Milic, Ghewa Alsabeh, Dr. Gianluca Bravetti, Weifan Luo, Lorenzo Miele, Mengqiong Zhu

Key Publications

1. Ganaie, M. M.; Bravetti, G.; Sahu, S.; Kumar, M.; Milić, J. V. Resistive Switching in Benzylammonium-Based Ruddlesden–Popper Layered Hybrid Perovskites for Non-Volatile Memory and Neuromorphic Computing. *Mater. Adv.* **2024**, 5 (5), 1880–1886.

2. Dučinskas, A.; Jung, M.; Wang, Y.-R.; Milić, J. V.; Moia, D.; Grätzel, M.; Maier, J. Mixed Ionic-Electronic Conduction in Ruddlesden–Popper and Dion–Jacobson Layered Hybrid Perovskites with Aromatic Organic Spacers. *J. Mater. Chem. C* **2024**, 12 (22), 7909–7915.

3. Loizos, M.; Rogdakis, K.; Luo, W.; Zimmermann, P.; Hinderhofer, A.; Lukić, J.; Tountas, M.; Schreiber, F.; V. Milić, J.; Kymakis, E. Resistive Switching Memories with Enhanced Durability Enabled by Mixed-Dimensional Perfluoroarene Perovskite Heterostructures. *Nanoscale Horizons* **2024**, 9 (7), 1146–1154.

4. Ballestas, K.; Milić, J. V.; Ramírez, D. Interfacial Host–Guest Complexation for Inverted Perovskite Solar Cells. *The Journal of Chemical Physics* **2024**, 160 (20), 204712.

5. Luo, W.; Kim, S.; Lempesis, N.; Merten, L.; Kneschaurek, E.; Dankl, M.; Carnevali, V.; Agosta, L.; Slama, V.; VanOrman, Z.; Siczek, M.; Bury, W.; Gallant, B.; Kubicki, D. J.; Zalibera, M.; Piveteau, L.; Deconinck, M.; Guerrero-León, L. A.; Frei, A. T.; Gaina, P. A.; Carteau, E.; Zimmermann, P.; Hinderhofer, A.; Schreiber, F.; Moser, J.-E.; Vaynzof, Y.; Feldmann, S.; Seo, J.-Y.; Rothlisberger, U.; Milić, J. V. From Chalcogen Bonding to S–π Interactions in Hybrid Perovskite Photovoltaics. *Advanced Science* **2024**, 11 (32), 2405622.

Power interface

_ Electric fish inspire biomimetic membranes

Scientists from the Adolphe Merkle Institute's Bio-Physics group, together with research teams across Europe, have developed a novel membrane that takes its cue from the electric organs of rays and eels. This ultra-thin, self-repairing material combines several useful properties that could find applications in sustainable energy, water treatment, and medical devices.

Biological cell membranes do two jobs: they keep cells together and let the right tiny particles, ions, pass through. Nature strikes a perfect balance of strength and openness, but human-made membranes have always forced a trade-off: tough but leaky, or tight but fragile. The new membranes break that rule.

They are assembled at the interface between two immiscible, water-based solutions. A carefully chosen block copolymer – a polymer made of two segments with different affinities for water – accumulates at this boundary. By gently replacing an organic solvent with a second aqueous solution, the polymer chains align to form a continuous film just 35 nanometers thick, while covering areas up to 10 square centimeters. This method avoids complex equipment and can be adapted by varying the container shape and size. "This approach takes advantage of favorable interactions to stabilize ultra-thin self-assembled structures that are at least one thousand-fold larger than was previously possible," adds Assistant Prof. Alessandro Ianiro, a former group leader in AMI's Biophysics lab.

Once formed, the membranes exhibit a degree of fluidity that allows them to close small punctures on their own. Tests showed that tiny defects heal within seconds, restoring the barrier function, because its molecules flow and reseal, just like a droplet of mercury. This resilience stems from the mobility of polymer segments within the bilayer, which flow to seal gaps without external intervention.

Electric rays stack thousands of cell membranes to shock prey. The researchers copied this by adding a natural molecule called valinomycin, which only lets potassium ions pass through. When one side has potassium salt and the other sodium salt, ions rush across, creating about 60 millivolts per layer. Stacking multiple films increases the output proportionally. Published in the prestigious journal Nature, the results showed low power densities – around 0.04 mW/m² – but improvements in ion-channel design could boost performance in the future.

Potential Applications

The researchers have suggested several potential applications. By controlled mixing of freshwater and seawater across these membranes, it should be possible to generate renewable power on a small scale, complementing existing salinity-gradient technologies. Their selective ion-separation capability could also lead to membranes that remove salt from water more efficiently than current polymer filters, with less energy input. Finally, as materials for dialysis or implantable sensors, the membranes' thinness and biocompatibility could yield gentler filtration and the possibility of devices powered by the body's own ion gradients.

"This advancement takes our previous aspirations to develop fish-inspired artificial electric organs a significant step closer towards biocompatible power sources. Ultimately, our goal is that these human-made systems will closely mimic, and interact with the complex functions of biological organisms," says AMI's Chair of Biophysics, Prof. Michael Mayer.

