Applications of biomimicry in cosmetic industries

2025

Ceebios

Editorial

At the forefront of human beauty sciences, has the cosmetics industry adequately explored the beauty of the living world?

Across the vast array of plant, animal, fungal, and microbial species, it is fascinating to delve into the palette of colors, shades, optical effects, textures, and shapes—sometimes geometric and regular, other times curved and chaotic. Yet, far from a naïve perspective, some species still provoke disgust and rejection. What is our relationship with the living world: fascinating, pleasant, reassuring, or repulsive, hostile, often misunderstood, or ignored?

Beyond aesthetics, it is vital to remember that this living world, of which we are a part, is the result of an evolutionary story: we are all connected through the first LUCA cell, which appeared at least 3.8 billion years ago. Life has multiplied, grown more complex, combined, resisted, explored, and flourished in every corner of the planet. Every branch of life embodies a delicate balance between uniqueness and universality.

Yet, through the development of our technologies, humanity has believed itself to be separate from this web of life. The current and future consequences of climate change and the biodiversity crisis harshly remind us of our interdependence. The primary challenge today is to reintegrate human activities into cycles compatible with the biology and physico-chemistry of our planet. Using life as both a model and compass, biomimicry relies on a robust methodological framework and serves as a powerful tool for transformation.

This document outlines bio-inspired opportunities for all dimensions of R&D in cosmetics, gradually expanding to address broader systemic challenges. However, a profound transformation cannot be achieved solely through scientific advancements. Culture, attitudes, organizations, economic models, and policies are equally essential components.

Sommaire

Biomimicry for cosmetics

Specificities and opportunities for this industry

Due to its strong need for responsible innovation combined with a unique relationship with the living world, cosmetics has historically been a major player in the biomimetic approach. Various forms of bio-inspiration have therefore always fueled developments in this sector, even if they have not necessarily been labeled as such.

Innovation

In its fields of hygiene, skincare, and aesthetics, the cosmetics industry is in a constant search for innovation, which is reflected in significant R&D investments and numerous patent filings.

The challenge is to meet the evolving needs of consumers. For example, lifestyle, the aging population, and environmental factors (pollution, diet, sun exposure) impact the skin and create significant skin disorders. At the same time, consumers expect new and personalized sensory experiences.

Innovation must contribute to a responsible and sustainable transformation of the industry. In order to maintain an activity that is compatible with planetary boundaries and international climate and biodiversity recommendations, the sector must evolve its practices in terms of natural resource consumption, waste reduction, and pollution management.

Biology

The cosmetics industry has developed a unique expertise at the interface between chemistry and human body biology. This privileged relationship with the living world is also reflected in the use of bio-based ingredients in its products, along with a marketing universe inspired by natural references.

Vegetable oils (castor, seed, argan...), organic pigments (from leaves, flowers, roots, barks...), bee products (honey, propolis, royal jelly...): both current and ancestral practices largely rely on bio-based ingredients in the pursuit of naturalness.

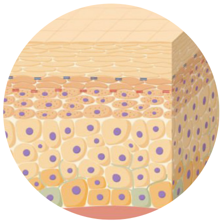
Beyond the ingredients, the transformation processes follow the same logic, with the use of biotechnologies, enzymatic catalysis, fermentation, and more.

Practical applications of biomimicry for cosmetics

Bio-inspired molecules

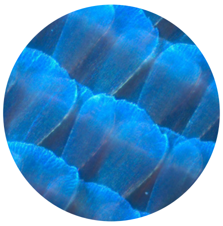
Ingredients inspired by venoms and toxins for anti-aging treatments

Biomimetic structures



Biomimetic creams replicating the lamellar structure of the skin

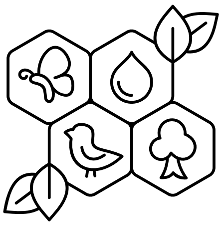
Biological strategies



Structurally colored makeup, such as the wings of the Morpho butterfly

Action levers for a responsible bio-inspired innovation

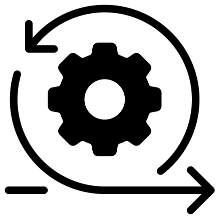
Recent developments in biomimetics, as a strategy for innovative design tools aimed at sustainability, make it a powerful lever for ecological transformation in support of corporate strategy. Three approaches must be combined to unlock its potential.



Design based on biology and interdisciplinarity

Biomimicry is an innovative design strategy that relies on biology: the living world is used as a model to meet human needs.

Biological expertise in the R&D fields of cosmetics (application substrates and ingredients) is a valuable resource for facilitating the adoption of biomimetics. However, it is important to go beyond the usual practices of extracting and using natural substances. Biomimetics facilitates dialogue in this fertile space at the intersection of scientific disciplines, between biological research and technical application fields. By decoupling inspiration from usage, biomimetics allows exploration of all realms of life: plants, animals, microorganisms, fungi…



A universal method at multiple size scales

The multidisciplinary approach of biomimicry relies on a methodological reasoning and a cognitive process, which notably includes: a functional perspective on the living world, abstraction of the observed mechanisms, and their transposition into a technical realization.

Molecules, cells, tissues, organs, organisms... as well as communities of organisms, animal architectures, ecosystems... biomimicry can be applied at all scales, for all R&D topics, across all sectors. For the cosmetics industry, the most documented topic is the chemistry of bio-inspired ingredients. A vast field of possibilities remains to be explored to rethink the product or even the production site in a more holistic way.

