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Green-Bio-Economy and Bio-Nanotechnology for a More Sustainable Environment

Pierfrancesco Morganti, Hong-Duo Chen and Yuan-Hong Li

Abstract: There is growing recognition that the transition to a green bioeconomy can generate more sustainable growth. This is the reason why the EOCD and EU economic platform until 2030 is based on the use of natural raw materials obtained from plant biomass and fishery waste, in substitution to fossil-derived ones. From this new economic vision, fundamentally focused on innovative agriculture and bionanotechnological systems, great potential for delivering economic growth with environmental protection and social inclusion is expected. Thus the green bioeconomy will have a positive impact on our quality of life, maintaining in equilibrium the planet's ecosystem and biodiversity. Since the realization of a global sustainability depends on renewable sources of materials and energy, bio-based polymers and products to replace petroleum-based ones must become a mainstay of our society. The use of chitin nanofibrils (obtained from crustacean waste) to produce goods and innovative nanocomposites is a step in this direction, as reported in this chapter.

1. Introduction

The bio-economy, synonym for a green economy or ecological economics [1–3], can be described as an interdisciplinary field of academic research that, strictly connected with the bio-nanotechnologies, is based on building blocks of materials, chemicals, and energy derived from renewable industrial byproducts such as plant biomass and fishery waste [4,5].

This new branch of economy, based on the use of natural bio-energy instead of fossil fuels and focused on socioeconomic, agricultural, and technical systems, will represent a fundamental platform of the 2030-EU and OECD economy [6,7]. This new economic vision will meet the requirements for industrial sustainability and environmentally friendly social and economic impacts. At the same time, it is essential not only to increase human well-being and decrease environmental pollution and climate change, but also to stop the depletion of natural resources [1–7]. To this purpose, both biotechnologies and nanotechnologies will be indispensable to stimulate the increase of a sustainable economy, fundamental for developing jobs and the industrial production of tools and energy at low cost. This will make it possible to maintain the actual standard of living, ameliorating its quality and considering human health and wellness as the real goal for an advanced economy and a safe industrial development [6–8].

From this knowledge-based bio-economy (KBBE) potential benefits are expected, such as a reduction of greenhouse gas emissions, a decrease in dependence on fossil "resources, wiser management of natural resources, and improved food security" [6–9].

2. Maintaining Biodiversity through an Ecosystem in Equilibrium

For all these reasons, a must of our future society should be the amelioration of the Earth's habitat, developing a sustainable economy based on the use of materials and processes of biological origin [10].

This new way to produce goods and services has to be based on the same methodologies adopted from nature, such as the use of enzymatic reactions instead of the classical chemical reactions. Thus the bio-economy, driving the growth of smart agriculture and forestry sustainability by innovative processes of bio-engineered technologies, must produce enzymes, amino acids, and active ingredients for pharmaceutical, food, and cosmetic products, as well as make biopolymers and bio-fibers from renewable industrial resources and biofuel produced by bio-refineries, necessary for transporting raw materials and goods [4,10].

It is interesting to underline that, in this different economic vision, the use of industrial byproducts derived from plant biomass and fishery waste (Figure 1) [11,12] should be considered an alternative way to produce goods without impoverishing the earth of its natural resources, which is indispensable to maintain the ecosystem' equilibrium and species biodiversity [13].

Figure 1. Plant and fishery waste.

Thus, the green bio-economy could solve the majority of the aspects required for industrial sustainability, which, by respecting the biodiversity of our planet, will safeguard the health of humans, animals, and plants together (Figure 2).

Figure 2. Biodiversity and socio-assets of the planet.

3. The Bio-Economy and Industrial Sustainable Development

The green bio-economy is considered a way to ensure all the social, economic, and environmental prerequisites to meet a sustainable development. However, it is also increasingly recognized as a greater economic opportunity for removing barriers and enabling poor and disadvantaged groups to participate in, contribute to, and benefit from the transition [14]. To obtain these results it will be necessary to develop a new economy by meeting different economic, social, environmental, and political parameters.

To this purpose, the following will be necessary to realize: (a) an economic growth capable to support the efficient use of resources with low carbon emissions, and favoring the adoption of green and high-tech nano-biotechnologies with the use of raw materials, obtained from byproducts and poor countries; (b) a social development that can improve health and well-being, especially among the poor, thus promoting social equity; (c) an environmental sustainability based on the increase of productivity and efficiency of the natural resources used, with a simultaneous reduction of pollution obtained by the right investments necessary to sustain ecosystem health, and resilience in management of environmental risks; (d) a governance that can empower citizens through access to information, justice, and participation in decision-making, particularly among marginalized groups, contemporary improving transparency and accountability in the public and private sectors, including a better regulation of the market [1].