This work brought together AMI's Biophysics, Polymer Chemistry and Materials, and Soft Matter Physics groups with partners at TU Darmstadt, the University of Paris-Saclay, and EPFL. Future research will focus on integrating more efficient ion channels to raise ion-transport rates by orders of magnitude. The long-term goal is to develop membranes fueled by biological molecules (such as ATP, which powers virtually every cellular activity) for non-stop operation, narrowing the gap between laboratory prototypes and practical devices.

Reference

Sproncken, C. C. M.; Liu, P.; Monney, J.; Fall, W. S.; Pierucci, C.; Scholten, P. B. V.; Van Bueren, B.; Penedo, M.; Fantner, G. E.; Wensink, H. H.; Steiner, U.; Weder, C.; Bruns, N.; Mayer, M.; Ianiro, A. Large-Area, Self-Healing Block Copolymer Membranes for Energy Conversion. *Nature* **2024**, 630 (8018), 866–871.

Carolina Pierucci is a PhD student in AMI’s BioPhysics group. After completing her Master’s degree at the University of Bologna (Italy), she joined the Institute in 2022 as part of the Integrate Pathfinder project. Her research includes work on energy conversion and power generation from physiologic ion gradients.

BioPhysics

Team

Prof. Michael Mayer, Dr. Mariano Barella, Dr. Wachara Chanakul, Jessica Dupasquier, Prof. Alessandro Ianiro, Dr. Edona Karakaci, Dr. Yu-Noel Larpin, Yuanjie Li, Dr. Pau Molet Bachs, Dr. Anasua Mukhopadhyay, Dr. Liviana Mummolo, Carolina Pierucci, Dr. Anna Protopopova, Dr. John Puguan, Andela Vracar, Dr. Justus Wesseler, Dr. Lijian Zhan

Key Publications

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New players

_ Structural color is not just for animals and plants

A collaboration between the Adolphe Merkle Institute, the University of Fribourg's botanical garden and the University of Salzburg has uncovered that structural color is far more prevalent in slime molds than previously thought.

Slime molds, also know as myxomycetes, are simple, single-celled organisms that often found as blobs on decaying wood or leaves. They move slowly to feed on bacteria and other tiny life forms, and when conditions are right, they form small, highly colorful, spore-producing structures that help them spread. Although they look somewhat like fungi, myxomycetes belong to a different group of organisms called protists.

Single species had been previously investigated. This time, the researchers took different mold species into consideration and found that all of them exhibited thin film interference, a phenomenon responsible for their iridescent appearance. Thin film interference happens when light reflects off the top and bottom surfaces of a very thin layer, like a soap bubble or an oil slick, in this case, the peridium, the membrane surrounding the spore mass. The two reflected light waves combine in ways that can either strengthen or cancel each other out. This interference creates bright, colorful patterns because some colors of light are amplified while others are reduced, depending on the thickness of the film and the angle of the light. It is also found in some insects and flowers.

All 22 studied species showed this interference in their outer layers, producing a range of colors across the visible spectrum. According to the researchers, the colors result from a combination of structural effects and pigment absorption. Some species, like Metatrichia vesparium, have complex, multi-layered structures including calcium-rich deposits. However, the structural color likely doesn't serve a biological purpose but may be a by-product of the organisms' life cycle.

AMI Soft Matter Physics PhD student Viola Bauernfeind explained, "We were surprised to find that this structural coloration is so widespread across different slime mold species. It's an unexpected feature in organisms traditionally classified as simple amoebae."

The research team used a combination of advanced imaging techniques, including light microscopy, scanning electron microscopy, and optical simulations, to analyze the slime molds' structures in detail. Prof. Gregor Kozlowski, head of the University of Fribourg's botanical garden, coordinated contacts with the Polish researchers who made the samples available, and suggested the analysis.

While the colorful display doesn't appear to have a specific biological function, unlike in plants or animals where it might attract pollinators or mates, it provides valuable insights into the organisms' development and structure. The findings were published in the journal *Optics Express*.

Reference

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Viola Bauernfeind joined the Soft Matter Physics group in 2020 as a PhD student. During her thesis, which she successfully defended in 2025, she investigated how nature produces its remarkable color palette through biological nanostructures. Her research focused on understanding the driving forces behind the emergence of non-iridescent, fade-resistant colors in nature.

Soft Matter Physics

Team

Prof. Ullrich Steiner, Doha Abdelrahman, Bilel Abdennadher, Martino Airoldi, Viola Bauernfeind, Nicolas Bruder, Victoire de Cabannes de Cauna Kenza Djegdhi, Dr. Andrea Dodero, Andrea Escher, Dr. Ilja Gunkel, Florin Hemmann, René Iseli, Thomas Kainz, Tri Minh Nguyen, Andrea Palumbo, Alessandro Parisotto, Cristina Prado, Dr. Matthias Saba, Cédric Schumacher, Niklas Schwarz, Brian van Büren, Dr. Viola Vogler-Neuling

Key Publications

1. Djeghdi, K.; Karpov, D.; Abdollahi, S. N.; Godlewska, K.; Iseli, R.; Holler, M.; Donnelly, C.; Yuasa, T.; Sai, H.; Wiesner, U. B.; Steiner, U.; Wilts, B. D.; Musya, M.; Fukami, S.; Ohno, H.; Diaz, A.; Llandro, J.; Gunkel, I. Block Copolymer-Directed Single-Diamond Hybrid Structures Derived from X-Ray Nanotomography. *ACS Nano* **2024**, 18 (39), 26503–26513.
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Under pressure
_ Revealing hidden stress in plastics

The Adolphe Merkle Institute's Mechanoresponsive Materials group is developing an innovative method to visualize mechanical stress in plastics and rubbers at the molecular level, offering insights into why these materials fail – and how to design ones that last longer, heal themselves, or safely decompose.

