



NovaQ10[®]

Nanotechnology in Agrifood sector

Market Report

Updated version April 2010



Pour faciliter la lecture, les parties essentielles en ce qui concerne la coenzyme Q10 NOVA ©SOL (hydrophile et micellaire) et la société Aquanova sont colorées en vert



Prepared by the Technology Centre ASCR, 2010

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Executive summary

This is an updated version of the observatoryNANO project report on economic impact of nanotechnologies in the Agrifood sector. This report focuses on market potential of nanotechnology applications in the food industry, driving forces and boundaries of their further development in respect to their commercialization and market utilization. Four applications of nanotechnologies have been selected for more detailed description in this report:

- Controlled-release encapsulation system for food additives, ingredients and flavours
- Delivery systems for nutraceuticals and nutritional supplements
- Food packaging based on nanoclay composites: multilayer PET
- Food contact materials (FCMs) based on metal/metal oxide nanoparticles

From the global food market perspective, the European food industry is weak in economies of scale and in labour productivity; however, it is powerful in attracting sufficient capital and labour, is open to the world market and is in an open internal and external competition. The European food industry is also characterised by a considerable diversity of products and firms.

Looking at the impact of nanotechnology in the food industry more than 400 companies around the world today are active in nanotechnology research and development (R&D) and this number is expected to increase to more than 1000 within the next 10 years. Nanotechnology applications are expected to bring a range of benefits to the food sector, including new tastes, textures and sensations, less use of fat, enhanced absorption of nutrients, improved packaging, traceability and security of food products.

The food industry is ultimately driven by profitability, which is consequent on gaining consumer acceptance by offering added-value in terms of quality, freshness, new tastes, flavours, textures, safety or reduced cost. Food companies are also looking out for new technologies to improve the nutritional value, shelf-life and traceability of their products. They are also aiming to develop improved tastes, reduce the amount of salt, sugar, fat and preservatives, address food-related illnesses (e.g. obesity and diabetes), develop targeted nutrition for different lifestyles and aging population, and maintain sustainability of food production, processing and food safety.

On the other hand, the main possible barriers, which could hamper the future development of nanotechnologies in Agrifood sector, are the perception of new technologies in food by the public and regulations applied to food safety. Therefore, it is necessary to gain confidence of consumers in nanotechnology. The European public should be assured that Food Safety Authorities led by EFSA oversee safety of nanotechnology applications in Agrifood sector. This should avoid a negative attitude of public to nanotechnology.

Controlled-release encapsulation system for food additives, ingredients and flavours

Multi-component delivery system delivers multiple active ingredients that do not normally mix well, such as water-soluble and fat-soluble ingredients, and releases them consecutively. It enhances the stability and bioavailability of a wide range of nutrients and other ingredients, controls their release characteristics and prolongs their residence time in the oral cavity, and thus prolongs the sensation of flavours in the mouth.

Several products based on MultiSal™ technology from Salvona Technologies are in the market at present (MultiSal™ Flavor/Cooling, MultiSal™ Collagen Tripeptide, etc.)

There is no economic information about the present products available. However, the value of the global food additives market was expected to reach 25.3 billion US\$ in 2007. Further growth in this market will be prompted by greater use of additives to improve finished product quality and to control costs, as well as by fast growth of newer food and beverage products, such as enhanced and flavoured waters.

The further development in this area is strongly dependent on the perception of nanotechnologies in food and food contact materials by the public. Food companies are still hesitant to incorporate nanomaterials for uncertainty of future regulations and standards and for fear of negative consumer reactions. Experts also alert to the absence of reliable data relevant to consumer health and lack of regulations for use of nanomaterials.

Delivery systems for nutraceuticals and nutritional supplements

The use of nanotechnologies can improve the solubility and utility of nutraceuticals and nutritional supplements. Solubility problems can affect the applicability and performance of a biologically active compound in a variety of ways.

There are several systems using nanotechnology for delivering nutraceuticals and nutritional supplements in the market (e.g. Ubisol-Aqua™, NovaSOL®, NSSL technology, Bioral®); however the economic information about the present products is not available.

The global nutraceuticals market is estimated at 120 billion US\$ in 2007 growing at 7% compound annual growth rate. The US has been the major market for nutraceuticals with India and China becoming fastest growing markets. Nutraceuticals are gaining acceptance for their ability to address several diseases. Vitamins, Minerals and Nutrients constitute about 85% of the market while antioxidants and anti-agents account for 10% other segments such as herbal extracts occupy 5% of the market, globally.

The further development in this area is strongly dependent on the perception of nanotechnologies in food and food contact materials by the public. Food companies are still hesitant to incorporate nanomaterials for uncertainty of future regulations and standards and for fear of negative consumer reactions. The efficiency of nanotechnologies in this application must be verified by further research.

Food packaging based on nanoclay composites: multilayer PET

The polymer composites incorporating clay nanoparticles are among the first nanocomposites to emerge on the market as improved materials for food packaging. Nano-layer structure of clays increases the path of diffusion that penetrating molecules of gases or other substances must take and significantly improves the polymer's barrier properties.

Commercial products (e.g. Imperm®, Aegis® or Durethan®) fall into two general categories: regular and high load. Regular products have nanoclay loading in the 2–4% range and high load 5–8%. Regular load products bring 2 times barrier improvement for oxygen and water vapour transmission. High load products are 4–5X better than neat polymer and about 2X better for CO₂.

Nanocomposites are the fastest growing segment in the forty billion dollar polymer composite market. This segment is estimated to more than double in size in the next four years. Analysts predict that nanoclays will be the largest component of the nanocomposite market in 2010. Currently, clay particles at the nanoscale are the most common commercial application of nanoparticles in food packaging and account for nearly 70% of the market volume (the market for food packaging containing nanomaterials has been predicted to reach \$360m in 2008 and \$20bn by 2020).

Except of uncertainty in the perception of nanotechnologies in food contact materials by the public, a higher price can be considered as a possible barrier to further development of market applicable products in this area.

Food contact materials (FCMs) based on metal/metal oxide nanoparticles

The food contact materials based on metal/metal oxide nanoparticles use especially Nano-Silver, Nano-Titanium, Nano-Aluminium and Nano Zinc Oxide. Nano-Silver particles can significantly reduce bacteria and insure safer, fresher and tastier food. Nano-Titanium is used in filtration systems in fridges and vacuum cleaners. Nano-Aluminium enables to improve properties of the foil surface, for instance to develop anti-adhesive coating or black coating of baking foil which does not reflect heat in an oven. Nano ZnO is used as a non-organic antibacterial agent, which does not discolour nor does not need ultra-violet light to be activated.

Products based on metal or metal oxide nanoparticles used in FCMs are already in the market, e.g. food containers, cutting boards, refrigerators, kitchenware and tableware, aluminium foil or plastic wrap.

Detailed information about the market size of this relatively narrow segment is not publicly available. From the global point of view, the number of nano-based packaging applications is reported to be growing fast. Three years ago fewer than 40 packaging products containing nanoparticles were thought to be on the market, compared to the 400 plus currently available. The market for food packaging containing nanomaterials has been predicted to reach \$360m in 2008 and \$20bn by 2020.

The further development in this area is strongly dependent on the perception of nanotechnologies in food contact materials by the public. Furthermore, several expert studies show that nanoparticulated substances might cross cell membranes and thus introduce new risks to human health.

1. Methodology

1.1. Definition

Generally, nanotechnology is manipulation at a molecular or even atomical level with the aim to create products, materials and devices with new or significantly different properties. In term of size we speak about nanotechnologies when referring to materials with the size of up to 100 nanometres ($1\text{nm} = 10^{-9}\text{m}$).

Although a general definition has been discussed in the Proposal for a Regulation on novel foods¹, there is no generally accepted definition of nanofood. With respect to this report on nanotechnologies in Agrifood sector we use the term nanofood when nanoparticles, nanotechnology techniques or tools are used during cultivation, production, processing, or packaging of the food.²

European Food Safety Authority (EFSA) in its opinion on the potential risks arising from nanotechnologies on food and feed safety uses term engineered nano materials (ENM). An engineered nanomaterial is any material that is deliberately created such that it is composed of discrete functional and structural parts, either internally or at the surface, many of which will have one or more dimensions of the order of 100 nm or less. The term "engineered" as used in this opinion is equivalent to the term "manufactured" as used in other reports (e.g. SCENIHR, 2009 or EFSA, 2009).

1.2. Methodology for preparing the report

The whole process of preparation of the report consists of several stages. First, comprehensive desk research was carried out, which helped to identify main sources, databases and analyses on recent development of nanotechnology application in the Agrifood sector. Based on acquired information a first draft of the report was prepared. This first draft became a background document for further discussion and interviews with selected experts. At the same time this preliminary version of the report raised specific questions which were included in a comprehensive questionnaire distributed to a pool of experts all around the world. This second draft version of the report was extended on the basis of first discussions with experts and findings of further desk research. The final version of the report contains corrections, specifications and clarifications acquired by means of evaluation and interpretation of answers form questionnaires and further expert interviews.

1.3. Methodology for market quantitative assessment

The market quantitative assessment is based on publicly available data, experts' statements and recent forecasts about the potential development on respective markets. Although the market assessment is expressed quantitatively the results should be taken with cautious since these estimates encompass high degree of uncertainty. This uncertainty results especially from inability to estimate the approach of individual societies and their regulatory authorities to nanotechnologies in food industry in respect to the food safety. It is evident (the most recent example are the genetically modified crops and food) that lack of knowledge of potential effects and impacts of new technologies, accompanied with the deficiency in communication of risks and benefits, can raise mistrust of these technologies amongst the public. For these reasons the estimates of development in respective segments of Agrifood market need further précising and validation.