According to EU, OECD, and USA reports [6,7,15], it seems that the economic, environmental, and social benefits ,obtained from the use of nanotechnologies

(Figure 3), could represent the optimum route towards sustainable development at a regional, national, and international level.

Shifting to the European view, the bio-economy is defined as "the production of renewable biological resources and the conversion of these resources and waste into value-added products, such as food, feed, bio-based products and bio energy" [9,16,17]. Environmental assets such as fertile soil, clean water, and biodiversity help drive economic growth, contributing to public health and providing safety nets for the poor [18]. Thus, investing in improved natural resources through proper environmental management in rural and urban areas, such as sustainable forestry and fisheries, can not only reduce carbon emissions but generate also high social rates of return.

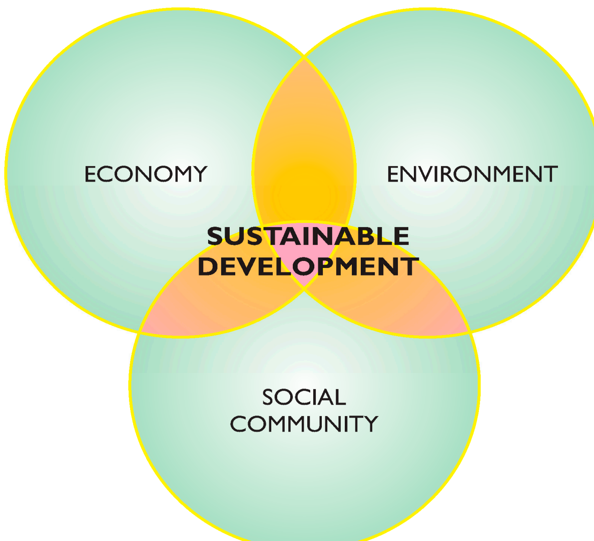


Figure 3. Sustainable development.

However the success of using nano-biotechnologies and byproducts as principal raw materials to make goods and produce clean energy is subject to institutional capacity within implementing agencies and technological organizations from the municipal level up, to meet the requirements with minimal costs. The process of transforming a fossil-based economy into a novel green economy takes time and requires continuous government intervention. The necessary technologies require a strong emphasis to realize a sustainable growth, together with up-front investments in research, development, and innovation.

Thus, the EU has emphasized the research projects by the Seventh Program Framework and are going in this direction with the Horizon 2020 program also [18,19].

To this purpose, our group has realized three interesting projects: Bio-Mimetic (www.biomimetic.eu), coordinated by P&G UK, n-Chitopack (www.n-Chitopack.eu), and Chitofarma (www.chitopharmam.it), both coordinated by MAVI Sud, Italy. By these projects innovative cosmetic products, biodegradable food packaging, and advanced medications have been developed, using chitin nanofibrils and other natural polymers, obtained from fishery waste and plant biomass, respectively, by the use of green industrial processes with low consumption of energy and water [20–22].

In this way new green technologies and new safe products have been developed, with added value for consumers in the fundamental fields of cosmetic, food, wellness, and biomedicine. The food industry is, in fact, one of the largest sectors of the European economy, with a yearly turnover of €800 billion and roughly 4 million employees; the EU cosmetics industry had a turnover of €69 billion in 2012, representing one-third of the global cosmetic market, with direct and indirect employment in EU of 1.7 million people and more than 4000 industry companies, while the global sheet face mask market is expected to reach US$336 million by 2024 (source:Trasparency Market Research) with a year growth of 8.7% from 2016 to 2024 [23].For all these reasons, it is expected that food ,tissue masks and advanced medications with an expected grow of 11%–12% during the forecast period 2014–2019 will play a more prominent role in the future through an increase in innovative diet supplements, therapeutics, and diagnostics.

Nutrition and biomedicine are, in fact, two economic pillars of progress and the key to health prevention, which requires both high-tech technologies and innovative products. Moreover, technological development is hampered by the aging population of the industrialized countries and the necessity of maintaining a high standard of health care, reinforced by the limited availability of raw materials and energy resources, accompanied by global warming also. Thus, the growing demand for a sustainable supply of food, raw materials, and fuel as the major driving force behind the KBBE will probably be based on a combination between plant breeding and industrial nano-biotechnology [7–9,24].

4. The Bioeconomy and R&D Worldwide

The bio-economy, as a key component of the green growth, has a current market in the EU of over 2 trillion euros and provides 22 billion jobs across diverse sectors, representing around 9% of the total labor force of different sectors, including agriculture, forestry, food, chemicals, and bio-energy [7,16,17]. Thus, Europe is the global leader and pioneer in bioscience and related technologies [9,24–26], with many investments dedicated to R&D in nano-biotechnologies, considered the most critical component for the industrial innovation. However, since 2006, the world's four largest spenders on R&D were the United States with US$343 billion, the EU with US$231 billion, China with US$136 billion, and Japan with US$130 billion, respectively, while in terms of percentage of GDP, the order was China, Japan, USA, and EU, with approximate percentages of 4.3, 3.2, 2.6, and 1.8, respectively [27].