From car tires to food packaging, polymers are indispensable but prone to unexpected breakdowns. Tiny cracks, invisible to current imaging tools, form under stress and spread, causing failures in everything from medical devices to bridge supports. Traditional microscopes can only handle resolutions down to around a few hundred nanometers, not enough to spot the nanoscale fractures that trigger collapse. "With current microscopes, the damage that matters most is still too small to see," explains Prof. Jessica Clough, head of the group.

The proposed advance, dubbed by the researchers super-resolution force imaging (SRFI), combines cutting-edge microscopy with custom "stress-sensing" molecules, bridging a critical gap in materials science that cannot be addressed with existing techniques.

SRFI adapts super-resolution microscopy, a Nobel Prize-winning tool in biology, to the world of synthetic materials. By tagging polymers with specially designed mechanophores, molecules that glow when mechanically stressed, the team hopes to achieve nanoscopic resolutions down to tens of nanometers, revealing previously hidden damage hotspots. Their trump card is a novel coumarin-based mechanophore developed by Clough and PhD student Yang Li, which activates a bright blue, fluorescent dye when its chemical bonds break under force. This sensor is easy to synthesize, stable under heat and light.

The team embedded their coumarin mechanophores into polymethyl acrylate, a common synthetic polymer used in adhesives and coatings. When subjected to ultrasound, exerting high stress on the polymer chains, the material lit up visibly under UV light, as confirmed by spectroscopy and other analytical methods. Another test used the mechanophores as cross-links in rubbery networks, demonstrating the activation and detection of coumarins in the solid-state for the first time. Stretching these materials triggered fluorescence where molecular bonds break, suggesting that SRFI should be able to map how damage develops under deformation.

The premature failure of polymeric parts can have severe and costly consequences. A plastic pipe suddenly breaking after many years of safe operation as a result of fatigue requires an often-expensive replacement. Failures in high-performance composites such as those used in the aviation and automotive industries can also impact safety. SRFI could help reduce the impact of these issues in a variety of ways: by enabling polymers to detect microcracks early and trigger self-healing mechanisms; and emitting visible signals when nearing breakdown. Clough and her colleagues plan to tweak the coumarin design to create a "color-coded" system. By adjusting the mechanophore's structure, they aim to produce sensors that glow red, green, or yellow under different stress levels. This could allow, for example, engineers to visually gauge material fatigue in bridges or aircraft components.

"Ultimately, we want to move beyond improving mechanical properties alone and think about how materials can contribute to sustainability throughout their whole life cycle," says Clough. For example, polymeric parts could be designed to decompose safely thanks to pre-programmed weak points that ensure rapid disintegration post-use.

These developments come as global industries seek to meet sustainability targets. Super-resolution techniques are just starting to be taken up by the polymer science community and have the potential to inform the development of recycling approaches. "By marrying biology's imaging prowess with materials science, SRFI can pave the way for the development of polymers that don't just survive but thrive under pressure, making them safer and more sustainable," adds Clough.

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Mechanoresponsive Materials

Team

Prof. Jessica Clough, Yang Li, Hrishikesan Kalpakassery Pattam, Iulia Scarlat

Key Publications

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Li Yang joined the Mechanoresponsive Materials group as a PhD student in 2023. He completed his studies at the Beijing University of Chemical Technology (China) and also worked in industry at the Polymer Competence Center Leoben in Austria. His current research focuses on nanoscopic force imaging and the study of how tiny defects can lead to mechanical failure in polymers.

Crossing lung barriers

_ New insights into diesel particle translocation

Only a small fraction of diesel exhaust particles (DEPs) – a key componente of urban air pollution – are able to cross the thin tissue barriers of the human lung and enter the bloodstream, according to research from the Adolphe Merkle Institute's BioNanomaterials group. By optimizing a combination of analytical methods, the team was able to track how these traffic-related particles move through the lung and potentially reach organs beyond.

Air pollution, especially fine ($PM_{2.5}$, ≤ 2.5 μm) and ultrafine (UFP, ≤ 100 nm) particulate matter (PM), is a leading environmental health risk, linked to adverse respiratory and cardiovascular effects. Diesel engines are a major source of $PM_{2.5}$ and UFPs, emitting a complex mix consisting of solid, liquid, and gas phases. The solid phase contains a carbonaceous core with adsorbed metals and semi-volatile organic compounds, some of which are carcinogenic polycyclic aromatic hydrocarbons (PAHs), alongside volatile organic compounds in the gas phase. These particles are small enough to penetrate deep into the lungs, reaching the alveolar region where gas exchange occurs.