Anchoring in sustainability

Through its evolutionary history and the interdependencies between species, all of life has developed environmental performances that are now strategic for businesses: circularity, resource efficiency, resilience…

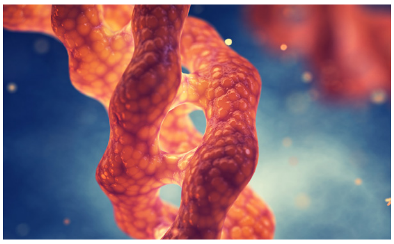
All biological species are part of the major planetary resource cycles (water, carbon, nitrogen…). Through their activities, they contribute to ecosystem services (soil structure, CO_2 storage, pollination…). At the same time, they ensure their vital functions (energy management, material transformation, communication, movement…). Biomimicry seeks to harness all of these properties within a framework of eco-design and regenerative design.

Bio-inspired innovation

For all dimensions of R&D in cosmetics

From product effectiveness (such as sun protection) to environmental performance (such as end-of-life packaging management) and eco-process development, the R&D challenges in the cosmetics industry span a wide range. This document aims to explore each of these aspects through the lens of biomimicry to reveal the strategic opportunity of this innovation approach.

At the product innovation level

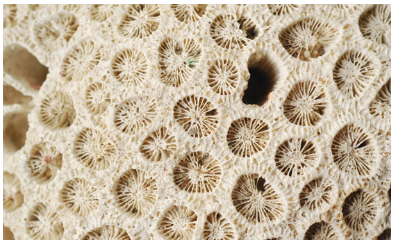


Active ingredients

The molecules and mechanisms of life serving the main functionality of cosmetic products to rethink actives and ingredients.

Formulation and galenics

Focus on the overall structure and properties of matter to facilitate its shaping and use, based on the observation of biological fluids and macromolecular interactions.



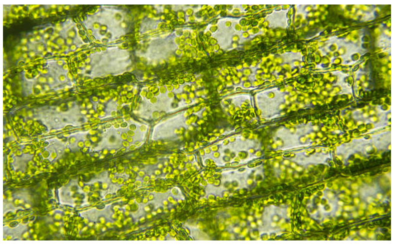
Packaging

Preserve, transport, inform, differentiate, apply: the coverings of life (skins, barks, cuticles, shells...) to meet the demanding specifications of packaging in cosmetics.

At the level of resource management

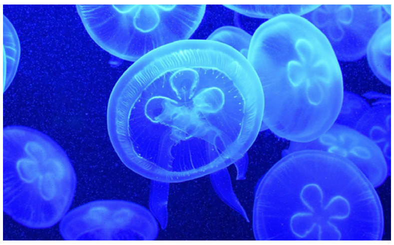
Raw material and circularity

Origin of ingredients, production conditions, waste management: the interactions between species within natural ecosystems provide the operational model for circularity.



Transformation processes

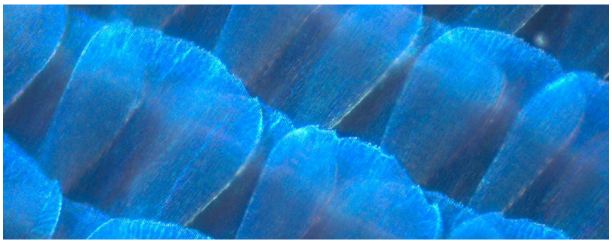
Bottom-up strategies, enzymatic catalysis, and mild chemistry conditions... life has a catalog of efficient processes to create functional and structural materials.



Water: quantity and quality

As a universal biological solvent and vital element for all species, numerous strategies are deployed in nature: capturing, storing, processing, and distributing.

Originality and transversality of biomimicry



Multi-functionality and adaptation

Unlocking the secrets of life's multi-scale organization to develop multifunctional and adaptive solutions in response to the environment.

Infrastructures and organisations

The universality and power of the bio-inspired approach, which applies at all scales: from biomolecules to territories, including buildings; and across all fields: from physical chemistry to corporate strategy.

Bio-inspired active ingredients

Product innovation

At the intersection of chemical ingredients and the functionality of the finished product, active ingredients are a central and differentiating element in the cosmetics industry. Using nature as a model at this scale ensures alignment with the principles of green chemistry, which are fully convergent with biochemistry. For each desired function, it also provides access to a catalog of biological solutions that implement a diversity of inspiring mechanisms.

At the heart of cosmetics: Active Ingredients

Active ingredients are the cornerstone of cosmetic products, ensuring their main functions for the human body: sun protection, skin hydration, anti-aging effects, optical properties in makeup, etc. Faced with increasing demands for quality and safety, the cosmetics industry is constantly seeking innovations to develop ever more effective ingredients.

Biomimicry to meet the challenges of cosmetic innovation

Many of the functions expected from active ingredients have explicit parallels in nature (see table on the following page). These natural models already adhere to demanding specifications, with rigorous standards for optimal effectiveness and sustainability. The goal of biomimicry is to bring industrial practices closer to these biological strategies.

Zooming on...