¹ See COM(2007)872

² Tiju, J. – Morrison, M.: Nanotechnology in Agriculture and Food. Nanoforum Report, May 2006.

2. General market description

2.1. Brief market description

The European food industry is with a share of 1.9% in the value added of the total economy (14.5% of the total manufacturing) and 2.2% of the employment (14% of the total manufacturing) Europe's second largest manufacturing sector after the metal industry. Reflecting the country size Germany, the United Kingdom and France together produce over 51% of the EU's value added. The EU is also the largest exporter and importer of food products. On the other hand, the competitiveness of the European food industry is weak compared to the US and Canada.³

The European food industry is weak in economies of scale and in labour productivity. However, it is powerful in attracting sufficient capital and labour, is open to the world market and is in an open internal and external competition.

The food industry is characterised by a considerable diversity of products and firms. It is made up of about 310 000 companies. There are few European multinational companies competing worldwide with a wide variety of products. In terms of turnover, the biggest food companies in the EU are in the United Kingdom (Unilever, Diageo, Cadbury-Schweppes), France (Danone) and the Netherlands (Heineken). In addition to a relative small number of very large multinational companies 99% of all enterprises in the food sector are small and medium sized enterprises (SMEs). Therefore, SMEs play an important role in the European food industry (dominantly in the southern part of Europe). The food industry sector is thus relatively traditional and relatively less impacted by advanced technologies.

According to the study of Wijnands, van der Meulen and Poppe, 2006 the European food industry is shaped by the following external factors:

- Lower population growth in the EU compared to the US and other countries, which results in a lower growth of demand for processed food in the EU.
- Consumers prefer more convenient and healthy food and ethical issues are becoming more important: both in relation to higher levels of income and wealth.
- Although the technology development increases the efficiency and efficacy of raw material use and biotechnology enables production of functional food, use of new technologies is controversial in the EU.
- Innovation (including micro-machine processing) stimulates product differentiation in the market responsive food chain. The level of R&D expenditures in the food industry is rather low compared to total manufacturing. However, it should be recognised that R&D is important in the food industry, but its character is different. Innovation in the food industry is more process, marketing and management oriented and less technology-push based on basic science. R&D investments are relatively (in a % of production value) higher in major EU exporting countries like France, UK, the Netherlands (0.6%) and Denmark than in the US (0.35%). In Germany and Italy the R&D investments are relatively lower.
- The philosophy of the Common Agriculture Policy shifted from market price support to income support decoupled from production but coupled to public goods. As a result, product price gaps between EU and world market levels have declined substantially.

2.2. Nanotechnology Impact

"Nanotechnology is an enabling technology that has the potential to revolutionize agriculture and food systems" (Rutzke, C.J. (ed): *Nanoscale Science and Engineering for Agriculture and Food Systems*. A Report Submitted to Cooperative State Research, Education and Extension Service. The United States Department of Agriculture, September 2003, <http://www.nseafs.cornell.edu/web.roadmap.pdf>)

According to the Helmut Kaiser Consultancy (2004) nanofood market might grow to 20.4 billion US\$ by 2010. The report published by the consulting firm Cientifica (2006) has valued food applications of nanotechnologies at around 410 million US\$ in 2006 (food processing 100 million US\$, food ingredients 100 million US\$ and food packaging 210 million US\$). According to the report, the current applications are mainly for food packaging (improved barrier properties, etc), with some applications for delivery systems for nutraceuticals. The report estimated that by 2012 the overall market value

³ For the comparison see e.g. Wijnands, van der Meulen and Poppe, 2006.

would reach 5.8 billion US\$ thereof food processing 1,303 million US\$, food ingredients 1,475 million US\$, food safety 97 million US\$ and food packaging 2,930 million US\$. The differences between estimations of Helmut Kaiser Consultancy and Cientifica indicate that there is a considerable uncertainty of the future nanofood market development.

More than 400 companies around the world today are active in nanotechnology research and development (R&D) and this number is expected to increase to more than 1000 within the next 10 years. In terms of numbers, the USA leads, followed by Japan, China, and the EU. Furthermore, many of the world's largest food companies are reported to have been actively exploring the potential of nanotechnology for use in food or food packaging. To give an example, following main food companies have their R&D projects concerning the application of nanotechnology:

- Aquanova (<http://www.aquanova.de>),
- Campbell Soup (<http://www.campbellsoup.com>),
- ConAgra Food (<http://www.conagrafoods.com>),
- General Mills (<http://www.generalmills.com>),
- H.J. Heinz (<http://www.heinz.com>),
- Nestlé (<http://www.nestle.com>),
- Kraft Foods (<http://www.kraft.com>),
- PepsiCola (<http://www.pepsi.com>),
- Sara Lee (<http://www.saralee.com>),
- Unilever (<http://www.unilever.com>),
- Hershey (<http://www.thehersheycompany.com>),
- etc.

Summing up, in addition to the biotechnologies and information and communication technologies, nanotechnologies are significantly influencing the agricultural sector and food industry. According to some expertises⁴ nanotechnologies will be a driving force of changes in the Agrifood sector over the next two decades.

A potential for applications of nanotechnologies appears in all aspects of Agrifood value chain including production, processing, storage, transportation, traceability, safety and security of food. However, the use of nanotechnology in food industry has not demonstrated its economic effectiveness and commercial potential yet. Most developed in this respect is currently the food packaging, which makes up the largest share of the current and short-term predicted market for nanotechnology applications.⁵ In addition, nanoparticles of iron or zinc, and nanocapsules containing ingredients like co-enzyme Q10 or Omega 3 fatty acids can be mentioned as examples of nano-ingredients, which are already in the market. Some information concerning the market potential of nanotechnology gives us also availability of food additives, supplements and food-contact materials in some countries today.

Generally, four major areas in food production may benefit from nanotechnology:

- development of new functional materials,
- microscale and nanoscale processing,
- product development, and
- methods and instrumentation design for improved food safety and biosecurity.

Nanotechnology applications are expected to bring a range of benefits to the food sector, including:

- new tastes, textures and sensations,
- less use of fat,
- enhanced absorption of nutrients,
- improved packaging,
- traceability and security of food products.

⁴ OECD, Allianz: Opportunities and risks of Nanotechnologies. Report in co-operation with the OECD International Futures Programme, 2005.

⁵ GREINER, R. Current and projected applications of nanotechnology in the food sector. *Nutrire: rev. Soc. Bras. Alim. Nutr.* = *J. Brazilian Soc. Food Nutr.*, São Paulo, SP, v. 34, n. 1, p. 243-260, abr. 2009.

Some examples for applications nanotechnology in Agrifood sector are shown in the overview and figure below.

Agriculture	Single molecule detection to determine enzyme/substrate interactions
	Nanocapsules for delivery of pesticides, fertilizers and other agrichemicals more efficiently
	Delivery of growth hormones in a controlled fashion
	Nanosensors for monitoring soil conditions and crop growth
	Nanochips for identity preservation and tracking
	Nanosensors for detection of animal and plant pathogens
	Nanocapsules to deliver vaccines
Food processing	Nanoparticles to deliver DNA to plants (targeted genetic engineering)
	Nanocapsules to improve bioavailability of nutraceuticals in standard ingredients (e.g. cooking oils)
	Nanocapsulated flavour enhancers
	Nanotubes and nanoparticles as gelation and viscosifying agents
	Nanocapsule infusion of plant based steroids to replace a meat's cholesterol
	Nanoparticles to selectively bind and remove chemicals or pathogens from food
	Nanoemulsions and nanoparticles for better availability and dispersion of nutrients
Food packaging	Antibodies attached to fluorescent nanoparticles to detect chemicals or foodborne pathogens
	Biodegradable nanosensors for temperature, moisture and time monitoring
	Nanoclays and nanofilms as barrier materials to prevent spoilage and oxygen absorption
	Electrochemical nanosensors to detect ethylene
	Antimicrobial and antifungal surface coatings with nanoparticles
	Lighter, stronger and more heat-resistant films with silicate nanoparticles
	Modified permeation behaviour of foils
Supplements	Nanosize powders to increase absorption of nutrients
	Cellulose nanocrystal composites as drug carrier
	Nanoencapsulation of nutraceuticals for better absorption, better stability or targeted delivery
	Nanocochleates (coiled nanoparticles) to deliver nutrients more efficiently to cells without affecting colour or taste of food
	Vitamin sprays dispersing active molecules into nanodroplets for better absorption

Table 1 – Examples of potential applications of nanotechnologies in Agrifood

Source: Berger, M.: *The promises of food nanotechnology*. Nanowerk, 2007. Available at (September 2008): <http://www.nanowerk.com/spotlight/spotid=1846.php>.

Appendix A of the Report of Friends of the Earth (http://www.foe.org/pdf/nano_food.pdf) contains a list of claimed 104 commercially available foods, nutritional supplements, food contact materials like storage containers and chopping boards, and agricultural chemicals such as pesticides, plant growth treatments and chemical fertilisers that contain manufactured nanomaterials. The following overview provides only a few examples.