Earlier animal studies have shown that a small fraction of inhaled engineered nanoparticles can cross the lung barrier and enter the bloodstream, potentially reaching the brain, heart, liver, and other organs. However, quantifying this translocation for DEPs in humans has been a major scientific challenge.

The research team, led by BioNanomaterials Co-Chair Prof. Barbara Rothen-Rutishauser, aimed to develop a more precise in vitro approach to measure DEP crossing the lung tissue. The solution involved combining three complementary analytical techniques, including transmission electron microscopy (TEM) to visualize particles at the nanoscale, and both ultraviolet-visible (UV-VIS) spectroscopy and lock-in thermography (LIT) to detect and quantify the particle fraction translocation based on their light-absorbing and thermal-emitting properties of the carbon core, respectively. This approach was applied to a model of the human alveolar tissue grown on permeable inserts, enabling analysis of DEP translocation across this barrier.

"This combined analytical approach is a powerful tool for studying not just diesel particles, but a wide range of traffic-related particles with a carbon core," says Rothen-Rutishauser. "This could help determine whether the harmful effects of inhaled PM on organs beyond the lungs are caused by particles crossing into the bloodstream or by inflammatory mediators from lung tissue and explore 'Trojan horse' effects where particles carry adsorbed hazardous compounds."

Testing results showed that only a very low, concentration-dependent fraction of DEPs crossed the alveolar tissue barrier. The study also revealed that at higher concentrations, DEPs formed larger agglomerates in the presence of lung fluid components such as surfactants, which reduced the translocation. Smaller agglomerates crossed more readily, but still, the analyzed fractions were less than one percent. These findings highlight the importance of an intact lung barrier in protecting against PM crossing.

Although only a small fraction of DEPs crosses the lung barrier in this experimental setup, the long-term consequences of particles inhaled daily in polluted environments should be considered for risk assessments. The researchers note that chronic, low-concentration exposures could result in gradual accumulation in secondary organs, a hypothesis that would require further investigation.

The use of the analytical toolbox, optimized as part of the European-funded ULTRHAS project, opens the door to more detailed studies on PM translocation and systemic effects, providing crucial data for regulators and public health officials seeking to mitigate the risks of air pollution in urban environments.

This study was supported by H2020 EU project ULtrafine particles from TRansportation-Health Assessment of Source (UTRHAS, Grant # 955390).

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Gowsinth (Gao) Gunasingam is a PhD student in AMI's BioNanomaterials group. He joined the Institute in 2020 after completing his Master's degree in biochemistry at the University of Geneva. As part of the European-funded ULTRHAS project, his research focuses on the development and characterization of advanced *in vitro* models.

BioNanomaterials

Team

Prof. Alke Fink, Prof. Barbara Rothen-Rutishauser, Liliane Ackermann-Hirschi, Dr. Mauro Sousa de Almeida, Dr. Sandor Balog, Laura Baraldi, Dr. Amélie Bazzoni, Dr. Anne-Marinette Cao, Dr. Jessica Caldwell, Shui Ling Chu, Luigi di Stolfo, Dr. Jules Duruz, Emma Fink, Roman Fortunatus, Regina Gomes, Gowsinth Gunasingam, Laetitia Haeni, Moritz Haeffner, Fatima Hameedat, Dr. Ruiwen He, Viktoriya Ivasiv, Dr. Nathalie Jung, Dr. Sandeep Keshavan, Dr. Jorge Larios, Henry Lee, Dr. Wang Sik Lee, Isidora Loncarevic, Aura Maria Moreno Echeverri, Maria Porteiro, Barbara Rani Borges, Dr. Flavia Sousa, Dr. Patricia Taladriz, Dr. Dimitri Vanhecke

Key Publications

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Vitamins

_ New tools to improve nutrient delivery

Researchers from the Adolphe Merkle Institute's BioNanomaterials group have developed an improved method for studying how nutrients survive their journey through our digestive system. Their work advances techniques for characterizing nanocarriers for oral delivery of essential vitamins that would be incorporated into food and supplements.

The research focused on beta-carotene, a natural antioxidant and a form of vitamin A, found in plants such as carrots. Since the human body cannot synthesize vitamin A, it must be acquired through diet, where absorbed beta-carotene is converted into its active form. This vitamin is essential for vision, immune function, and cell growth.

In wealthy countries, beta-carotene provides approximately one-third of vitamin A requirements, but in developing nations, this proportion reaches 80%. However, beta-carotene breaks down quickly during food processing and in the stomach's acidic environment, and because of its poor water solubility, its absorption in the intestine is limited. With vitamin A deficiency affecting over 330 million children globally, improving beta-carotene bioavailability could have a significant impact in reducing this public health problem. Scientists have attempted to protect beta-carotene by encapsulating it, but measuring what happens to these carriers in simulated digestive fluids has proven challenging.