... The biomimetic white pigment

A promising alternative to minerals like titanium dioxide for their optical properties, the company Seprify replicates the whiteness of the exoskeleton of the Cyphochilus beetle from cellulose.

https://seprify.com

Syurik J, et al. Bio-inspired, large scale, highly-scattering films for nanoparticle-alternative white surfaces. Sci Rep. 2017 Apr 21;7:46637

Seprify MATERIALS

... The iridescent colors of life

Morpho butterfly wings and the fruits of Pollia condensata produce spectacular iridescent colors. Sparxell replicates these metallic effects using cellulose, without plastics, mica, or titanium.

https://sparxell.com

S. Vignolini et al. Pointillist structural color in Pollia fruit. PNAS2012 Sept 10; 109 (39) 15712-15715

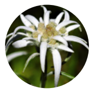
Sparxell

From a cosmetics functionality to biological models

What are the convergences between cosmetic functions and biological properties?

What natural sources of inspiration for tomorrow's active ingredients?

What is the potential for biomimetic innovation?

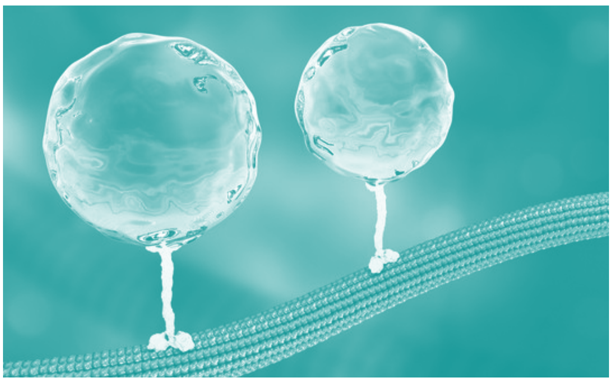
In cosmetics Target property	**In nature** Relevant biological models	
UV protection	 	→ Filamentous down covering the Edelweiss (flowers, leaves, stems). *A network of fibers that reflects a significant portion of radiation, reduces surface accessibility, and dissipates UV energy through multiple reflections.* → Film-forming secretion on the skin of the hippopotamus. *A peak of absorption in the UV range by the synthesized pigments; the pigments self-assemble into liquid crystals that block transmission through their regular structure.*
Cicatrization	 	→ Rapid regeneration of pangolin scales. *Reorganization of biopolymers under the action of water to restore mechanical properties.* → Composition of rubber tree sap. *Microcapsules containing a viscous sub tance, released under mechanical stress.*
Hydration	 	→ Hygroscopic property of snake skin. *Maintains a water film through a granular surface and interscaleral channels.* → Water storage in succulent plants. *Limits evaporation with a waxy coating and the role of mucilage to contain water in the form of a viscous gel.*

To go further

Beyond the desired function, taking inspiration from the molecules themselves

Living organisms are full of three-dimensional, complex, and multifunctional molecular superstructures: the solubility of globular proteins in water; the mechanical properties of fibrous proteins; targeted identification enabled by membrane proteins (channels or receptors).

The specific interactions between molecules allow the activation of certain functions, typically through conformational changes: transport and/or release of the contents of a vesicle; triggering of enzymatic activity; opening/closing of a channel.



Kinesin proteins transport vesicles along the cytoskeleton, the internal "skeleton" of cells.

Bioinspired formulations & galenics

The Art of Formulation: Science, Creativity, and Awareness

A key step in shaping products, formulation must meet several criteria:

- Stability: Compatibility of active ingredients with each other, maintaining the desired functions over time;
- Sensory experience: Offering user experiences, interactions with the product, behaviors, and usage patterns;
- Safety: Biocompatibility, harmlessness, and impact on the product's lifecycle.

Unveiling the Physico-Chemistry of Life

Secretions, mucus, saliva, sap, films, membranes... the vast diversity of biological fluids and surfaces offer numerous potential sources of inspiration for new and high-performance formulations, both functionally and environmentally.

Zooming on...

... Vaccine preservation, inspired by extremophiles

Certain species, known as extremophiles — such as the tardigrade or the resurrection plant — are famous for their ability to withstand extreme drought. This phenomenon is explained by the mobilization of a sugar that helps maintain the three-dimensional structure and thus the functionality of their biomolecules.

This principle has been adapted for vaccine preservation, using trehalose and exploring the glass transition state. A solution that is now commercially available, notably by companies like Biomatrica and Nova Laboratories.

https://laboratorytalk.com/article/345805/samplematrix-technology-protec

https://m.novalabs.co.uk/stabilisation-technologies

O. Schill et al. Molecular mechanisms of tolerance in tardigrades: New perspectives for preservation and stabilization of biological material, Biotech Adv. 2009 July-Aug, 27, 4, 348-352.

Biomātrica

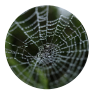
Nova Laboratories Ltd

Transversal problems addressed by nature

What biological strategies can ensure the interfaces between ingredients?

How to achieve trade-offs in functional properties?

What rheological characteristics of life can be used to transform cosmetic products?

In cosmetics Target property	**In nature** Relevant biological models	
Miscibility		→ Storage of lipids in oilseed plant seeds. *Intracellular structures (oleosomes) and stabilization against coalescence by highly hydrophobic molecules.*
		→ Production of spider silk. *Polymerization under flow by mixing ingredients stored in separate glands.*
		→ Sudden expansion of hagfish mucus. *Instant hydration of fibers, multiplicity of filamentous elements, and release of elastic energy.*
Adhesion		→ Climbing plant strategy: ivy glue. *Rheo-fluidifying nature of the sap, based on organic nanoparticles, followed by solvent evaporation for solid crosslinking.*
		→ Underwater construction by marine worms. *Assembly through static electricity based on the ionic charge of proteins, solidification through pH difference with the saline environment.*
		→ Locomotion of snails. *Viscoelastic properties of gastropod mucus to alternate between lubricant and adhesive depending on mechanical stress.*

To go further

A resource-saving formulation

How to reduce the number of ingredients?