Type of product	Product name and manufacturer	Nano content	Purpose
Nutritional supplement	Nanoceuticals 'mycrohydrin' powder, RBC Lifesciences	Molecular cages 1-5 nm diameter made from silicamineral hydride complex	Nano-sized mycrohydrin has increased potency and bioavailability. Exposure to moisture releases H ⁻ ions and acts as a powerful antioxidant.
Nutritional drink	Oat Chocolate Nutritional Drink Mix, Toddler Health	300nm particles of iron (SunActive Fe)	Nano-sized iron particles have increased reactivity and bioavailability.
Food contact material (cooking equipment)	Nano silver cutting board, A-Do Global	Nanoparticles of silver	Nano-sized silver particles have increased antibacterial properties.
Food contact material	Nano silver baby mug,	Nanoparticles of silver	Nano-sized silver

(crocery)	Baby Dream		particles have increased antibacterial properties.
Food contact material (kitchenware)	Antibacterial kitchenware, Nanocaretech/NCT	Nanoparticles of silver	Nano-sized silver particles have increased antibacterial properties.
Food packaging	Adhesive for McDonald's burger containers, Ecosynthetix	50-150nm starch nanospheres	These nanoparticles have 400 times the surface area of natural starch particles. When used as an adhesive they require less water and thus less time and energy to dry.
Food packaging	Durethan® KU 2-2601 plastic wrapping, Bayer	Nanoparticles of silica in a polymer-based nanocomposite	Nanoparticles of silica in the plastic prevent the penetration of oxygen and gas of the wrapping, extending the product's shelf life.
Food additive	Aquasol preservative, AquaNova	Nanoscale micelle (capsule) of lipophilic or water insoluble substances	Surrounding active ingredients within soluble nanocapsules increases absorption within the body (including individual cells).
Plant growth treatment	PrimoMaxx, Syngenta	100nm particle size emulsion	Using nano-sized particles increases the potency of active ingredients, potentially reducing the quantity to be applied.

Table 2 – Examples of the current use of nanomaterials in agriculture, foods and food packaging

Source: Miller, Georgia – Rye Senjen: *Out of the laboratory and on to our plates. Nanotechnology in Food and Agriculture. Friends of the Earth Australia Nanotechnology Project, March 2008. Available at (September 2008): http://www.foe.org/pdf/nano_food.pdf.*

The rapid proliferation of nanotechnologies in a wide range of consumer products has also raised a number of safety, environmental, ethical, policy and regulatory issues.

The main concerns stem from the lack of knowledge with regard to the interactions of nano-sized materials at the molecular or physiological levels and their potential effects and impacts on consumer's health and the environment.

EFSA's Scientific Committee in its opinion on the potential risks arising from nanotechnologies on food and feed safety recommends that additional research and investigation is needed to address the many current uncertainties and data limitations. (EFSA, 2009)

2.3. Drivers and Barriers to Innovation

The most significant challenges in the Agrifood sector today are to increase the efficiency of agriculture and utility of food and at the same time to ensure their safety for human being and for the environment.

Drivers:

The food industry is ultimately driven by profitability, which is consequent on gaining consumer acceptance by offering added-value in terms of quality, freshness, new tastes, flavours, textures, safety or reduced cost.

Food companies are also looking out for new technologies to improve the nutritional value, shelf-life and traceability of their products.

They are also aiming to develop improved tastes, reduce the amount of salt, sugar, fat and preservatives, address food-related illnesses (e.g. obesity and diabetes), develop targeted nutrition for

different lifestyles and aging population, and maintain sustainability of food production, processing and food safety.

Many of the current nanotechnology applications in the food sector appear to have emerged from related sectors, such as pharmaceuticals, cosmetics and nutraceuticals. The boundaries between food, medicine and cosmetics are already obscure, and the advent of nanomaterials, which can interact with biological entities at a near-molecular level, is likely to further blur these boundaries. Some food and cosmetic companies are known to be collaborating to develop cosmetic nutrition supplement.

Estimates of the current global market size and the number of companies involved in the nanofood sector are varied. This reflects the difficulty in obtaining the exact information due to commercial and environmental sensitivities.

Such sensitivities have led to a number of food corporations, who were, until a few years ago, at the forefront of food nanotechnology R&D, to disassociate themselves from publicity in this field and becoming very protective of their activities in this area. This is the case of Kraft Foods' the Nanotek Consortium that was established in 2000, than was renamed the "Interdisciplinary Network of Emerging Science and Technologies" (INEST). Now it is sponsored by Altria, and its single webpage makes no mention of food at all.

A lot of the currently available information is aimed at projecting the "magical potential" of nanotechnologies when applied to food or food packaging, rather than "real" products and applications that are available now or in a few years time.

CIAA which represents the food and drink industry in EU launched in 2005 the European Technology Platform "Food for Life". The Strategic Research Agenda for this ETP includes nanotechnologies.

Barriers:

The main possible barriers, which could hamper the future development of nanotechnologies in Agrifood sector, are the perception of new technologies in food by the public and regulations applied to food safety.

It is necessary to gain confidence of consumers in nanotechnology. Public should be assured that Food Safety Authorities led by EFSA oversee safety of nanotechnology applications in Agrifood sector. This should avoid a negative attitude of public to nanotechnology.

For the food chain in particular, comprehensive and stringent safety rules are in place. Their scope covers the possible specific risks from nanotech applications. In the EU the General Food Law lays down the obligation for operators to put on the market only safe food. Furthermore, for certain food categories, such as novel food, food additives and food contact materials, detailed provisions concerning pre-marketing authorisation or inclusion into a positive list, are laid down.

Whereas DG SANCO's non-food Scientific Committees are involved in the general safety assessment of nanotechnology, the risk assessment of the use of nanotech in food/feed is falling within the competence of EFSA.

The most recent opinion of the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) was adopted on 19 January 2009, Risk assessment of products of nanotechnologies.

In the case of nanomaterials, hazard identification and the assessment of risks to verify compliance with the legislation requires specific exposure and toxicological data, taking into account the special characteristics of nanomaterials. It is the responsibility of industry to timely identify specific hazards, make the appropriate tests and provide the specific data to the authorities and the risk assessment bodies.

The European Commission requested EFSA (Question number: EFSA-Q-2007-124a) to conduct an initial scientific opinion of the risks arising from nanoscience and nanotechnology in food and feed with respect to human health, safety and environmental quality. EFSA which started the process in November 2007 requested from industry the following information:

- Data on the safety of nanomaterials used in food and feed
- Food and feed applications and products containing or consisting of nanomaterials or produced by nanotechnology
- Methods, procedures and performance criteria used to analyse nanomaterials in food and feed
- Use patterns and exposure to humans and environment.

- Risk assessments performed on nanomaterials used in food and feed
- Toxicological data on nanomaterials used in food and feed
- Environmental studies performed on nanotechnologies and nanomaterials used in food and feed
- Other data of relevance for risk assessment of nanotechnology and nanomaterials in food and feed

Scientific Committee (SC) of EFSA adopted its scientific opinion on nanoscience and nanotechnologies in relation to food and feed safety on 10 February 2009. In this opinion SC has concluded that established international approaches to risk assessment can also be applied to ENM. The SC also concluded that a case-by-case approach would be necessary and that, in practice, current data limitations and a lack of validated test methodologies could make risk assessment of specific nano products very difficult and subject to a high degree of uncertainty.

Opinion of EFSA focuses on the use of nanotechnologies, particularly ENMs, in the food and feed chain. It elaborates on approaches and methodologies available for risk assessment of these very small particles but does not address any specific applications of particular ENMs. The European Commission (EC) asked for this opinion because consideration needs to be given as to whether existing risk assessment approaches can be appropriately applied to this new technology.

The EFSA's SC recommends that additional research and investigation is needed to address the many current uncertainties and data limitations. Specific recommendations include the following:

- Investigating the interaction and stability of ENMs in food and feed, in the gastro-intestinal tract and in biological tissues.
- Developing and validating routine methods to detect, characterise and quantify ENMs in food contact materials, food and feed.
- Developing, improving and validating test methodologies to assess toxicity of ENMs (including reliability and relevance of test methods). (The EFSA Journal (2009) 958, 1-39)

2.4. Relevant Sector Segmentation and Applications

Most nanotechnological research focuses on the development of applications in biosciences and engineering. Strategies to apply nanoscience to the food industry are quite different from these more traditional applications of nanotechnology. Food processing is a multitechnological manufacturing industry involving a wide variety of raw materials, high biosafety requirements, and well-regulated technological processes.

As mentioned above, following four major areas in food production may benefit from nanotechnology:

- development of new functional materials,
- microscale and nanoscale processing,
- product development, and
- methods and instrumentation design for improved food safety and biosecurity.

Figure 2 depicts possible segmentation of nanotechnology applications in the food industry.