It is interesting to underline the changing of the top 10 spender countries in terms of percentage of GDP, in 2011 respect 2006 were: Israel 4.3%, South Korea, 4.03%, Finland 3.78%, Japan 3.39%, Sweden 3.37%, Denmark 3.09%, Taiwan 3.02%, Germany 2.88%, USA 2.77%, and Austria 2.75%, with an average spent of US$104,000 per employee on R&D. However, in 2017 the top 10 innovative economies has been: Switzerland that continues to occupy the first position for the 7th consecutive year, followed from Sweden, Netherlands, USA, UK, Denmark, Singapore, Finland, Germany and Ireland [27]. In the top 25 some economies–such as the Netherlands, Denmark, Germany, Japan, France, Israel and China-move, up with the middle-income countries growing more distant to them. The exception is still China that became the 22th most innovative economy in the world.

To this purpose funding mechanisms have been boosted in the EU by the Horizon 2020 program, which has defined the framework for research and innovation for 2014–2020, continuing the Past Seventh Framework Program for Research and Technological Development (FP7) [18,19].

In these programs the chief purpose of funding has been to increase and innovate the fields of Food, Agriculture, Fisheries, and Biotechnology as part of the Bio-economy (FABS) [18,19,24–28].

5. Technological Bio-Revolution and the Bio-Economy

According to the OECD [6,28] the bio-economy, considered a new branch of the economy based on innovative technologies (biotechnology and nanotechnology), could substantially contribute to actual economic processes. The bio-economy, in fact, involves three fundamental pillars of biotechnology: (a) a deep knowledge of the biological systems or living organisms necessary to manufacture products or develop processes that benefit humans, such as molecules, enzymes, chemicals, and bio-materials.

As a result, for example, (a) the use of living cells from yeasts, molds, bacteria, plants, and enzymes to synthesize products would require less energy and create less waste; (b) the use of renewable biomasses and efficient industrial bioprocesses with more sustainable technologies for safeguarding humans and the environment; in this case, the main goal of the so-called bio-refinery has to be the organization of sustainable processing of biomass into a spectrum of marketable products, such as food, feed, and chemicals, producing both high-value, low-volume and low-value high-volume products, minimizing and recycling waste streams also [17,29,30]; (c) the integration of the new biotechnological knowledge with all the classic industrial sectors to obtain a real bio-revolution [31,32].

Thus the bio-economy, if designed and implemented intelligently, will have a positive impact on our quality of life, if we maximize the utilization of the animal and plant biomass, simultaneously meeting key sustainable goals and minimizing cumulative pollutants to maintain in equilibrium the Earth's ecosystem [33,34]. It is, in fact, important to remember that pollutants affect both human and climate health, so that the World Health Organization states that 2.4 million people die each year from causes directly attributable to air pollution, with 1.5 million of deaths attributable to indoor air pollution.

In fact, air and water pollution released from industrial, agricultural, and household waste have contaminated the environment to such an extent that, to save our planet, a rescue plan is urgently required. It seems, therefore, fundamental to recognize the economic value of natural capital and ecosystem services, treating them as goods and services to be valued in monetary terms. As a consequence, the bio-economy has to be considered a promising way to reconcile financial and ecological value, estimating how to maintain a stable environment and respect biodiversity before assessing the cost in dollar terms [33,35].

This is the reason why the bio-based economy was outlined, by the EU's public-oriented definition, as a "production paradigm that, relied on biological processes and with natural ecosystems, uses natural inputs, expends minimum amounts of energy and does not produce waste". So "all materials discarded by one process, will be input for another process to be reused in the ecosystem" [9,36].

By the same approach, the European Association for Bio-industries (EuroPaBio), considering industrial nano-biotechnology a key component of the bio-economy, underlines that "the application of biotechnology for sustainable production of chemicals, materials and fuels from biomass, creates an opportunity to reduce significantly our dependence on coal, oil and gas" [9,37].

Consumer attitude towards nanotechnologies is 64% positive with 71% willingness to purchase nano-products, according to a research study by the Nanotechnology Industries Association (NIA) reported by Denis Koltsov in 2011 (Figure 4), so the global manufacturing output of nanotechnologies is estimated to reach US$30 billion in 2015 (Figure 5) [38].