Traditional measurement techniques are compromised by the complex mixture of enzymes, acids, and salts present in the digestive environment. The BioNanomaterials team addressed this by employing Taylor dispersion analysis, a technique that tracks particles as they flow through narrow capillaries. Unlike conventional methods that depend on light scattering, this approach measures light absorption as particles move within the complex medium. This makes the technique significantly less susceptible to interference from digestive components, enabling researchers to study nanoparticles directly in simulated gastrointestinal conditions without sample purification.

With this clearer picture, the team could compare two types of protective capsules: PLGA nanoparticles, tiny spheres made from a biodegradable polymer that breaks down slowly in the body, and liposomes, microscopic bubbles crafted from the same types of fats that form cell membranes.

They were also able to demonstrate that adding vitamin C at the right concentrations dramatically reduced beta-carotene breakdown. 5% vitamin C worked best in acidic stomach conditions, while 3% was optimal in the more neutral intestinal environment. Using this approach, the team was able to accurately track the release of beta-carotene from the carrier systems and observed that the two delivery methods exhibited distinct release profiles. PLGA nanoparticles released only 9% of their beta-carotene over seven days, making them suitable for sustained nutrition applications. Liposomes released more than half their contents within 36 hours, which may be preferable for applications requiring rapid vitamin delivery.

"This research represents a significant step forward in addressing the challenges of beta-carotene delivery," said Dr. Patricia Taladriz-Blanco, one of the study's authors. "Our findings not only improve the bioavailability of this essential nutrient but also open new possibilities for functional food development and drug delivery systems."

The measurement technique has applications beyond beta-carotene research. It gives scientists a more reliable tool for studying how various nutrients and bioactive compounds behave in digestive environments, which could support the development of better delivery systems.

This study was supported by the Swiss Excellence Scholarship through the State Secretariat for Education, Research, and Innovation.

Roman Fortunatus

Roman Fortunatus is a Tanzanian PhD student in AMI's BioNanomaterials group. He previously obtained his Master of Science degree in food science and human nutrition from the University of Florida in 2014 in the US.

Reference

Fortunatus, R. M.; Balog, S.; Sousa, F.; Vanhecke, D.; Rothen-Rutishauser, B.; Taladriz-Blanco, P.; Petri-Fink, A. Taylor Dispersion Analysis and Release Studies of β-Carotene-Loaded PLGA Nanoparticles and Liposomes in Simulated Gastrointestinal Fluids. *RSC Adv.* **2025**, 15 (2), 1095–1104.


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In brief

Prizewinning

The Institute's students demonstrated once again AMI's excellence in 2024, taking home prizes from conferences in Switzerland and abroad.

Aura Moreno of the BioNanomaterials group was the winner of the best poster prize at the Swiss NanoConvention in Basel in June. She was recognized for her poster "Accumulation of different silica nanoparticles in the same lysosomal compartments of macrophages after sequential exposures". Another PhD student from the BioNanomaterials group, Isidora Loncarevic, was awarded the prize for best talk given by a Young Scientists Travel Awardee at the European Society for Alternatives to Animal Testing Congress in Linz, Austria.

New professor

Hans Jörg 'Hanjo' Limbach was appointed in late 2024 as AMI'sChair of Food Science and Technology.

Limbach has extensive industry experience, having worked in food research at the Swiss multinational company Nestlé for the past 20 years. His appointment signals AMI's strategic expansion into food innovation, leveraging its expertise in soft nanomaterials to address global food challenges.

Limbach brings a rare blend of industry and academic expertise to AMI. As a principal scientist and group leader at Nestlé, he pioneered research in colloidal systems, protein aggregation, and carbohydrate physics. His work has contributed directly to innovations in ice cream, coffee, and reduced-fat products. His academic roots in biophysics, polymer science, and statistical physics, coupled with his project management and team development experience, will enable him to bridge the gap between fundamental science and consumer-driven applications.

Promotion

The junior Smart Energy Materials group, led by Prof. Jovana Milic, relocated to the University of Turku in Finland.

Milic was appointed as an Associate Professor from September 2024 as SUSMAT Professor, supported by an ERC Starting Grant and the Research Council of Finland. Her research activities continue in Switzerland as she remains affiliated with the Adolphe Merkle Institute as a Swiss National Science Foundation PRIMA Fellow, and continues as a Principal Investigator of the NCCR Bio-Inspired Materials, as well as an active member of the Swiss Young Academy and the Swiss Chemical Society. At AMI, she was investigating hybrid materials that mimic control strategies found in nature, such as those in photosynthesis. Her group's research interests remain centered on the development of (supra)molecular materials for smart and sustainable nanotechnologies capable of responding to external stimuli and adapting to their operational conditions, focusing notably on renewable energy conversion in photovoltaics and neuromorphic computing. Milic was awarded her PhD at ETHZ in 2017, and joined AMI in 2020.

Faculty prizes

BioNanomaterials alum Jessica Caldwell, was awarded the faculty prize for the best experimental thesis of 2024.

Caldwell defended her thesis “In the Aftermath of Throwaway Living: Bridging the gap between analytical limitations and the need to assess growing concerns regarding micro-, submicron-, and nanoplastics” in October 2023. She is currently a postdoctoral researcher at the Italian Institute of Technology in Genoa.