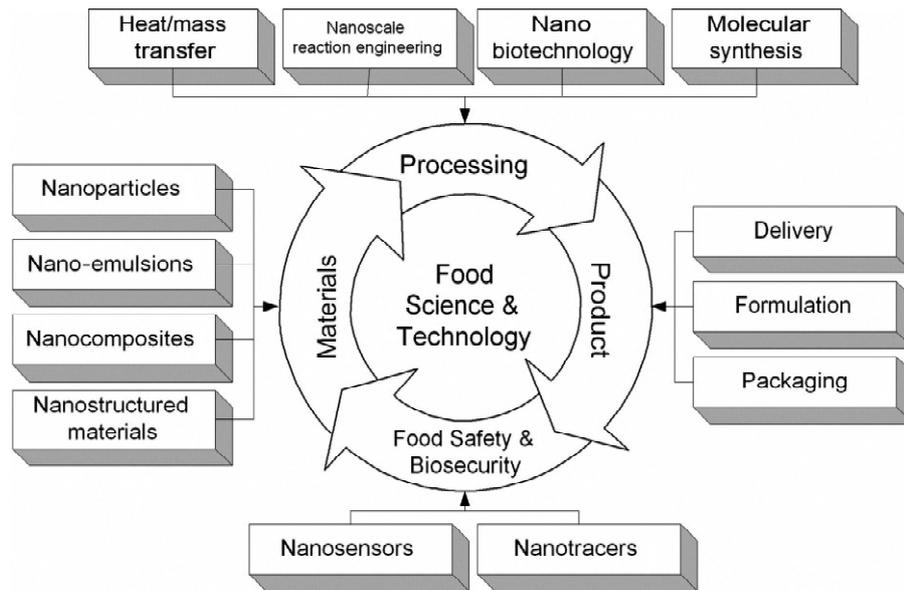


Figure 2 – Application matrix of nanotechnology in food science & technology

Source: Weiss, J. – Takhistov, P. – McClements, J.: *Functional Materials in Food Nanotechnology*. *Journal of Food Science*, Vol. 71, Nr. 9, 2006, pp. R107–R116.

Nanotechnology has the potential to impact many aspects of food and agricultural systems. Food security, disease treatment delivery methods, new tools for molecular and cellular biology, new materials for pathogen detection, and protection of the environment are examples of the important links of nanotechnology to the science and engineering of agriculture and food systems. Examples of nanotechnology as a tool for achieving further advancements in the food industry are as follows:

- Increased security of manufacturing, processing, and shipping of food products through sensors for pathogen and contaminant detection.
- Devices to maintain historical environmental records of a particular product and tracking of individual shipments.
- Systems that provide integration of sensing, localization, reporting, and remote control of food products (smart/intelligent systems) and that can increase efficacy and security of food processing and transportation.
- Encapsulation and delivery systems that carry, protect, and deliver functional food ingredients to their specific site of action.

In summary, there are a large number of potential applications of nanotechnology within the food industry; however, many of these may be difficult to adopt commercially because they are either too expensive or too impractical to implement on an industrial scale. (see Chaudhry et al, 2008)

2.5. Possible Future Products and Time Range

According to the International Food Safety Authorities Network – INFOSAN (see WHO, 2008) the main growth area will be in the development of new formulations of food additives. Generally, the aim is to develop nano-size carriers or materials in order to improve the function of food additives. The properties of nanoparticles also make them attractive for improving absorption and bioavailability of added nutritive substances, such as vitamins, nutrients and minerals.

Another example of the use of nanotechnology in the food industry is in the area of food contact materials. Nanocomposite materials are already available as packaging or as coatings on plastic containers to control gas diffusion and prolong the shelf life. Nanotechnology-based products are increasingly being used to produce antimicrobial food contact materials commercially available as

packaging or as coatings. Current research on such 'smart' surfaces is aimed at the development of surfaces that can detect bacterial contamination and react against bacterial growth.

Following areas may be according to the experts^{6,7} considered as the most important application fields for nanotechnologies in the near future:

- Smart control systems
- Nanodevices for Identity Preservation and Tracking
- Nanosensors for Pathogen and Contaminant Detection
- Nanodevices for Smart Treatment Delivery Systems
- Nanodevices for Molecular and Cellular Biology
- Nanoscale Materials Science and Engineering, Environmental Issues, Agricultural Waste and Nanoparticles in the Environment

According to experts, also arisen of new applications of nanotechnologies that will conduct for instance to novel food with innovative texture or other parameters can be expected.

Certain trends in the recent European research can be explored in research projects on nanotechnology funded by European Commission in the FP6 and FP7. The list of recent research projects is covered in the Annex I. Further clue of state of the art in nanotechnology for food applications can be found in patent statistics. Overview of patents with relation to nanotechnologies in food industry is listed in Annex II.

⁶ Scott, Norman – Chen, Hongda: Nanoscale Science and Engineering for Agriculture and Food Systems. USDA, September 2003.

⁷ Tiju, J. – Morrison, M.: Nanotechnology in Agriculture and Food. Nanoforum Report, May 2006.

3. Application profile

Four applications of nanotechnologies have been selected for more detailed description in this report:

1. Controlled-release encapsulation system for food additives, ingredients and flavours
2. Delivery systems for nutraceuticals and nutritional supplements
3. Food packaging based on nanoclay composites: multilayer PET
4. Food contact materials (FCMs) based on metal/metal oxide nanoparticles

3.1. Controlled-release encapsulation system for food additives, ingredients and flavours

3.1.1. Short application description

Multi-component delivery system delivers multiple active ingredients that do not normally mix well, such as water-soluble and fat-soluble ingredients, and releases them consecutively. It enhances the stability and bioavailability of a wide range of nutrients and other ingredients, controls their release characteristics and prolongs their residence time in the oral cavity. The system consists of solid hydrophobic nanospheres composed of a blend of food-approved hydrophobic materials encapsulated in moisture-sensitive or pH-sensitive bioadhesive microspheres. A proprietary suspension technology generates nanospheres with a diameter of about 0.01-0.5 microns. The nanospheres are then encapsulated in microspheres of about 20-50 microns in diameter. The nanospheres are not individually coated by the moisture-sensitive microsphere matrix, but are homogeneously dispersed in it. When the microsphere encounters water, such as saliva, it dissolves, releasing the nanospheres and other ingredients, c.f. **Fig. 3**. Nanospheres (blue) containing an active ingredient (purple) are encapsulated with other ingredients such as flavours, cooling or heating agents, or sweeteners, within a microsphere (yellow). Over an extended period of time the nanospheres release the encapsulated active ingredient via molecular diffusion and enzymatic degradation by lipase. The surface properties of the nanospheres (shown as squiggly lines) can be altered to be bioadhesive or negatively or positively charged depending on the intended target site.

The active ingredients and sensory markers encapsulated in the nanospheres can be the same as, or different from, those encapsulated in the microspheres. The nanosphere surface can include a moisture-sensitive bioadhesive material, such as starch derivatives, natural polymers, natural gums, etc., making them capable of being bound to a biological membrane such as the oral cavity mucosa and retained on that membrane for an extended period of time. The nanospheres can be localised and the target ingredient encapsulated within their structure to a particular region, or a specific site, thereby improving the bioavailability of ingredients with poor bioavailability. Enhancing the hydrophobicity of these ingredients enhances their bioavailability.

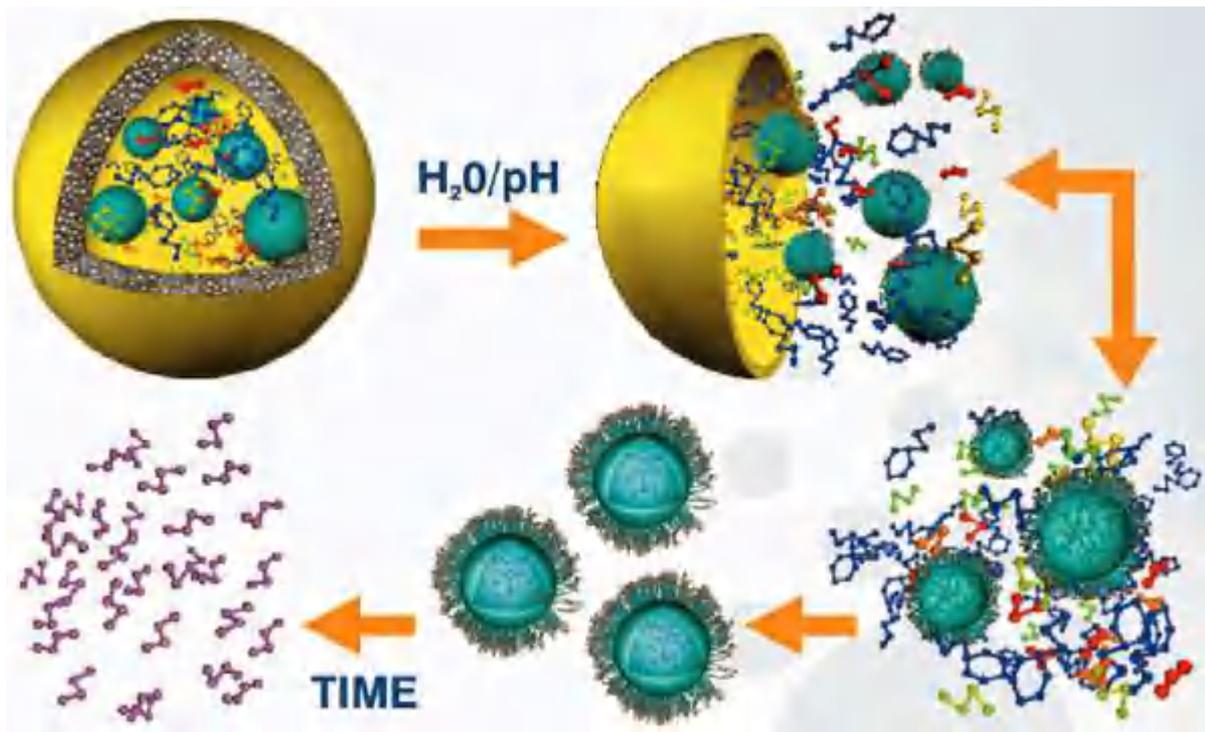


Figure 3 – How the controlled-release encapsulation system works

Source: <http://www.salvona.com>

Major potential product applications for the nanosphere/microsphere system are:

- baked goods,
- refrigerated/frozen dough and batters,
- tortillas and flat breads,
- processed meats,
- acidified dried meat products,
- microwavable entrees,
- seasoning blends,
- confectionery,
- specialty products,
- chewing gum,
- dessert mixes,
- nutritional foods,
- products for well-being,
- health bars,
- dry beverage mixes.