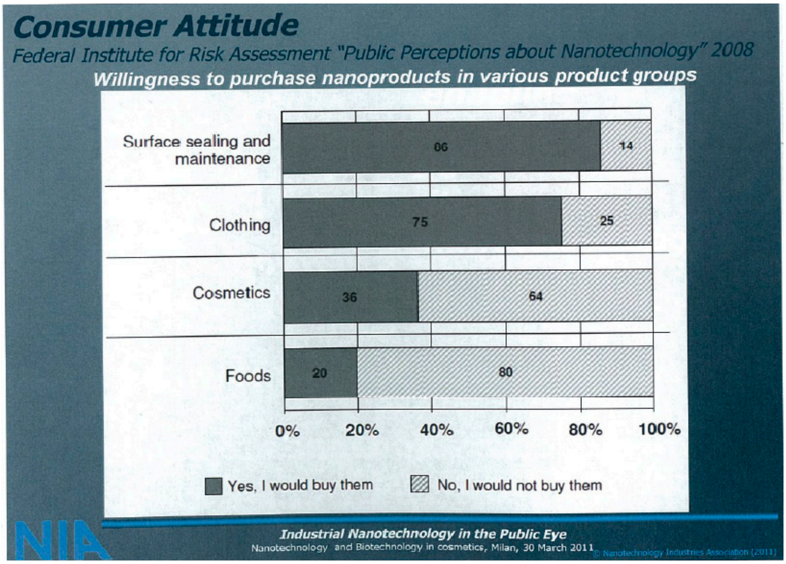


Figure 4. The willingness of consumers to buy nanotechnological products (courtesy of NIA).

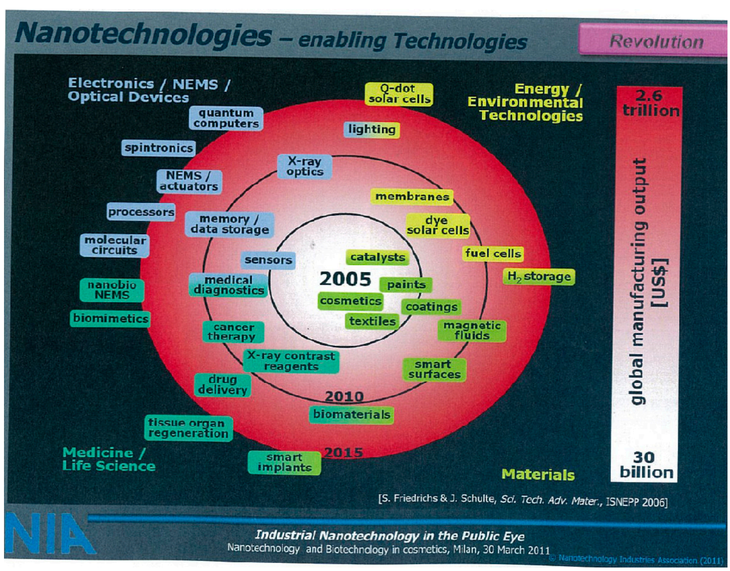


Figure 5. Global manufacturing output of nanotechnologies (courtesy of NIA).

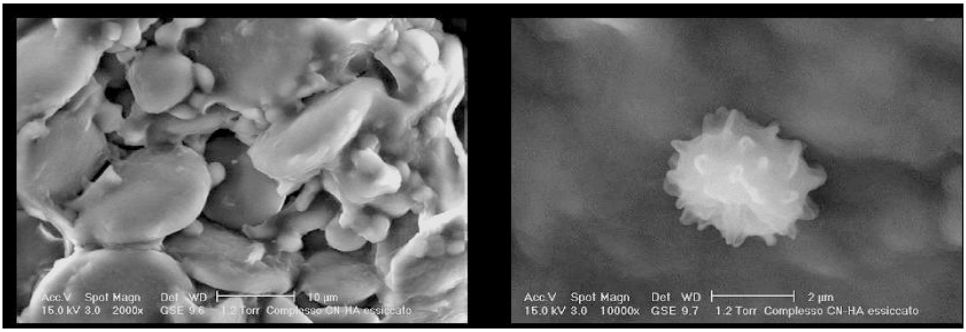
6. Bionanotechnology in Health Care

Bio-nanotechnology has found a wide range of applications in medicine, health care, and cosmetic dermatology, including prevention, diagnosis, and cure of diseases. It is a multidisciplinary field that covers a vast array of devices and machines derived from engineering, physics, material science, chemistry, and biology and deals with the study and application of biological and biochemical activities from elements of nature to target drug delivery, bio-imaging, sensing, and diagnosis of pathologies at early stages [27]. On the other hand, naturally occurring nano-structures in biology have been a source of inspiration for new nanotechnological hybrid nano-structures made of biological and non-biological, organic and inorganic building blocks.