BioNanomaterials PhD student Henry Lee was also the recipient of the faculty’s Thürler-Reeb Grant, recognizing his 2024 first-author publication “The impact of macrophage phenotype and heterogeneity on the total internalized gold nanoparticle counts” in the journal Nanoscale Advances. The grant is awarded for an excellent research outcome (Master, PhD, or publication) to researchers from the canton of Fribourg or with strong ties to it. Lee successfully defended his PhD thesis, “Macrophage-nanoparticle interactions across the spectrum of polarization, senescence, and imaging” in June 2025.

Sparking innovation

AMI researchers secured two Spark grants from the Swiss National Science Foundation (SNSF) in 2024 to explore innovative materials with potentially transformative applications.

AMI’s Chair of Polymer Chemistry and Materials, Prof. Christoph Weder, is investigating a new class of materials called elastic liquid metal gels, combining the properties of liquid metals (high thermal and electrical conductivity) with the mechanical characteristics of gels (elasticity and softness). The project aims to overcome the limitations of current liquid metal composites by creating gels where liquid metal is the primary component, with gelating agents forming a 3D network within the metal. This approach could yield extremely soft, stretchable, and conformable electronic materials with potential applications in heat transfer, soft robotics, wearable electronics, and biomedical devices.

Dr. Andrea Dodero, a group leader in AMI’s Soft Matter Physics group, is focusing on the development of novel laser materials using all-polymer spherical microcavities. These are comprised of microspheres, invisible to the naked eye, that could produce laser light in a radial pattern, opening new possibilities for compact device integration. The process, if successful, could significantly reduce production costs and make advanced laser technology more accessible. The project design also suggests that these new laser materials would operate at remarkably low energy levels while still producing coherent light.

According to the SNSF, the aim of Spark grants is to fund the rapid testing or development of novel and unconventional scientific approaches, methods, theories, standards, and ideas. It is designed for projects that introduce a unique approach. The focus is on promising ideas of high originality for which preliminary data are not necessarily available and are unlikely to be funded under other existing schemes. Negative results will also be regarded as knowledge gained. The scheme is open to applicants from all disciplines with a doctorate or comparable research experience, employed at or hosted by a Swiss research institution with funding given for up to 12 months.

Research council

AMI's Co-Chair of BioNanomaterials, Prof. Barbara Rothen-Rutishauser, was one of 15 new members elected to the Swiss National Science Foundation (SNSF) Research Council in 2024.

At its December meeting, the Foundation Council elected 52 current members of the Research Council to continue their mandates while also electing 15 new highly qualified members. These were selected from nearly 200 applications to complete the body. The Council convened for the first time on on April 1, 2025. According to the SNSF, these appointments, including Rothen-Rutishauser's, strengthen the Research Council's expertise in key areas, reflecting the ongoing commitment to rigorous scientific evaluation and support tailored to current challenges.

Rothen-Rutishauser was elected as one of the council's representatives for life sciences and will focus more specifically on long-term research and infrastructure. She is an expert in the field of cell-nanoparticle interactions, with a special interest in 3D tissue models.

Her work includes the development of alternative testing methods that can be used for hazard assessments and drug testing approaches. Rothen-Rutishauser is also committed to gender equality issues and has initiated several activities to promote talented (female) scientists. She is a member of or has served on multiple international and national scientific associations and advisory committees, including Switzerland's Federal Commission for Air Hygiene.

Trends in Micro Nano Conference 2024

AMI hosted the Trends in Micro Nano conference in November, bringing together experts from academia and industry to discuss recent advances and applications in micro- and nanotechnologies. The event was organized under the Swiss MNT Network, showcasing the latest developments in material analytics, high-throughput experimentation, biomedical engineering, and functional materials. The Trends in Micro Nano conferences are a recurring series of Swiss events dedicated to the latest advancements. They serve as a platform for researchers, industry professionals, and innovators to present new research, discuss emerging applications, and network.

Swiss NanoAnalytics Day

The Swiss NanoAnalytics (SNA) platform, managed by the BioNanomaterials group, organized in October an event to showcase its advanced services for nanomaterial characterization.

It was a unique opportunity for attendees to learn about cutting-edge analytical techniques, connect with experts, and engage in the Swiss nanoscience community, as well as foster collaborations and innovation in the field of nanoscience. SNA offers industry, regulators, and academic researchers analytical methods to detect, and characterize synthetic nanomaterials in consumer products, biological matrices, and material systems.

Alternative fuel safety

AMI's Co-Chair of BioNanomaterials, Prof. Barbara Rothen-Rutishauser, has joined an EU-funded study into the safety of future shipping and aviation fuels.

The LowC initiative will assess potential health and environmental risks of low-carbon fuels like hydrogen and ammonia, critical for decarbonizing transport. Heavy-duty vehicles, aircraft, and ships are major sources of greenhouse gases and air pollutants, prompting the exploration of low- or zero-carbon fuels such as hydrogen, ammonia, and synthetic eFuels for decarbonization, while raising questions about their impact on emissions of air toxicants and climate-active compounds. The €3.5 million project, announced in 2024 and running from 2025 to 2029, is led by Norway's Institute of Public Health and will test emissions from ships, aircraft, and heavy-duty engines under real-world conditions, simulating atmospheric interactions to predict air quality impacts. Researchers from Norway, Finland, Germany, Austria, and Switzerland will analyze real-time exhaust data and expose lab-grown lung tissues to emissions, one of Rothen-Rutishauser's specialized fields, evaluating risks of inflammation or respiratory harm.