Some products based on this application are already on the market (see point 3.1.4 for examples).

3.1.2. Functional requirements

Following functional attributes of multi-component delivery system can be considered as the main benefits of nanotechnologies:

- *Ease of handling* – The system can be utilised to transform volatile liquids such as flavours into a powder, which are in many cases easier to handle.
- *Enhanced stability* – The system can be utilised to isolate active ingredients as well as flavours that may interact with the other food ingredients. This provides long-term product shelf life.
- *Protection against oxidation* – The microspheres have very low surface oil (less than 0.5%) at very high payloads (30-40%) compared to conventional spray-dried particles utilising materials such as gum arabic or starch.
- *Retention of volatile ingredients* – The moisture-sensitive matrix provides excellent retention of highly volatile ingredients, such as flavours, over an extended period of time to reduce the flavour loss during the product shelf life.
- *Taste masking* – Unwanted taste can be masked by preventing interaction between the active molecule and the oral mucosal surface. The nanospheres are hydrophobic and can prevent bitter ingredients encapsulated within their structure from going into solution and interacting directly with taste receptors.
- *Moisture-triggered controlled release* – As discussed above, the microspheres dissolve in the presence of water or saliva to release the active ingredients or flavours, thereby providing a high impact flavour “burst.”
- *pH-triggered controlled release* – Ingredients can be encapsulated in the microspheres to enhance their stability during the product shelf life and to release them when needed or upon food consumption. This pH triggered release was initially designed to deliver drugs to different regions of the gastrointestinal tract.
- *Heat-triggered release* – The hydrophobic nanospheres are temperature sensitive and can be utilised to release active ingredients and flavours at a certain temperature, e.g., upon heating in an oven or microwave oven or the addition of hot water for hot drinks and soups.
- *Consecutive delivery of multiple active ingredients* – Two or more ingredients that would react with each other if put together can be separated and provided consecutively by placing one in the nanosphere and the other in the microsphere. An example is encapsulation of folic acid and iron that work synergistically.
- *Change in flavour character* – Encapsulation of a flavour in the nanospheres that is different from the flavour encapsulated in the microsphere can provide a perceivable change in the organoleptic perception in response to moisture during the use of the product.
- *Long-lasting organoleptic perception* – As a result of the bioadhesive properties of the nanospheres and their residence in the oral cavity, flavour perception and mouth-feel can be extended over a longer period of time.
- *Enhanced bioavailability and efficacy* – As a result of their hydrophobic/lipophilic nature, the nanospheres can enhance the bioavailability of various active ingredients, such as vitamins, nutrients and other biologically active agents encapsulated within their structure.

3.1.3. **Boundary conditions**

The further development in this area is strongly dependent on the perception of nanotechnologies in food and food contact materials by the public. Food companies are still hesitant to incorporate nanomaterials for uncertainty of future regulations and standards and for fear of negative consumer reactions. Experts also alert to the absence of reliable data relevant to consumer health and lack of regulations for use of nanomaterials, especially for food contact materials.

3.1.4. Product examples

MultiSal™ Flavor/Cooling is a product of Salvona Technologies, which utilizes multi component nanotechnology to provide multi-sensorial and dynamic release of active ingredients. It consists of solid hydrophobic nanospheres encapsulated in a water or pH sensitive microsphere which can hold multiple ingredients in the same carrier system and release them, one after another; even target specific sites. A submicron technology with a brand name of MultiSal™ Collagen Tripeptide is used to enhance the bioavailability of Tripeptides used for antiaging by enhancing collagen production. This technology permits the use of water based actives in dry and anhydrous formulations such as lip care, serum, etc.

3.1.5. Economical information for present products

There is no economic information about the present products available; however, the global food additives market is expected to reach a value of 25.3 billion US\$ in 2007. The recent growth has been most impressive in those additives most relevant to the prevailing trend towards lower-fat foods. In US the food and beverage additive demand is projected to exceed \$8 billion in 2012. Growth will be prompted by greater use of additives to improve finished product quality and to control costs, as well as by fast growth of newer food and beverage products, such as enhanced and flavoured waters.

3.2. Delivery systems for nutraceuticals and nutritional supplements

3.2.1. Short application description

Nanotechnology provides a mean of manipulating and altering food products more effectively which enables to overcome several technological limitations negatively impacting the development of nutraceuticals and nutritional supplements and their efficient delivery. For instance, the use of nanotechnologies can improve the solubility and utility of nutraceuticals and nutritional supplements. Solubility problems can affect the applicability and performance of a biologically active compound in a variety of ways: First, poor water solubility can limit the range of formulations available for a bioactive compound. For example, they cannot readily be formulated for intravenous, tablet, or liquid administration. For the same reasons, insoluble nutrients are not useful for enhancing foods or beverages. Second, poorly soluble compounds are likely to have limited bioavailability because they do not remain in solution at the site of action, once in the body. This results in lower absorption and, by definition, reduced efficacy. To counter this, administration of higher doses is often necessary. However, higher doses can potentially lead to increased side effects. Third, because of a need for higher doses and/or complex formulations, the cost of drugs and nutrients to both manufacturer and consumer are increased.

A number of nano-micelle based carriers for nutraceuticals and nutritional supplements are currently available.

Delivery systems for nutraceuticals and supplements utilise a variety of processes, including:

- nano-emulsions,
- surfactant micelles,
- emulsion bilayers,
- reverse micelles.

3.2.2. Functional requirements

Benefits of nano-based delivery systems (micelles, nanocochleates) compared to current systems of encapsulation/microencapsulation are:

- Broader applications for nutraceuticals
- Superior efficiency for antioxidants and preservatives
- Superior bioavailability of actives
- Chemically unmodified substances
- Crystal clear, liquid solutions
- Mechanically, thermally, pH stable
- Ready to use for production
- Processing without additives

3.2.3. **Boundary conditions**

The further development in this area is strongly dependent on the perception of nanotechnologies in food and food contact materials by the public. Food companies are still hesitant to incorporate nanomaterials for uncertainty of future regulations and standards and for fear of negative consumer reactions. The efficiency of nanotechnologies in this application must be verified by further research.

3.2.4. **Product examples**

Ubisol-Aqua™ Delivery System Technology from Zymes LLC (USA)

Ubisol-Aqua™ is a patented family of neutral, non-ionic carriers for water-insoluble compounds. The family includes compounds PTST™, PCS™, and PSS™. The water insoluble substance to be solubilised forms a non-covalently bound complex with Ubisol-Aqua™, which has both hydrophobic and hydrophilic subsections. This leads to self-assembly into micellar arrays with a hydrophobic interior and a hydrophilic exterior shell when mixed with water. The solubilized complex is both water and lipid soluble and stable through a wide range of temperatures (-80 to 120 °C), phase changes (freezing, melting) and across a broad pH range (2.0-8.0). The Ubisol-Aqua™ technology has successfully solubilised a number of bioactive molecules including for instance: coenzyme Q10, vitamin A acetate, vitamin A palmitate, vitamin B pentapalmitate, squalene, α -tocopheryl acetate, fish oil (EPA/DHA), β -carotene etc..

NovaSOL® from AQUANOVA (Germany)

AQUANOVA offers a key technology, which creates liquid carrier solutions, the so-called "solubilisates", based on its own technology. The solubilisates transport the respective active raw materials and active substances in the smallest capsules, the so-called "product micelles". The product micelle is stable with respect to pH and temperature and has a diameter of approximately 30 nm. Here, where microemulsions and liposomes prove to be problematical and unsuitable, the product micelle represents the optimum solution in the fields of functional food, cosmetics, pharmaceuticals and biotechnology. The 100% water-soluble micelle can be integrated directly and independently of recipe characteristics into the final products in the quoted fields. The product micelle is proving to be an optimum carrier system of hydrophobic substances for a higher and faster intestinal and dermal resorption and penetration of active ingredients.

The incorporation of micellated fat-soluble or water-insoluble substances into final products occurs directly and without additional intermediate production steps and independently of matrix and final product quality. Due to AQUANOVA product micelles, the physiological mechanism of intestinal micelle formation is bypassed and consequently, a higher bioavailability is achieved. AQUANOVA product micelles are thermally, mechanically and pH-stable as well as being unsusceptible

microbiologically. Due to higher resorption and better bioavailability or penetration of the micellated active substances, the concentrations of active substances in the final products can be reduced.

Bioral® (Nanocochleate Delivery System) from BioDelivery Sciences International (BDSI) (USA)

Bioral® is a novel drug delivery system, based upon cochleate technology (see **Fig. 5**). Bioral® encapsulates and protects a drug without chemically bonding to it and may facilitate oral dosing of drugs that typically need to be given by intravenous administration. Alternating layers of lipids spiral around a drug molecule, encapsulating and potentially protecting it from degradation by acid or digestive enzymes in the stomach. The Bioral® technology is being evaluated as a new means of overcoming the poor oral absorption of drugs.