These bio-technological systems involve the fabrication of nano-devices or nano-particles on the order of 100 nm or smaller that, when made of organic polymers, colloids or molecules, including DNA, proteins, lipids, and polysaccharides, are classified as soft nanotechnology [39,40]. The physicochemical properties of nano-particles, in fact, can be engineered at the molecular level; their shape, size, and charge can be controlled, and the surface density of the eventual targeting ligand can be optimized for specific applications [40–43], so that charged particles may create electrostatic interactions with charged skin elements in the interstitial matrix, such as positively charged collagen or negatively charged glycosaminoglycans [44]. This is the reason why "many efforts to reduce material dimensions are motivated by the attractive properties and functions unique to their nanometer regime".

"At nanoscale, certain properties of matter become scale-dependent, including capillary forces, optical effects/color, conductivity, electron affinity", surface reactivity, and so on [45]. In fact, as material size decreases, the surface properties of the atoms increasingly dominate, producing significant changes in material reactivity [45,46]. Hence, surface effects are a unique and very significant functional nano-property that requires both control and careful characterization for exploitation in specific nanotechnologies.

According to the different and controlled technologies adopted by our research group, it is possible to produce block co-polymeric micro/nano-lamellae or nano-particles (NPs) (Figure 6) made of chitin nanfibrils (electropositive polymers) and hyaluronan (an electronegative polymer), which, by entrapping different active ingredients, may have their surface covered by positive or negative charges [29,47–51].



(**a**) (**b**)

Figure 6. Micro/nano-lamellae (**a**) and nanoparticle at SEM (**b**).

When the surface is covered with positive charges these NPs show an ability to disturb lipid lamellae of the stratum corneum, enabling better diffusion of the entrapped active ingredients through the skin layers; when their surface is covered with negative charges the active ingreduents seem to remain at the level of the more external corneocytes (Figure 7).

In the first case, by entrapping the positive nano-particles with antioxidant ingredients it is possible to design formulations with anti-aging activity, while in the second case the negative nano-particles, entrapped with sunscreen ingredients, have been shown to be effective for sunscreen emulsions to protect the skin against the sun [50–52].

In the same way, it was possible to produce interesting composites by the use of natural fibers for making non-woven tissues made by electrospinning (Figure 8a) or casting technology (Figure 8b), for cosmetic or medical utilization.

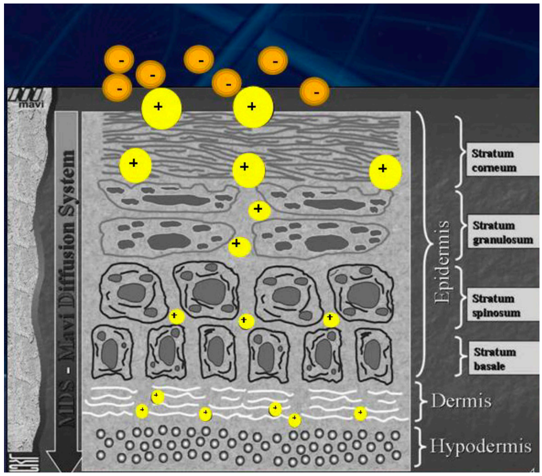
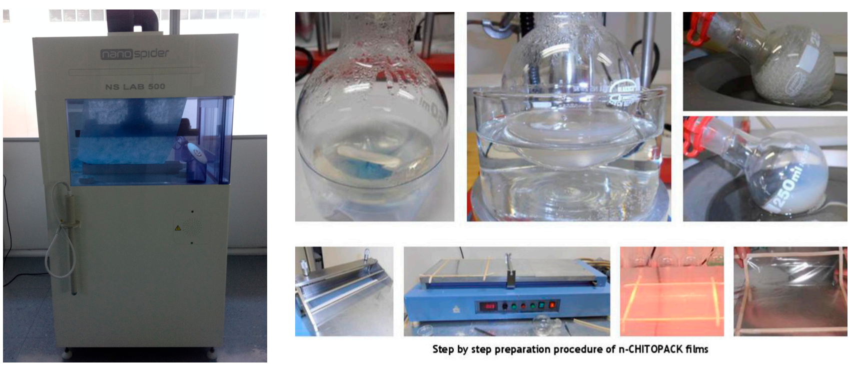


Figure 7. Negatively charged nano-particles remain on the skin surface; meanwhile, positively charged ones penetrate through the different skin layers depending on their dimension.



(**a**) (**b**)

Figure 8. (**a**) The electrospinning technology at lab level; (**b**) the casting technology at lab level.

It is important to remember that a composite may be defined as a physical mixture of two or more different materials, having properties that are generally better than those of any one of the materials used.

Different from synthetic fibers, natural ones possess more desirable properties such as biodegradability, renewability, and a lower price, although they may have poorer mechanical properties. Composites are made of a strong load-carrying material (known as the reinforcement filler) embedded in a weaker material (known as the matrix). Reinforcement provides strength and rigidity, helping to support the structural load. The matrix or binder (organic or inorganic) maintains the position and orientation of the reinforcement. Other advantages of natural fibers lie in their low density, high toughness, comparable specific strength, reaction in tool wear, ease of separation, and low energy of fabrication.