The goal is to ensure that switching fuels should not trade one crisis for another, while balancing climate goals with public health. While hydrogen and ammonia promise near-zero carbon dioxide outputs, concerns include ammonia's irritant properties and hydrogen-linked nitrogen oxide (NO_x) spikes. Findings will inform EU pollution models and safety standards for hard-to-electrify sectors. Funded via the Horizon Europe program, the project highlights Europe's push to lead in sustainable transport without unintended consequences.

Sharing duties

AMI's Co-Chairs of BioNanomaterials, Prof. Alke Fink and Prof. Barbara Rothen-Rutishauser, were elected as Co-Vice Deans of the University of Fribourg's Faculty of Science and Medicine for the 2024–2025 academic year.

As part of the Dean's Council, they assisted and advised the dean. Key duties of the council include preparing policy documents, development plans, and budget proposals for the faculty's section councils and its finance commission; promoting and representing the faculty's external interests; and selecting recipients for faculty-awarded prizes. Both professors have led the BioNanomaterials group at AMI since 2011 as part of a pioneering job-sharing agreement.

Pitching

The Institute hosted in June 2024 the Falling Walls Lab Fribourg pitching competition.

Organized by the National Center of Competence in Research Bio-Inspired Materials, in collaboration with AMI and the University of Fribourg, the event aims to identify solutions with societal and scientific impact.

Six researchers took part, including AMI's Isidora Loncarevic (BioNanomaterials), who advocated for organ-on-chip technologies to replace animal testing in pharmaceutical research, and Wachara Chanakul (BioPhysics), who pitched a non-invasive diagnostic tool for neurodegenerative diseases using biomarkers in blood samples.

The winner was Amith Kamath of the University of Bern, who presented an AI-driven cancer therapy approach. The goal would be to use machine learning to optimize radiation doses while minimizing damage to healthy tissues, potentially reducing treatment side effects. Chanakul and Loncarevic finished second and third respectively. Kamath and Chanakul both took part in the global final organized in Berlin in November.

Fierce competition

The Polymer Chemistry and Materials group was the winner of the 2024 AMI Cup.

This now-traditional competition pits the Institute's different research groups, as well as the (reinforced) administration team, against each other. The previous year's winners were responsible for the organization, in this case, the Soft Matter Physics group, including games of skill, strength, and intellect, as well as the barbecue that followed.

Public service

AMI PhD student elected to the global board of a non-profit organization.

Bilel Abdennadher (Soft Matter Physics) was chosen as vice-president for 2025 of the global board of the International Association for the Exchange of Students for Technical Experience (IAESTE). This non-profit organization facilitates paid, course-related internships abroad

for students, primarily in technical and scientific fields to gain relevant technical training. Students gain relevant technical training lasting from 4 weeks up to a year. IAESTE includes committees representing more than 80 countries. Abdennadher is also the president of the IAESTE Local Committee in Bern.

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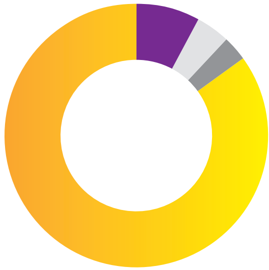
_Finance & Organization

Finance
_ Cost structure at AMI

The Adolphe Merkle Institute's overall expenditures rose slightly in 2024 to CHF 9.43 million. 85% of this sum was spent on research, while an additional 3% was invested in research equipment. Around 3% of the budget supported valorization activities such as technology transfer, communication, and marketing, with another 8% covering administration costs.

Overall expenses 2024
CHF 9.43 million



Research / 85%
Administration / 8%
Research equipment / 4%
Valorization / 3%

Funding sources of overall expenses 2024

Adolphe Merkle Foundation / 34%
Grants / 54%
University of Fribourg / 11%
Industry / 1%

Third-party funding 2024
CHF 5.17 million

SNSF / 58%
EU / 19%
Other sources / 19%
Innosuisse / 2%
Industry / 2%

Organization

In late 2007, Adolphe Merkle set up the Adolphe Merkle Foundation and donated CHF 100 million to support the University of Fribourg. The donation has been used primarily to establish the Adolphe Merkle Institute.

The Institute Council plays an important role in controlling and supervising the development of the Institute at the University of Fribourg's science faculty. It guarantees optimal communication and coordination between the University and the Foundation and helps the Institute to fulfill its mission and to smoothly integrate into the university.

The Scientific Advisory Board is an independent team of experts with backgrounds and expertise in fields that are relevant for AMI. It provides an external view to help position the institute in its national and international environment.

The Executive Board oversees daily operations at AMI and meets once a week. All AMI professors are members of this management body. They are responsible for ensuring that the strategy approved by the Institute Council is implemented.