Relying on the multifunctionality of biomolecules. For example, flavonoids, which are abundant in the plant kingdom.

Flavonoids have several functions, such as coloration and photoprotection. They play a crucial role in combating both biotic and abiotic stresses, such as cold or nutritional deficiencies. This multifunctionality allows for a certain efficiency in the number of molecules needed for the functioning of a plant.

Replacing chemical ingredients with physical strategies.

Antimicrobial protection can be achieved through compounds like sphingicins — identified in the stomachs of penguins to preserve food intended for juveniles. This same property is replicated by the micro- and nano-textured topology of surfaces such as cicada wings and shark skin.

Bio-inspired packaging

Product innovation

The packaging: an element not to be overlooked in product design

The container for cosmetics is essential to consider as it requires paradoxical properties:

- It must protect the product (from mechanical, physical, chemical, biological stress...) but also facilitate its use and easily transform at the end of life (recycling or biodegradation);
- It must convey a maximum of information (composition, batch number, recommendations, brand image, claims...) while using the least material possible;
- It faces the challenge of meeting demanding specifications while eliminating plastic materials.

Nature: an ally for more sustainable, innovative packaging

Maintaining stable internal conditions in a changing environment is the very definition of life. Organisms wrap and preserve at all scales, from molecules to organisms, in various ways: globally or compartmentally, permanently or temporarily... using abundant and recyclable biomolecules (lipids, proteins, polymers...).

Zooming on...

... Structures combining strength and lightness

Leveraging porosity, as many organisms do (vertebrate bones, diatom frustules, bamboo...), is the proposal of alveolar materials by Modulatio' and Metavoxel Technologies.

inforcing materials with helical structures, like the polymer arrangement in crustacean exoskeletons: Helicoid Industries INC. and Logoplaste (Vitalis).

https://www.modulatio.fr

https://www.metavoxel.tech

https://www.helicoidind.com

https://www.logoplaste.com

... Functional surfaces

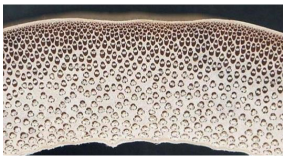
Antibacterial solutions inspired by shark skin (Sharklet Technologies) or self-cleaning surfaces based on carnivorous plants like Nepenthes (SLIPS Technologies) rely on micro and nanometric surface texturing to mimic the organization of biological materials at the subcellular scale. Laser technologies are the most commonly used manufacturing techniques (ALPhA NOV, FUSION BIONIC).

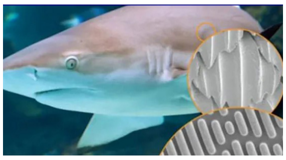
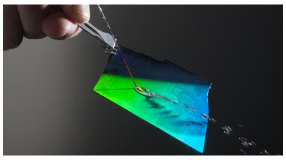
https://www.sharklet.com

https://wyss.harvard.edu/technology/slips-slippery-liquid-infused-porous-surfaces

https://www.alphanov.com

https://fusionbionic.com



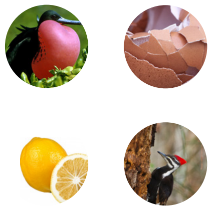
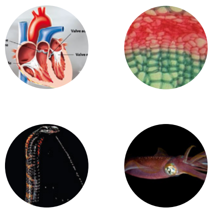
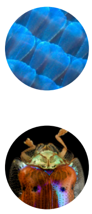



An envelope to preserve and transport

How to preserve the product from external conditions: light, humidity, temperature, microorganisms?

How to maintain the product's physical integrity all along its life cycle?

How to ensure product traceability?

In cosmetics Target property	**In nature** Relevant biological models	
Protection		→ Combine elasticity and impermeability to isolate contents. *Biological films: gular sacs of birds, egg membranes...* → Absorb mechanical shocks. *The skin of fruits: alveolar foam, property gradient from soft inside to rigid outside. The tongue of the green woodpecker that extends around the brain.*
Fluids management		→ Ensure efficient fluid circulation. *Heart valves for unidirectional flow. Integrated valves that prevent gas embolisms in the xylem of trees* → Disperse a fluid. *Spitting protective substances (snake venoms, cuttlefish ink...). Propulsion system for movement (squid).*
Communication		→ Use the optical signature of microstructures to protect against counterfeiting. *Morpho butterfly wings.* → Transmit and modulate information: color changes induced by a stimulus (conditions and duration of preservation...). *Shell of the Charidotella sexpunctata beetle.*

To go further

New materials

Reintegrating packaging within the biological cycles

Mycomaterials

Made from fungal mycelium, fibrous materials are developed, notably as alternatives to polystyrene. Mycomaterials combine the advantages of a fast-growing material (compared to other biomaterials), customizable (in terms of shape, density...), and biodegradable.

Chitin

A polymer material equivalent to cellulose, found in the exoskeletons of crustaceans, as well as in insects and fungi, chitin is a structural material with antibacterial properties. The by-products from the agro-food industry make chitin a valuable resource for improving the lifecycle of packaging.