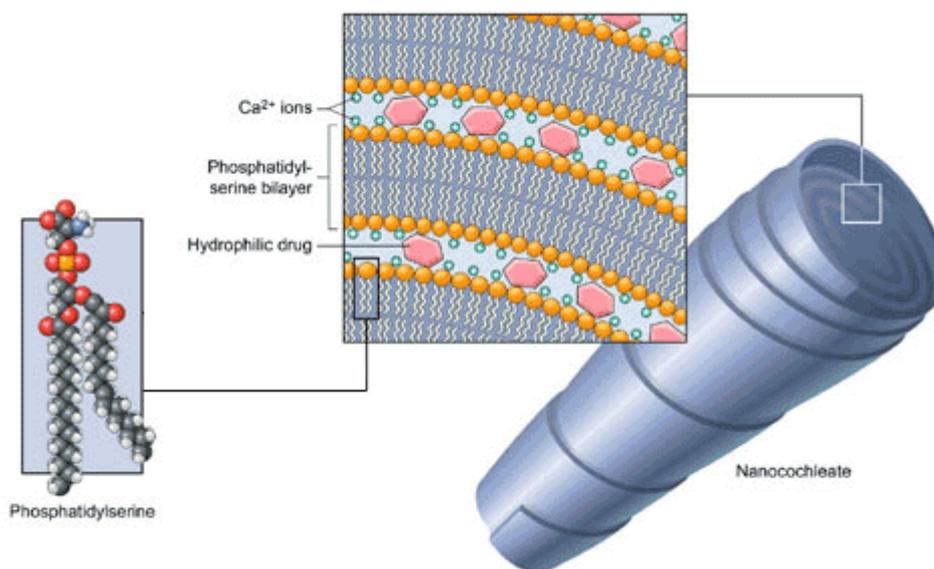


Figure 5 - Cochleate technology used in Bioral® drug delivery system

Source: <http://www.biodeliverysciences.com/Bioral.php>

In the food and beverage industry, attempts to add micronutrients as a supplement to human and pet foods have been hampered by the susceptibility of micronutrients and antioxidants to degradation during manufacturing and storage. The Bioral™ Nanocochleate Delivery System protects micronutrients and antioxidants from degradation during manufacturing and storage. With Bioral™ micronutrients, stability is enhanced and shelf-life is extended.

3.2.5. Economical information for present products

There is no economic information about the present products available; however the global nutraceuticals market is estimated at 120 billion US\$ in 2007 growing at 7% compound annual growth rate. The US has been the major market for nutraceuticals with India and China becoming fastest growing markets. Nutraceuticals are gaining acceptance for their ability to address several diseases. Vitamins, Minerals and Nutrients constitute about 85% of the market while antioxidants and anti-agents account for 10% other segments such as herbal extracts occupy 5% of the market, globally.

3.3. Food packaging based on nanoclay composites: multilayer PET

3.3.1. Short application description

The polymer composites incorporating clay nanoparticles are among the first nanocomposites to emerge on the market as improved materials for food packaging. Nanoclays are nanoparticles of

layered mineral silicates with a specialized structure, characterized by platelet morphology. The platelets have submicron dimensions, excepting their thickness, which is only about one nanometer. These platelets force gases to follow a tortuous path through the polymer greatly slowing their transmission. Nano-layer structure of clays thus increases the path of diffusion that penetrating molecules of gases or other substances must take and significantly improves the polymer's barrier properties.

Depending on chemical composition and nanoparticle morphology, nanoclays are organized into several classes such as montmorillonite, bentonite, kaolinite, hectorite, and halloysite. Organically-modified nanoclays (organoclays) are an attractive class of hybrid organic-inorganic nanomaterials with potential uses in polymer nanocomposites, as rheological modifiers, gas absorbents and drug delivery carriers. Based on report from Pira International Conference held in 2005, there are eight nanocomposite barrier products available. Seven are based on polyamide 6 and one is a specialized polyamide known as MXD6 (see Table 3).

Product	Region	Producer	Resin base	Website
Durethan®	Europe	Lanxess	PA6	www.lanxess.com *
NycoNano™	USA	Nycoa	PA6	www.nycoa.net
Aegis™	USA	Honeywell	PA6	www.honeywell.com
Nanoblend™	Europe	PolyOne	PA6	www.polyone.com
Nanomide™	Asia	NanoPolymer	PA6	www.nanopolymer.com
Ecobesta®	Asia	Ube Industrie	PA6 kopolymer	www.UBE.com
Systemer	Asia	Showa Denko	PA6	www.showadenko.com
Imperm®	All	Nanocor	MXD6	www.nanocor.com

* LANXESS was spun-off from Bayer in early 2005

Table 3 – Polyamide nanocomposite products and producers

Source: Maul, P.: *Barrier Enhancement Using Additives*. Nanocor Inc., Pira International Conference, Brussels, December 2005.

3.3.2. Functional requirements

The fundamental functional requirement on the nanoclay multilayer PET bottle is the low penetration rate of gases (particularly carbon dioxide and oxygen), water, alcohol and other substances which can significantly extend the shelf life of stored beverages. A typical example is the plastic bottle to ship beer. Plastic beer bottles of volume 500 ml or less require significant barrier protection against oxygen ingress. In addition they require considerable barrier to CO₂ loss. In this respect beer packaging is perhaps the most demanding for barrier enhancement. European producers wished to package lager beer in a 330 ml bottle and achieve five month's shelf life. During this period total oxygen ingress was limited to 2 ppm and CO₂ loss could be just 10 %.

3.3.3. Boundary conditions

The further development in this area is strongly dependent on the perception of nanotechnologies in food contact materials by the public. Food companies are still hesitant to incorporate nanomaterials for uncertainty of future regulations and standards and for fear of negative consumer reactions. Experts consider also higher price as another possible barrier to further development of market applicable products in this area. Another hampering aspect is the absence of reliable data relevant to consumer health and lack of regulations for use of nanomaterials, especially for food contact materials.

3.3.5. Economical information for present products

Nanocomposites are the fastest growing segment in the forty billion dollar polymer composite market. This segment is estimated to more than double in size in the next four years. Analysts predict that nanoclays will be the largest component of the nanocomposite market in 2010.

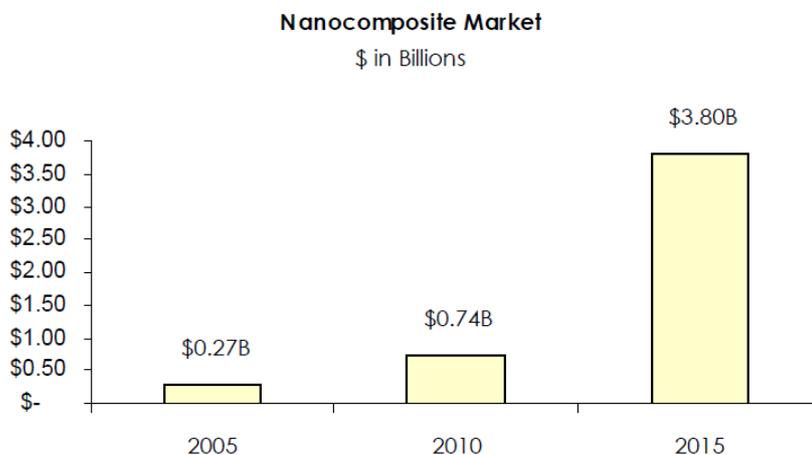


Figure 6 – Nanocomposite market

Source: <http://www.naturalnano.com>

Currently, clay particles at the nanoscale are the most common commercial application of nanoparticles in food packaging and account for nearly 70% of the market volume (the market for food packaging containing nanomaterials has been predicted to reach \$360m in 2008 and \$20bn by 2020)⁸. They are less expensive to produce than some other nanomaterials because full-scale production facilities already exist and the basic materials come from available natural sources.

The plastic bottle is slowly emerging as alternative packaging format for beer. Carlton & United Breweries first introduced PET beer bottles in 1996 and during the period from the late 1990s to the early 2000s, around 20 beer brands were introduced in plastic bottles, including Heineken which used creative packaging to differentiate its Cruzcampo brand.

The economical information about the plastic bottles containing nanoclays is not publicly available, however, the market seems to be very promising. Outstanding barrier properties of these layers resulting in low permeability for gases and other substances, extended shelf life of beverages, light weight and resistance to shock are significant prerequisites for further replacement of glass bottles and metal cans by nanoclay multilayer PET bottles.

3.4. Food contact materials (FCMs) based on metal/metal oxide nanoparticles

3.4.1. Short application description

Food contact materials (FCMs) are all materials and articles intended to come into contact with foodstuffs, including packaging materials but also cutlery, dishes, processing machines, containers etc. The food contact materials based on metal/metal oxide nanoparticles use especially:

- 1) Nano-Silver

⁸ Packaging-Gateway.Com (<http://www.packaging-gateway.com>)

The finely dispersed nanosilver particles permanently imbedded in the containers can significantly reduce bacteria by as much as 99 % and insure safer, fresher and tastier food.

2) Nano-Titanium

Nano-Titanium particles measure 5nm, which is about 1/200 of the size of traditional anti-bacterial agents or 1/1000 of the size of bacteria. This enables the Nano Titanium's catalyst action to eliminate bacteria and odours effectively, protecting the food with clean chilled air. The Nano-Titanium ultrafine filters can capture and eliminate bacteria and odours up to 99% of the particles and ensure fresh and purified air is circulated through the fridge compartments (for instance Hitachi's Advanced Multi Flow system described later).