Naturally, the type of the final natural composite is dependent upon the variations in the characteristics and amount of their components, such as cellulose, lignin, pectin, or chitin nano-fibrils, as well as their chemical structures and the production processes. While natural fibers are an interesting option for wider application in composite technology, natural ingredients are of increased use in the cosmetic and food fields [53].

Chitin nano-fibrils (CN), obtained from fishery and crustacean waste, and ligno-cellulosic polymers from plant biomass provide powerful toolboxes for innovative nano-biotechnological processes. These natural polymers offer, in fact, characteristics with interesting properties for various purposes (energy, textiles, cosmetics, biomedicine, etc.) [54].

In cosmetic dermatology CN, complexed or non-complexed with different active ingredients, have been embedded into numerous emulsions characterized by anti-aging (Figure 9) [55], anti-inflammatory (Figure 10) [56,57], anti-acne (Figure 11) [58], or photo-protective activity (Figure 12) [59].

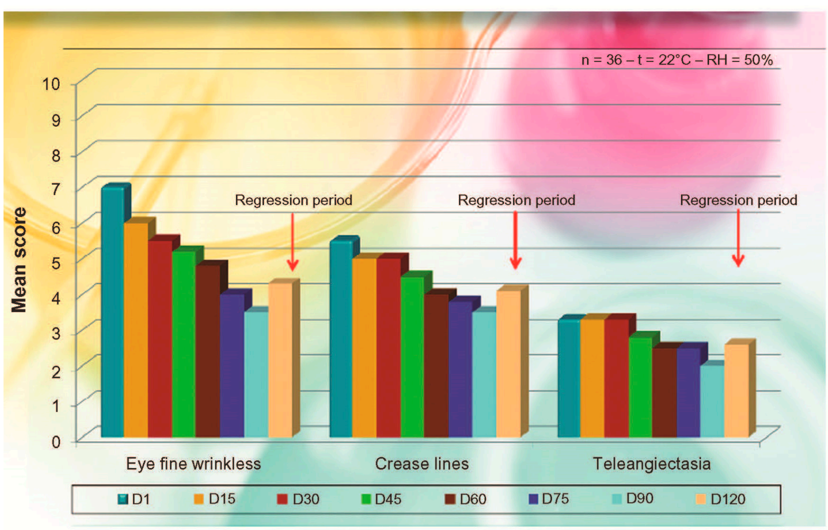


Figure 9. Dermatological mean evaluation on sign of photo-aging after injective treatment with phosphatidylcholine-hyaluronic acid-chitin nano-fibrils encapsulating active compounds (BPN). Note: all p values are highly significant in comparison to the baseline ($p < 0.005$). Abbreviations: BPN block-polymer nano-particles; RH: Relative Humidity; D: day.

Moreover, CN have been bound with other natural polymers to produce non-woven tissues for developing wound dressings by electrospinning (Figure 13), or to make films for food packaging by the casting technology (Figure 14) (unpublished data).

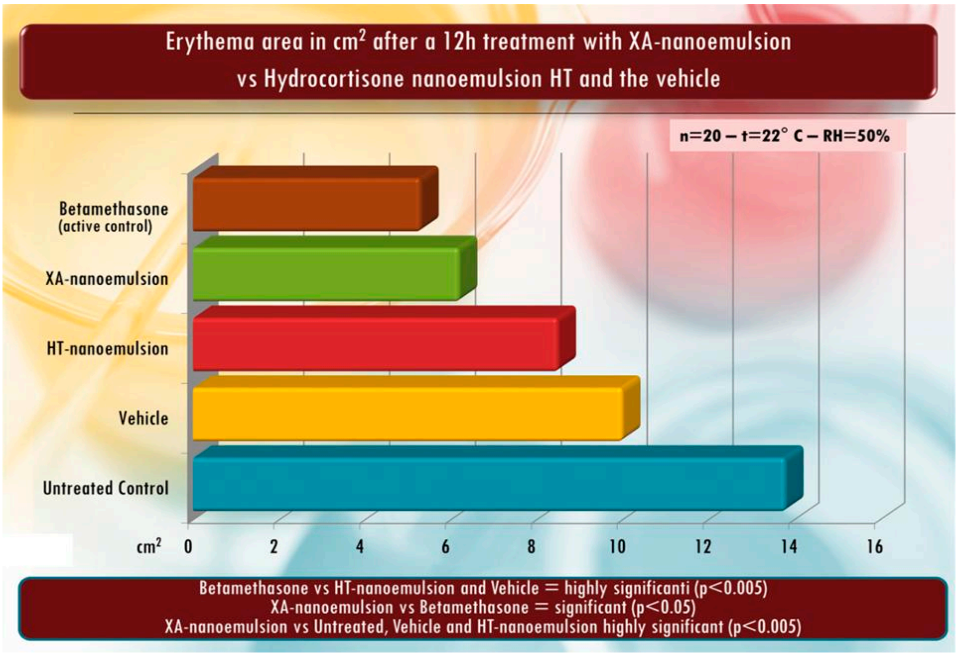


Figure 10. Anti-inflammatory activity of a CN-HA emulsion entrapping active ingredients (XA-nano-emulsion) compared to betamethasone and hydrocortisone (HI) emulsion.