The Administration team provides support in many aspects of the Institute's daily work and acts as an interface between the University of Fribourg and AMI.

Foundation Board

Members

Peter Huber (President)
Administrator, Sublevo AG, Kloten, Switzerland

Jean-Pierre Siggen
State Minister in charge of Education, Culture and Sport of canton Fribourg

Chantal Robin
Former Director, Fribourg Chamber of Commerce and Industry

Prof. Rolf Mülhaupt
Former Managing Director Freiburg Center of Interactive Materials and Bioinspired Technologies

Prof. Claude Regamey
Former chairman of the Department of Internal Medicine, Hôpital Cantonal Fribourg, former President of the Ethical Committee of the Swiss Academy of Sciences

André Broye (Managing Director)

Institute Council

Members

Prof. Katharina Fromm (President)
Rector of the University of Fribourg, Professor at the Faculty of Law, University of Fribourg

Peter Huber (Vice-president)
Administrator, Sublevo AG, Kloten, Switzerland

Prof. Ulrich Ultes-Nitsche
Professor in the Department of Informatics, University of Fribourg

Prof. Rolf Mülhaupt
Managing Director Freiburg Center of Interactive Materials and Bioinspired Technologies

Scientific Advisory Board

Members

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Texas A&M University, United States

Prof. Luisa De Cola
Istituto di ricerche farmacologiche Mario Negri and University of Milano, Italy

Prof. Giovanni Dietler
Former head of the Laboratory of Physics of Living Matter, EPFL, Switzerland

Prof. Alex Dommann
Former head of Department “Materials meet Life”, Empa, St. Gallen, Switzerland

Dr. Corinne Jud
Agroscope, Switzerland

Prof. Eugenia Kumacheva
University of Toronto, Canada

Prof. Scott McNeil
University of Basel, Switzerland

Dr. Alexander Moscho
Operating Partner, Triton Investments Advisers, Germany

Prof. Dieter Richter
Former director of the Institute of Solid State Research, Forschungszentrum Jülich, Germany

Executive Board

Prof. Ullrich Steiner
Director and Chair of Soft Matter Physics

Prof. Jessica Clough
Mechanoresponsive Materials

Prof. Alke Fink
Co-Chair of BioNanomaterials

Prof. Michael Mayer
Deputy Director and Chair of Biophysics

Prof. Jovana Milic
Smart Energy Materials

Prof. Barbara Rothen-Rutishauser
Co-Chair of BioNanomaterials

Prof. Christoph Weder
Chair of Polymer Chemistry & Materials

Administration

Scott Capper
Responsible for Communications & Marketing

Carine Jungo
Secretary

Catherine Jungo
Responsible for Human Resources

Thierry Mettraux
Responsible for Finance & Controlling

Dr. Lucas Montero
Coordinator

Dr. Ana Marques
Head of Knowledge & Technology Transfer

Tomas Perez
Responsible for IT Support

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PhDs & Alumni

PhDs

Our new doctors

Martino Airoldi
(Soft Matter Physics)
“Advancing Lithium-Metal Anode Batteries through Electrode Surface Engineering: An Exploration of Mechanism, Optimization, and Application”

Claudio Cappelletti
(Polymer Chemistry and Materials)
“In-situ synthesis of polymer nanocomposites”

Yuanjie Li (BioPhysics)
“Reversible Covalent Bonds for Selective and Transient Trapping of Single Proteins in Nanopores”

Weifan Luo
(Smart Energy Materials)
“Supramolecular Engineering for Hybrid Perovskite photovoltaics”

Aura Moreno Echeverri
(BioNanomaterials)
“Exploring the Interaction of Amorphous Silica Nanoparticles with Macrophage Lysosomes”

Ilaria Onori
(Polymer Chemistry and Materials)
“Healable supramolecular double polymer network elastomers”

Andrea Palumbo
(Soft Matter Physics)
“Synthesis, Characterization, and Performance Evaluation of Mesoporous Microsized Electrode Materials for Lithium-ion Batteries”

Alumni

People who left AMI in 2024

Martino Airoldi
Soft Matter Physics

Simone Bertucci
Soft Matter Physics

Anne-Marinette Cao
BioNanomaterials

Jessica Caldwell
BioNanomaterials

Sicheng Cheng
BioPhysics

Satyajit Das
Polymer Chemistry and Materials

Davide de Luca
Polymer Chemistry and Materials

Jessica Dupasquier
BioPhysics

Jules Duruz
BioNanomaterials

Emma Fink
BioNanomaterials

Sandeep Keshavan
BioNanomaterials

Fatima Hameedat
BioNanomaterials

Jimmy Hemmer
Polymer Chemistry and Materials

Viktoriya Ivasiv
BioNanomaterials

Yu-Noel Larpin
BioPhysics

Weifan Luo
Smart Energy Materials

Lorenzo Miele
Smart Energy Materials

Aura Moreno
BioNanomaterials

Ilaria Onori
Polymer Chemistry and Materials

Shohei Shimizu
Polymer Chemistry and Materials

Athanasios Skandalis
Polymer Chemistry and Materials

Flavia Sousa
BioNanomaterials

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