3) Nano-Aluminium

Aluminium foil is widely used in flexible packaging for food because it offers outstanding barrier properties. Nanotechnologies enable to improve properties of the foil surface, for instance to develop anti-adhesive coating or black coating of baking foil which does not reflect heat in an oven.

4) Nano ZnO

Moreover, ZnO nanoparticles do not discolor, nor does it require ultra-violet to get activated. These properties make nano ZnO a superior non-organic antibacterial agent versus other materials used nowadays.

3.4.2. Functional requirements

Nano-Silver:

- anti-bacterial and anti-biotic properties
- sunscreen and anti ultraviolet (anti UV-A and anti UV-B) properties
- dishwasher safe, microwave safe and freezer safe
- hard to break
- prevents the static electricity

Nano-Titanium:

- anti-bacterial properties
- odours elimination (deodorant effects)
- trapping dust particles

Nano-Aluminium:

- excellent barrier properties for various gases (e.g. carbon dioxide and oxygen)
- UV screening effect
- anti-adhesive coatings
- colour coatings
- coatings reducing heat reflection

Nano ZnO

- anti-bacterial properties without UV activation
- odours elimination (deodorant effects)

3.4.3. Boundary conditions

The further development in this area is strongly dependent on the perception of nanotechnologies in food contact materials by the consumers. Food companies are still hesitant to incorporate nanomaterials for uncertainty of future regulations and standards and for fear of negative consumer reactions. The public attitude towards the use of nanotechnologies in food or food contact materials is distinguished by high degree of uncertainty, scepticism, wariness, or even refusal. This was highlighted by the FSA Evidence Review of Public Attitudes to Emerging Food Technologies published recently.⁹ This report also indicates that attitudes to novel food technologies in the USA and Asia seem to be generally more positive than in Europe. Nevertheless, we can suppose that the general public attitude to nanotechnologies in food packaging might be less negative than to nanotechnologies incorporated into food itself.

The use of nanotechnologies in food packaging in Europe is in principle sufficiently¹⁰ regulated by the Regulation EC/1935/2004¹¹ that covers all materials come into contact with foodstuffs. According to this regulation the EC or individual Member States may ask the European Food Safety Authority (EFSA) to conduct a safety evaluation of food contact materials. Food contact plastics are subject to additional measures regulated by the Regulation (EC) 282/2008 on recycled plastic materials and articles¹² and by the Regulation (EC) No 450/2009 which sets down additional requirements to Regulation (EC) No 1935/2004 for active and intelligent materials and articles.¹³

Furthermore, according to the study “Out of the Laboratory and On to Our Plates: Nanotechnology in Food and Agriculture” published by the Friends of the Earth Australia, Europe, United States, and Germany in April 2008¹⁴, there is a rapidly expanding body of scientific studies demonstrating that some of the nanomaterials now being used in foods and agricultural products introduce new risks to human health and the environment. For example, nanoparticles of silver, titanium dioxide, zinc and zinc oxide, materials now used in nutritional supplements, food packaging and food contact materials, have been found to be highly toxic to cells in test tube studies. Preliminary environmental studies also suggest that these substances may be toxic to ecologically important species such as water fleas.

3.4.4. Product examples

1) Examples of products based on nanosilver:

- **Food containers**

Sharper Image® (USA)

FresherLonger™ Miracle Food Storage Containers infused with naturally antibacterial silver nanoparticles easily keep foods fresher three or even four times longer — fruits, vegetables, herbs, breads, cheeses, soups, sauces and meats. In tests comparing FresherLonger to conventional containers, the 24-hour growth of bacteria inside. FresherLonger containers was reduced by over 98 percent because of the silver nanoparticles. *FresherLonger™* Plastic Storage Bags, re-sealable zip-top food storage bags are infused silver nano-particles in order to reduce the growth of bacteria, mold and fungus. FresherLonger bags are transparent with the signature gold tint of silver nanoparticles.

⁹ See Lyndhurst, B.: An Evidence Review of Public Attitudes to Emerging Food Technologies. Food Standards Agency, March 2009.

¹⁰ The FSA regulatory review “A review of potential implications of nanotechnologies for regulations and risk assessment in relation to food” published in August 2008 has not identified any major gaps in regulations relating to the use of nanotechnologies in food.

¹¹ See <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:338:0004:0017:EN:PDF>

¹² See <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:086:0009:0018:EN:PDF>

¹³ See <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:135:0003:0011:EN:PDF>

¹⁴ <http://www.nanolawreport.com/2008/03/articles/nano-food-and-packaging-scare-tactics/>

BlueMoonGoods, LLC (USA)

BlueMoonGoods™, a new super airtight Fresh Box Silver Nanoparticle Food Storage Containers can reduce bacteria by as much as 99.9%

Baby Dream® Co. Ltd. (South Korea)

Through silver nano poly system of *Nano Silver Baby Milk Bottle* 99.9% of germs are prevented and it maintains anti-bacteria, deodorizing function as well as freshness.”

▪ **Cutting Boards**

A-DO Global (Korea)

Nano Silver Antibacterial Cutting Board with thickness of 13mm restrains the breeding of bacteria and ensures it stays clean and hygienic.

▪ **Refrigerator**

Nano-Silver has also been incorporated into the inner surface of domestic refrigerators to prevent microbial growth and maintain a clean and hygienic environment in the fridge. Some examples of products already available on the market are:

Daewoo® Germany (Korea)

Silver particles were applied to major parts of refrigerator in order to restrain the growth and increase of a wide variety of bacteria and eliminate odor particles. Accordingly, it is latest pro-health technology to ensure freshness of food products and ultimately, your health. It also maintains balance of hormone within our body and intercepts electromagnetic waves significantly.

Haier YuHang™ (China)

Intelligent and nanotechnology insulation materials were used to halve the refrigerator's thickness and fluorescence.

▪ **Kitchenware/Tableware**

NCT (China)

NCT introduced a revolutionary coating nano-silver onto the surface metal products by utilizing Physical Vapour Deposition (PVD) technology. The properties of the coating (such as hardness, structure, chemical and adhesion) can be accurately controlled. The proprietary solution provides all coatings remain long lasting antibacterial function with hardness strengthened.

2) Examples of products based on nano-titanium:

Hitachi

Ranges of refrigerators (e.g. R550ET5X fridge) incorporate the Hitachi's innovative 'Triple Clean System' which combines a Nano-Titanium Filter, a new Negative-Ion Generator, and an Advanced Multi-Flow System. Nano- Titanium Filter and new Negative-Ion Generator work together to eliminate associated unwanted odours to ensure food stays to its original flavour and texture conventional

fridges. The Negative-Ion Generator produces negative-ions which absorb bacteria and odours, as well as suppress bacteria multiplication. The antibacterial Nano-Titanium filtration system then captures and eliminates those bacteria and odours to the scale of five nanometres through the ultra-fine filter in the air canal of the fridge wall. As well as trapping the particles, the Nano-Titanium filtration system also ensures fresh and purified air is circulated through the fridge compartments. Hitachi also launched the Nano Titanium range of vacuum cleaners which have several layers of filters that make up a synergistic filtration system capturing micro particles at the nano level.

3) Examples of products based on aluminium:

Melitta (Germany)

Toppits Back® aluminums combine the anti-adhesive properties of paper with the advantages of aluminum foil with regard to plasticity. Since 2004, the black coated *Toppits Fix Roast* aluminum foil with use of nanotechnology has been developed. The black coating material reached up to 100 degrees Celsius higher surface temperatures when cooking, which heat is directly forwarded to the baked food. The final effect is that the food is prepared quicker and it will remain outside crispy and juicy inside.

4) Examples of products based on Nano ZnO:

SongSing Nano Technology Co., Ltd. (Taiwan)

Nano Plastic Wrap with incorporated ZnO nanoparticles features the following functions: UV protection, IR reflection, sterilizing and anti-molding properties, better temperature tolerance, fire-proof and bearing grinding. *far longer than*

3.4.5. Economical information for present products

Detailed information about the market size of this relatively narrow segment is not publicly available. From the global point of view, the number of nano-based packaging applications is reported to be growing fast. Three years ago fewer than 40 packaging products containing nanoparticles were thought to be on the market, compared to the 400 plus currently available. The market for food packaging containing nanomaterials has been predicted to reach \$360m in 2008 and \$20bn by 2020 (<http://www.packaging-gateway.com>).