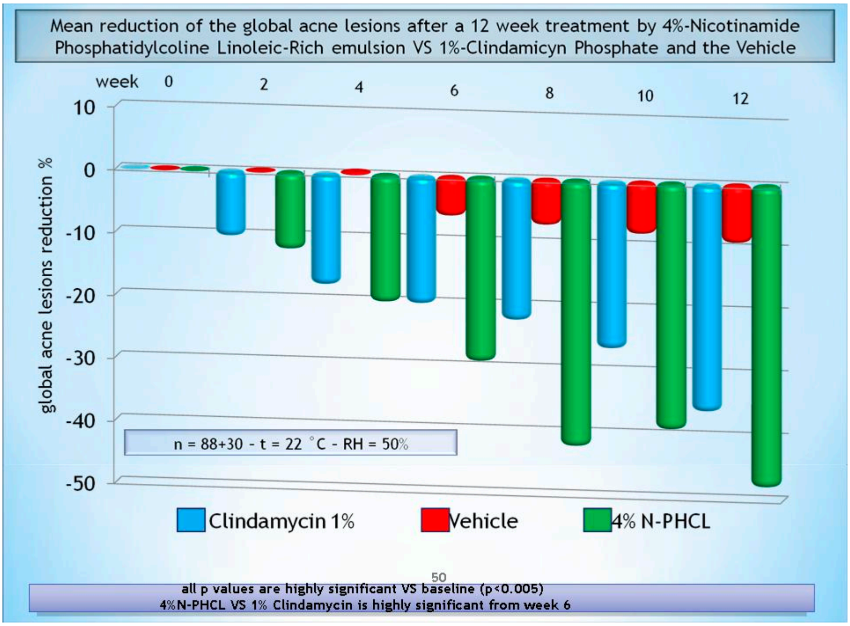
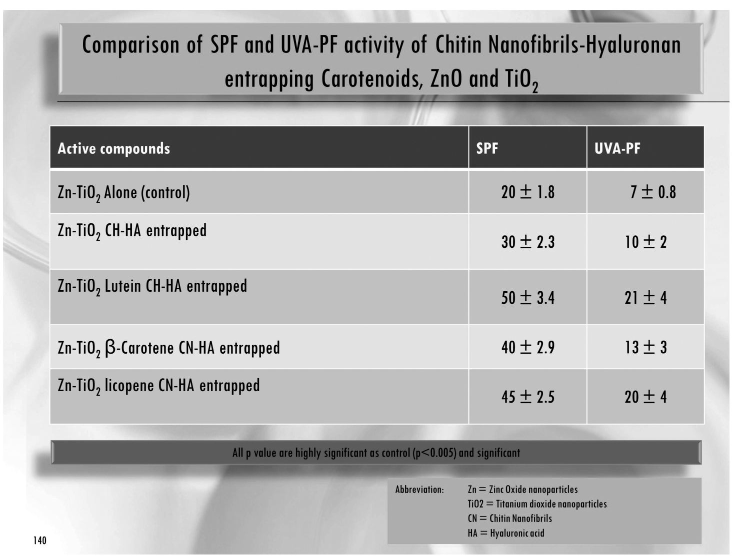


Figure 11. Reduction of acne lesions by a CN-phosphatidylcholine emulsion compared to the clindamycin phosphate emulsion activity.



Comparison of SPF and UVA-PF activity of Chitin Nanofibrils-Hyaluronan entrapping Carotenoids, ZnO and TiO_2

Active compounds	SPF	UVA-PF
Zn-TiO_2 Alone (control)	20 ± 1.8	7 ± 0.8
Zn-TiO_2 CH-HA entrapped	30 ± 2.3	10 ± 2
Zn-TiO_2 Lutein CH-HA entrapped	50 ± 3.4	21 ± 4
Zn-TiO_2 β-Carotene CN-HA entrapped	40 ± 2.9	13 ± 3
Zn-TiO_2 licopene CN-HA entrapped	45 ± 2.5	20 ± 4