Raw materials and circularity

Resource management

Toward More Resource-Efficient Management for a Sustainable Future

After having outsourced the production of raw materials for a long time, the challenge today is to bring production back closer to its source to ensure quality and reduce transportation times. It also involves limiting water-, fertilizer-, and pesticide-intensive plant crops that compete with food resources, as well as ingredients derived from petrochemical processes.

Valuing waste and by-products opens the way to optimization in terms of energy and yield on production lands. How can nature's principles once again serve as a guide for better resource management?

Living organisms use the resources of their natural environment and are part of the great material cycles (carbon, nitrogen...). They can function in symbiosis or use other organisms' waste to gather resources.

Zooming on...

... Ecosystem Regeneration

The sustained production of resources depends on the health of natural ecosystems. To ensure their regeneration, biomimicry encourages recreating optimal conditions through artificial systems (e.g., SeaBoost in marine environments) or by stimulating natural functions (e.g., Novobiom, Mycophyto or Gaïago for soil remediation and biological interactions).

https://www.novobiom.com

https://www.seaboost.fr

https://www.mycophyto.fr

https://www.gaiago.eu

... Biocontrol Solutions

To protect crops, M2I Life Science and ImmunRise mimic interaction strategies between individuals or biological species (chemical communication via pheromones, mobilization of microorganisms or insects...). These biocontrol methods offer a credible alternative to phytopharmaceutical products.

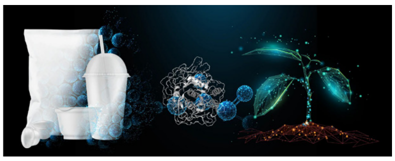
https://www.m2i-lifesciences.com

https://www.immunrisebiocontrol.fr

... Enzymatic Recycling

To bring the plastics and textiles industries into a circular economy, Carbios anticipates the end of life of materials through the use of enzymes. These natural molecules are selected and optimized to enable the biodegradation of PLA and the recycling (depolymerization) of PET.

https://www.carbios.com/fr



Producing like a natural ecosystem

How to rethink plant cultures respecting nature's principles?

How to synchronize industrial activities in order to mutualize resources?

Concept Production systems	**Inspiration and definition** Properties of natural ecosystems	
Soil protecting agriculture		→ Minimal soil disturbance, permanent soil cover, and plant diversity: This system prioritizes reduced soil disruption, maintaining a permanent soil cover, and diversifying plant species to enhance soil health and resilience.
Agroforestry		→ Integration of trees into agricultural lands: Through hedges, orchards, or groves, these species associations improve soil productivity and store carbon. Trees protect crops by acting as windbreaks and providing shade, while their roots promote the capillary rise of deep water.
Permaculture		→ Production systems inspired by natural ecosystems: This approach involves observing and emulating the efficiency of natural ecosystems to foster beneficial interactions among species. Forests serve as a major inspiration, utilizing different strata (canopy, shrubs, ground cover plants) to optimize productivity.
Integrated Multitrophic Aquaculture		→ Aquatic organism farming in diverse systems: The production of aquatic organisms (fish, mollusks, algae) is combined with a diversity of species to recreate a trophic network (food chains). The goal is to enhance yields while reducing pressure on natural ecosystems.

To go further

Depollution strategies

Partnering with life for the health of ecosystems

The principle of bioremediation involves the decontamination of environments through chemical degradation techniques or the activity of living organisms. Specifically, plants and fungi, through their root systems, penetrate deep into the soil and extract nutrients necessary for their metabolism. Some species can tolerate or even sequester toxic compounds such as heavy metals within their tissues. This property is leveraged to reintegrate pollutants into recycling circuits.

The work of Claude Grison on phytoremediation (ChimEco laboratory, CNRS) goes further by proposing ways to valorize these pollutants. Combined with organic molecules, they become catalysts of interest for the chemical industry.

Transformation processes

Resource management

Challenges of Processes from Raw Material to Finished Product

Raw material processing, ingredient extraction, compound purification, emulsification, encapsulation… the cosmetics industry relies on many chemical transformation processes during formulation. The number of steps, the use of solvents, and the generation of toxic waste/by-products are key factors to consider when defining the most efficient processes.

From Matter to Life: Chemistry? Chemistry! (J.M. Lehn, Nobel Prize in Chemistry)

The series of reaction cascades within each biological cell demonstrates the importance of the chemistry of life in its physiological processes (energy management, nutrition, immune system…) and in the construction of its structural materials. Modeled under the banner of green chemistry, 12 principles outline the guidelines for applying this life chemistry in industrial processes: water as a universal solvent, moderate temperature and pressure conditions, safety of reagents and products, and the use of catalysis… Biological inspiration goes even further: with green chemistry, the aim is to synthesize materials by directly drawing from the manufacturing processes of living organisms, with biomineralized glass produced by diatoms being the most emblematic example.

Zooming on…

… Bio-inspired Catalysts and Eco-catalysts

Novomer develops ultra-specific catalysts for target monomers, operating at room temperature and fully integrated into the carbon cycle: from plant-based raw materials transformed into biodegradable products.

NewIridium mimics photosynthesis to capture CO2 and convert it into energy molecules. This light-controlled chemistry (photocatalysis) helps reduce the use of heavy metals and energy consumption.

Bio-inspir leverages [metallic catalyst + biomolecule] complexes in industrial chemistry, obtained through soil decontamination.

https://www.novomer.com

https://newiridium.com

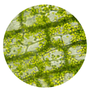
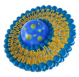
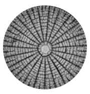
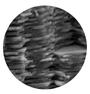
https://bioinspir.com

NOVOMER Catalyzed Chemistry NEW IRIDIUM BIOINSPIR

Manufacturing strategies in nature

How does life produces, transforms and assembles molecules?

What energy sources, what forces, what are the mechanisms at play?

Concept Process	**Definition and example in nature** Typology of molecules and structures	
Photosynthesis		→ Ementary Production of Organic Matter from Water, CO2, and Light Energy. *Synthesis of carbohydrates through carbon fixation.* → Artificial photosynthesis and electrochemical processes aim to mimic this natural process.
Self-assembly	 	→ Three-Dimensional Structures Obtained from Weak Bonds Between Chemical Groups and Hydrophilic Contrast: • Protein folding – *chemical specificity of enzymes or antibodies, structural role of actin filaments, triple helix of collagen…* • Polymerization of sugars and supramolecular assemblies, either fibrous *(cellulose, structure)* or branched *(glycogen, energy reserve) ;* • Extreme compactness of genetic material ; • Lipid membrane for compartmentalization – *cellular boundaries, vesicles…*
Biomineralization	 	→ Skeletons, Shells, Frustules… Production of mineral structures *(glass, ceramics, composites)* by living organisms. Mineral crystallization mechanism spatially controlled by an organic matrix *(molecular template obtained by self-assembly of lipids or block copolymers)* to architect the material.

To go further

Production modes and relationship with nature

The methodological approach of biomimicry leads to concepts, new ideas, and innovative strategies. However, there are still many degrees of freedom regarding its implementation: the way of realization can be more or less close to nature. Environmental, ethical, and technical criteria guide the choice towards one of the options.

Biological pathway

Natural productions, bio-based materials, nature-based solutions. The goal here is to integrate into the cycles of life.

Artificial pathway

Synthetic chemistry, technical solutions, artificial reproductions. The challenges are to reduce pressure on natural resources and evolve chemical processes based on the model of green chemistry.

Hybrid pathway

Use of biotechnology, combining biological processes with technical solutions to bridge the requirements of life and industry.

Water: quantity and quality

Resource management

A More Responsible Use of Water

Water is at the heart of many industrial uses such as washing, waste disposal, cooling of installations, etc. Significant efforts are being made to reduce the quantities used and limit the volumes withdrawn. Water savings and closed-loop systems are the main solutions available today. At the same time, water quality remains a major concern to prevent the release of pollutants through the treatment of effluents. For the cosmetics industry, in addition to these industrial challenges, there is also the issue of water usage by consumers during the application phase. Solid cosmetics, hygiene habits, and product rinseability are crucial concerns for the sector.

Biomimetic Approach: A Driver of Innovation at Different Scales of Water

Water, a vital element for all living beings, makes up an average of 80% of biological tissue composition. Managing both excess water (marine life), its scarcity (desert species), and its intermittency (seasonality) are daily challenges. Many biological functions are associated with water management: capture, storage, transport, distribution, filtration, etc.

Zooming on...

... Molecular Filtration

Aquaporin Inside® technologies are biomimetic membranes containing transmembrane proteins, such as aquaporins, which filter at the scale of a single molecule. These membranes come in flat surfaces or tubes and can be used for direct or reverse osmosis applications.

https://aquaporin.com

... Pollution-Control Wetlands

The Libellule zone, developed by Suez, ensures the filtration of residual elements at the output of wastewater treatment plants through the natural performance of plants and microorganisms. The distribution of species and the water circulation have been optimized to recreate the most favorable conditions.

https://www.suez.fr/fr-fr/notre-offre/succes-commerciaux/nos-references/zone-libellule-chateauneuf

... Waste Collection in Rivers

The H2OPE system is inspired by the morphology of whales, particularly their baleen plates, to collect as many elements as possible in aquatic environments, on the surface or under flow, without disrupting the fauna and flora.

https://www.h2ope.fr

... Water Management in Our Infrastructure

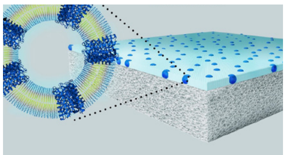
Tencate Aquavia develops a textile designed to treat runoff water that becomes contaminated with pollutants, especially hydrocarbons. The textile's structure and chemistry trigger biodegradation mechanisms and promote colonization by microorganisms that are also involved in water depollution.

https://www.tencategeoclean.com/fr

H2OPE

suez

AQUAPORIN



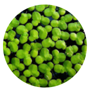
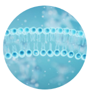
TENCATE AQUAVIA

Biological mechanisms and strategies for flow management

How can we integrate into the water cycles without compromising its quality?

How can we reduce our dependence and vulnerability to this particular resource?

How can we rethink our water usage based on the model of living organisms?