All p value are highly significant as control (p<0.005) and significant

Abbreviation: Zn = Zinc Oxide nanoparticles
TiO2 = Titanium dioxide nanoparticles
CN = Chitin Nanofibrils
HA = Hyaluronic acid

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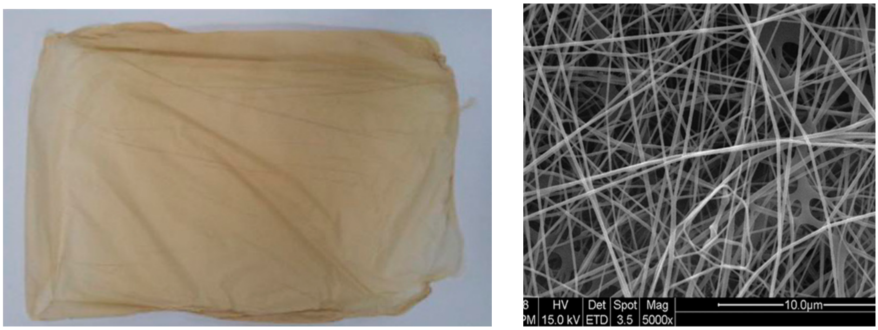
Figure 12. Sun protective activity of CN-HA block co-polymers entrapping different sunscreen agents.



(**a**) (**b**)

Figure 13. (**a**) is the wound dressing made by electrospinning. (**b**) is the same tissue at SEM.

The most important features of wound dressing are bio-adhesion to the wounded site and appropriate humidity, which are effective against the so called burden-microorganisms. Due to the difficulty of obtaining the ideal non-woven tissue, wound therapy represents a challenging area in drug product development. In the USA alone, more than 6.5 million patients are affected annually by burns and wounds, while the costs of treatment are estimated to be US$25 billion per year [59,60]. Moreover, wound infections are the most serious complications related to burn injuries and up to 1% of the world population requires medical treatment each year for burn injuries [60–62].

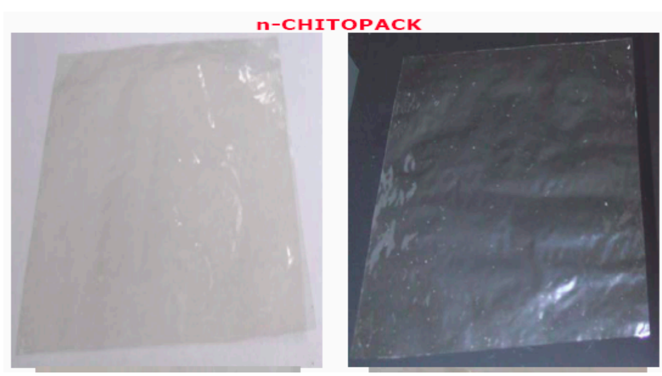


Figure 14. CS/CN film produced by the casting technique.

For all these reasons, modern wound dressings should preserve a humid environment, creating a protective barrier against both mechanical stress and secondary infections. Therefore, the dressing has to enable absorption of wound exudate and elimination of pathogen microorganisms, be safe, non-irritant, and acceptable to the patient with a low cost per unit, which would reduce the need for dressing changes [63,64]. These are the challenges solved by the Chitofarma research project.

7. Concluding Remarks

Global sustainability depends on finding renewable sources of materials and energy, so there is an ever-increasing need to develop bio-based polymers and products able to replace petroleum-based ones. Research in this field has shown the strong potential of generating high-performance functionalized polymers and nano-particles from plant and animal biomass. With the anticipated large-scale production of lignin, cellulose, and hemicellulosic polysaccharides from plant biomass as well as of chitin, chitosan, and oligosaccharides from fishery waste, renewable feedstock for nano-particles, biopolymers, and bio-composites will be available, having physicochemical properties that match or exceed those of petroleum-based compounds [65].

Thanks to our growing knowledge, bioinformatics, more secure energy supply, and the interaction of engineering and life sciences, it will be possible to find new foodstuffs, innovative cosmetics, and drugs opening avenues for developing novel crops and plants, as well as new diagnostic and therapeutic options. Thus, improved management of ecosystem goods and services, carried out by socially sustainable national and international institutions in both the public and private sectors, will increase the health and productivity of all the environmental assets, expanding and securing the green bio-economy and harnessing innovation to ensure well-being for all (Figure 15).

Figure 15. Green economy to protect the environment and human well-being.

In conclusion, the transition from the normal economy to the innovative, green bio-economy is a real future challenge for politicians and all scientists operating in the fields of cosmetology and dermatology who wish to promote and support equitable and pedagogic skills at all levels, respecting different cultural values, supporting equity between and within countries and between generations, and ensuring the conservation of natural resources with optimal water and energy use, thus restoring lost biodiversity, striving for zero emissions and zero waste, and promoting the quality of life over the long term.

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