In cosmetics Target property	**In nature** Relevant biological models	
Collecting		→ Horned Devil Lizard. *Condensation of dew in the micro-grooves covering its spines.*
Storing	 	→ Succulent Plants, like Witch's Claws. *Accumulation of water in tissues at the cellular level, protection against dehydration through a hydrophobic waxy coating.* → Duckweed (Lemna minor). *Partial or total coverage of water surfaces with its floating leaves to limit evaporation.*
Transporting	 	→ Ohalarope Birds. *Capillary ratchet technique to move water droplets up along their beak by leveraging capillary forces through repeated opening and closing movements of the beak.* → Cell Membranes. *Osmosis phenomenon: diffusion of water between two compartments according to the concentration gradient.*

To go further

Bio-inspired microfluidics

Life as a model for manipulating fluids at small scales

Circulation in blood vessels, sap pumping in the xylem of trees, production of silk threads from the silk-producing glands of spiders... Living organisms are full of miniaturized fluid systems. Many research efforts focus on these biological devices, whether from the perspective of the fluid dynamics specific to this scale (where capillary forces dominate) or for the manipulation of biological objects such as cells. Microfluidics is a powerful tool for replicating biological functions in a simplified manner (organ-on-a-chip, functional surfaces, etc.). In turn, microfluidics benefits from biomimetic developments: pumps, valves, filters, mixers, bubble management, inspired by living systems.

Multifunctionality and adaptation

Originality and transversality

An Unattainable Set of Requirements?

Cosmetic innovation faces contradictory aspirations:

- Products that are increasingly effective, combining cross-functional properties (cosmetic function, texture, preservation...), while being highly targeted to meet the specific needs of each individual.
- A trend toward naturalness, minimalism in formulations, and great simplicity.

One key to resolving this ambivalence may lie in the search for multifunctionality and adaptive properties to respond to the environment, programming differentiated behaviors.

Living organisms are constantly faced with this issue in multiple forms:

- Trade-offs in performance between vital functions (nutrition, protection, reproduction...).
- Morphological, metabolic, and behavioral adaptations according to the external environment (seasons, changes in ecosystems, specific events...).
- Use of organs and strategies that are either generalist and versatile or specialized and specific.

More specifically, the multi-scale organization of matter allows the combination of effects, with each physico-chemical phenomenon having its own characteristic size.

Zooming on...

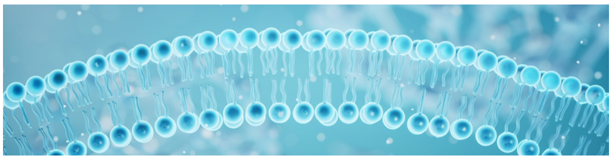
... "All-in-One" Materials

Modeled after the cell membrane, LipoCoat develops a coating similar to phospholipid bilayers with numerous properties: hydrophobicity, lubrication, antifouling, self-healing, and antithrombotic.

Made from bacterial cellulose, BIOM offers Nanulose, a material that is mechanically and optically (UV) highly resistant, an emulsifier and foam stabilizer, biocompatible, hypoallergenic, and biodegradable.

https://www.lipocoat.com

https://bioinspiredmaterials.com/en/products/nanulose



... Responsive materials

In the biomedical field, the company Tissium has developed a surgical glue for biological tissues inspired by the adhesion capabilities of marine organisms. This glue is specifically activated by an optical signal.

Basilisk imparts a self-healing property to concrete to extend the lifespan of infrastructures. Microorganisms are encapsulated, and their bioremineralization activity to fill cracks is triggered by external moisture.

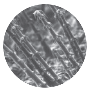
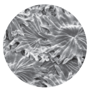
https://tissium.com

https://basiliskconcrete.com/en

Giving life to materials

Which composition and which structures for which properties?

Which stimuli, which triggers for which effects?

In cosmetics Target property	**In nature** Relevant biological models	
Multifunctionality	 *Caiophora coronaria*  *Hippophae rhaminoides*  *Kalanchoe tomentosa*	→ Leaves of many plants (ferns, conifers, flowering plants...) are covered by a protective outer layer called the cuticle, made of wax crystal structures. Depending on their size, shape, and organization, they contribute to various functions: • Waterproofing • Superhydrophobic surface state • Anti-adhesion and self-cleaning coating • Optical communication to pollinators • Protection against UV radiation • Thermal dissipation • Structural mechanical resistance
Controled activation	     	→ Humidity Level • *Seed Dispersion*. The opening/closing of pine cone scales is influenced by humidity levels due to the heterogeneous organization of cellulose fibrils: local swelling variation induces overall mechanical deformation. • *Defense, Information to Predators.* Color change in the elytra of the Hercules beetle, triggered by water infiltration into the multilayered chitin structure, altering the optical contrast of visual indicators. → Mechanical • *Defense, Protection Against Predators.* Rapid folding of Mimosa pudica leaves in response to tactile stimulation, causing water movement between cells. • *Camouflage, Protection Against Predators.* Contraction/dilation of pigment cells in chameleons and octopuses to select light-cell interactions that produce the desired color. → Chemistry • *Material Production, Prey Capture.* Crystallization under flow, based on pH, of liquid secretions from the silk-producing glands of the spider's abdomen, forming silk threads. • *Defense, Protection Against Predators.* Rapid swelling of hagfish mucus when exposed to seawater through interaction between the ions in the water and the densely folded protein fibers.

Infrastructures and organizations

Originality and transversality

Systemic Dimension of Our Infrastructures

The management of flows (water and energy) and the behavior of materials (mechanical, optical, acoustic...) are fundamental elements that extend from product R&D to infrastructure. Many bio-inspired building facades combine one or more of these properties to meet complex requirements in terms of technical feasibility, building usage, and durability.

From the scale of the building to that of the neighborhood, the question of interactions between our infrastructures and biodiversity becomes crucial. Biomimicry can and should be a lever not only to reduce our negative footprint (pressure on resources, generation of pollution...) but also to contribute positively through regenerative contributions (supporting biodiversity, air purification...).

Beyond R&D, Biomimicry Across All Business Services

While issues related to chemistry, raw materials, materials, and water quality are material in nature, biomimicry is also applied through optimization algorithms, logistical challenges, and the concept of services. Our perspective on life and its evolutionary history encourages us to re-question our organizations: from the economic model to corporate strategy, including governance.

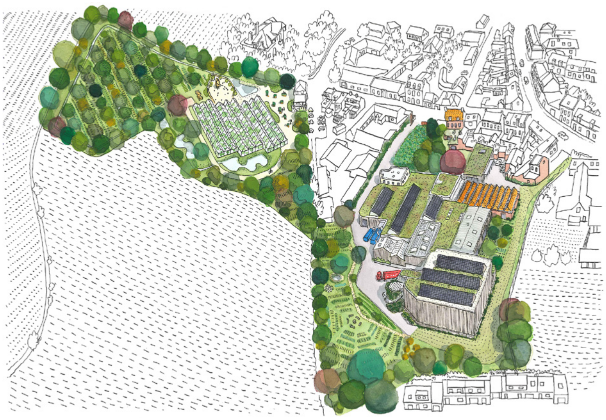
Zooming on...

... Pocheco

POCHECO

A French company specializing in the manufacturing of industrial envelopes, Pocheco has initiated a highly committed approach since 1997 to remain economically competitive while reducing the harmful impact of industrial activities on both human health and the environment. A pioneer in eco-economics, Pocheco develops an ecological economy approach that aligns with nature, working simultaneously on six key areas: biodiversity, water, energy, mobility, production, building, and site. The working method involves creating a shared vision that links ecological transition, changes within the company, and the mobilization of work teams.

https://pocheco.com/fr



Life as a guide for ecological sustainability

What are the underlying principles governing life's development?

Towards which goals should biomimicry's methodology be oriented?

Concept	**Definition and examples** Inspirations and insights	
Nature inspired principle for eco-design		→ Formulated by biologists M.B. Hoagland, B. Dodson, and J. Hauck in 1995, popularized for biomimicry by J. Benyus in 1997, and widely expanded by the biomimicry community since (see article G. Lecointre et al., Biomimetics, 2023), these principles aim to connect major trends observed in nature with sustainable development challenges, notably: • The bottom-up and self-organizing nature of biological materials • Energy frugality from renewable resources • The circularity of flows to eliminate the notion of waste • Multicriteria optimization preferred over maximizing a single quantity • ...
Ecosystem services		→ These principles reflect the benefits humans derive from natural ecosystems, such as: • Provisioning services – food, fuel, medicine, materials... • Regulation services – climate, flooding, pollination... • Socio-cultural services – recreational, aesthetic, spiritual... • Supporting services – biogeochemical cycles, soil formation... → Synergistic and regenerative effects are expected at the intersection of these ecosystem services, biomimicry, and nature-based solutions.

To go further

Industrial and territorial ecology

Foster resource exchange among players of the territory

Modeled after the cycles of materials and energy in a natural ecosystem, industrial and territorial ecology encourages the creation of flows between different activities to approach a closed-loop system and minimize the generation of ultimate waste. Possible flows include: heat and steam, water, gases, gypsum, biomass and liquid fertilizers, ashes, sewage sludge...

This principle is based on a strong complementarity between stakeholders, proximity and local integration, and a genuine logic of cooperation.

Ceebios

Centre d'études & d'expertises
en biomimétisme

Since 2015
+ 20 Ceebios experts, PhD, biologists, engineers
+ 200 clients and industrial projects supported
+ 500 partners in a unique eEurope

Ceebios is the Centre d'Etudes et d'Expertises en Biomimétisme, dedicated to deployment of biomimicry in support of the ecological transition. As a non-profit cooperative society with ESUS status, Ceebios is positionned at the interface between life sciences and transition issues.

Ceebios coordinates the struturing and implementation of a national roadmap for biomimicry, focusing in particular on three key areas :

. **Deploying biomimicry in France**: coordinating the national network and privileged ecosystem for cooperation, communication and training initiatives.

. **Exploring the potential of biomimicry**: through its own R&D actions, development of tools and resources to facilitate the biomimetic innovation process, thanks to robust and proven methodologies.

. **Innovate with biomimicry**: support for R&D and innovation through a recognized consulting activity applied to all industrial sectors.

www.ceebios.com

Cosmimetic Group

The Cosmimetic Group is a working group bringing together players from the cosmetics industry to discuss biomimicry, a responsible innovation approach inspired by the strategies of living organisms. This initiative aims to support the appropriation of the biomimetic approach for the sector, and in particular:

- Build **a collective and ambitious vision** of the benefits of biomimicry in the specific context of the cosmetics industry;
- Build **the group's skills in biomimicry**, through the aggregation and production of inspiring resources, the mobilization and meeting of expertise, and the discovery and appropriation of methodological challenges;
- Facilitate **the emergence of bio-inspired projects** that are collaborative, concrete, innovative and sustainable.

In 2024, the Cosmimetic Group, led by Ceebios, brings together: GREENTECH, L'Oréal, Lucas Meyer Cosmetics by Clariant, Mibelle Biochemistry, NAOS, Pierre Fabre, Stearinerie Dubois.

This synthesis was produced thanks to the support of the Nouvelle-Aquitaine region.

RÉGION Nouvelle-Aquitaine

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