4. References

- Berger, M.: The promises of food nanotechnology. Nanowerk, 2007. Available at (September 2008).
- Chaudhry Q. – Scotter, M. – Blackburn, J. – Ross, B. – Bodalo, A. – Kastle, L. – Aitken, R. – Watkins, R.: Applications and implications of nanotechnologies for the food sector. Food Additives & Contaminants: Part A, Volume 25, Issue 3 March 2008, pp. 241 – 258.
- Cientifica: Nanotechnologies and Food, August 2006.
- EFSA: Scientific Opinion of the Scientific Committee on a request from the European Commission on the Potential Risks Arising from Nanoscience and Nanotechnologies on Food and Feed Safety. The EFSA Journal (2009) 958, 1-39.
- European Commission: Prospects for agricultural markets and income 2007-2014. Directorate-General for Agriculture and Rural Development, March 2008.
- European Commission: Agriculture in the European Union - Statistical and economic information 2007. Directorate-General for Agriculture and Rural Development, February 2008.
- European Commission: Competitiveness of the European Food Industry. An economic and legal assessment. Directorate-General Enterprise and Industry, 2007.
- Helmuth Kaiser Consultancy: Nanotechnology in Food and Food Processing Industry Worldwide. 2004.
- Kuzma, J. – VerHage, P.: Nanotechnology in Agriculture and Food Production: Anticipated Applications. PEN 4, September 2006. Available at (September 2008).
- Lienhardt, J.: The food industry in Europe. Statistics in focus No. 39/2004. Eurostat, 2004.
- Lux Research: The Nanotech Report, 5th Edition, 2007.
- Malanowski, N. – Heimer, T. – Luther, W. – Werner, M. (eds.): Growth Market Nanotechnology: An Analysis of Technology and Innovation. WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim 2006.
- Maul, P.: Barrier Enhancement Using Additives. Nanocor Inc., Pira International Conference, Brussels, December 2005.
- Miller, Georgia – Rye Senjen: Out of the laboratory and on to our plates. Nanotechnology in Food and Agriculture. Friends of the Earth Australia Nanotechnology Project, March 2008. Available at (September 2008).
- OECD, FAO: Agricultural Outlook 2007 – 2016. Organisation for Economic Co-operation and Development, Food and Agriculture Organization of the United Nations, 2007.
- OECD, Allianz: Opportunities and risks of Nanotechnologies. Report in co-operation with the OECD International Futures Programme, 2005.

Rutzke, C.J. (ed): *Nanoscale Science and Engineering for Agriculture and Food Systems. A Report Submitted to Cooperative State Research, Education and Extension Service. The United States Department of Agriculture, September 2003. Available at (September 2008):*

SCENIHR: *Risk Assessment of Products of Nanotechnologies. Scientific Committee on Emerging and Newly Identified Health Risks, January 2009. Available at (March 2009):*

Scott, Norman – Chen, Hongda: *Nanoscale Science and Engineering for Agriculture and Food Systems. USDA, September 2003. Available at (September 2008):*

Tiju, J. – Morrison, M.: *Nanotechnology in Agriculture and Food. Nanoforum Report, May 2006. Available at (September 2008):*

Weiss, J. – Takhistov, P. – McClements, J.: *Functional Materials in Food Nanotechnology. Journal of Food Science, Vol. 71, Nr. 9, 2006, pp. R107–R116.*

WHO: *Nanotechnology. INFOSAN Information Note No. 01/2008, February 2008.*

Wijnands, J.H.M. – Van der Meulen, B.M.J. – Poppe, K.j. (eds.): *Competitiveness of the European Food Industry: An economic and legal assessment 2007. European Commission (DG Enterprise and Industry), November 2006.*

MATTHEWS J. A. , WNEK, G. E., SIMPSON, D. G. and BOWLIN, G. L. (2002) *Electrospinning of Collagen Nanofibers. Biomacromolecules 2002, 3, 232-238*

ZHAO, R. X., TORLEY, P. & HALLEY, P. J. (2008) *Emerging biodegradable materials: starch- and protein-based bio-nanocomposites. Journal of Materials Science, 43, 3058-3071.*

MARSH, K. & BUGUSU, B. (2007) *Food Packaging—Roles, Materials, and Environmental Issues. Journal of Food Science, 72, R39-R55.*

Food Packaging: Principles and Practice, Second Edition (2006). Gordon L. Robertson

Annex I – Research projects on nanotechnology in FP6 and FP7

FP6		
Search term(s)	Activity area	FP6 project acronym and title
Food	NMP	POLYSACCHARIDES: The European Polysaccharide Network
		SUSTAINPACK: Innovation and Sustainable Development in the Fibre Based Packaging Value Chain
		ECOBINDERS: Furan and lignin based resins as eco-friendly and durable solutions for wood preservation, panel, board and design products
		ECOTARGET: New and innovative processes for radical changes of the European pulp and paper industry
		FRONTIERS: NoE Research and facilities directed at instrumentation for manufacturing and analysis of single molecules and individual nanoclusters, targeted at life sciences
		NANOMEMPRO: Expanding membrane macroscale applications by exploring nanoscale material properties
		NANO2LIFE: A network for bringing NANOTEchnologies TO LIFE
		BARP+: Development of a bioartificial pancreas for type I diabetes therapy
		POLYCOAT: Economical exploitation of polymer coated steel sheet in large-scale production of new can types by the European can industry
		GENSENSOR-NANOPARTS: Nano-biotechnical components of an advanced bioanalytical microarray system
		METU-CENTER: Middle East Technical University Central Research Laboratory in nanotechnology, new materials, new processes and biotechnology
		NANOBIOMAG: Magnetic Field Assisted Biomaterials Processing
		NANOBIOSACCHARIDES: Nanotechnologies for Bio-inspired polysaccharides: biological decoys designed as knowledge-based, multifunctional biomaterials
		CONTROLLED RELEASE: New controlled release systems produced by self-assembly of biopolymers and colloidal particles at fluid-fluid interfaces
		STAG: Switchable multifunctional materials for quantitative monitoring temperature, ambient, and light exposure
		MAGDOT: Bridging Atomistic to Continuum - Multiscale Investigation of Self-Assembling Magnetic Dots during Epitaxial Growth
		ACTECO: Eco efficient activation for hyper functional surfaces
		BASE: Bio-based functional materials from engineered self-assembling peptides
		NANOCAT: Tailored nanosized metal catalysts for improving activity and selectivity via engineering of their structure and local environment
NANOWAYS: A roadmap for software ICT-enabled Micro/Nano-Biotechnology Applications		
Food and nanotechnology	IST	GOODFOOD: Food safety and quality monitoring with microsystems
		OPTOLABCARD: Mass Produced Optical Diagnostic Labcards Based on Micro and Nano SU8 Layers
		PARTICLE_RISK: Risk Assessment of Exposure to Particles
Food and nanotechnology	NEST	NANOBIOMAPS: Imaging mass spectrometry for nanoscale mapping of biological cells and tissues
		SAFER: Isolation of foetal cells from maternal blood: A nanomolecular approach
		SOCON: Self-organisation under confinement
Food and nanotechnology	MOBILITY	BIOPOLYSURF: Engineering advanced polymeric surfaces for smart systems in biomedicine, biology, material science and nanotechnology: A cross-disciplinary approach of Biology, Chemistry and Physics
		REMO: Fatigue of metal coated Polymers in micro-optics on the Nanoscale level
		BIOPOWDERS: Research training in powder technology for competitive manufacture of food, pharmaceutical, nutraceutical and biological powders

NMP=Nanotechnologies, Materials, New Processes, IST=Information Society Technologies, NEST=New and Emerging Science and Technology, MOBILITY=Marie Curie Actions

Source: <http://cordis.europa.eu/fp6/projects.htm>

FP7		
Search term(s)	Activity area	FP7 project acronym and title
Nanotechnology	KBBE	NANODETECT: Development of nanosensors for the detection of quality parameters along the food chain
		SYMBIOSIS-EU: Scientific synergism of nano-bio-info-cogni science for an integrated system to monitor meat quality and safety during production, storage, and distribution in EU
Food	NMP	BIOAGROTEX: Development of new agrotexiles from renewable resources and with a tailored biodegradability
		FLEXPARENEW: Design and development of an innovative ecoefficient low-substrate flexible paper packaging from renewable resources to replace petroleum based barrier films
Food and nanotechnology	People	INFULOC: Integrated and functional Lab-on-Chip
		MULTIFLOW: Multi-scale complex fluid flows and interfacial phenomena

KBBE=European Knowledge Based Bio-Economy, NMP=Nanosciences, nanotechnologies, materials & new production technologies

Source: http://cordis.europa.eu/fp7/projects_en.html

Annex II – Nano Patents for Food and Food Packaging

Patent/Application (Date Issued or Published)	Area of Application*	Patent Excerpt
Patent Assignee		
WO04012998A3 (2004-02-12) Atofina, France	FP	Composition for food packaging based on vinyl aromatic resin containing a mineral platy filler in the form of nanoparticles.
US 20030232095A1 (2003-12-18) Nutralease, Ltd., Israel	BD	The nano-sized concentrates of the present invention enable in an efficient manner the solubilization, transport and dilution of oil-soluble, oil non-soluble or water-soluble nutraceuticals, food supplements, food additives, plant extracts, medicaments, peptides, proteins or carbohydrates. Thus they may be used as efficient vehicles for transport of active materials into the human body.
US20030152629A1 (2003-08-14)	BD	Controlled release system that can encapsulate different flavours, sensory markers, and active ingredients, or combinations of flavours, sensory markers and various active ingredients and release multiple active ingredients in a consecutive manner, one after the other. The controlled delivery system is substantially free-flowing powder formed of solid hydrophobic nanospheres that are encapsulated in a moisture sensitive microspheres.
CN1409966A (2003-04-16) Qingtian New Material Research & Development Co., China	FA	An antibacterial nanometre powder without decolouring for food contains nanometre zirconium phosphate particles as carrier and active antibacterial component. Its advantages are small granularity, broad spectrum, high compatibility, stability and antibacterial efficiency, and no poison.
CN1408746A (2003-04-09) Pengcheng Vocational Univ., China	FP	Antibiotic fresh preserving plastic film and its producing method.
US6204231 (2001-03-20) Henkel, Germany	Food Processing BD	Aqueous caustic alkali for cleaning food industry facilities, giving regenerated concentrate useful directly in animal feed, contains aqueous potassium hydroxide and optionally other alkali, especially sodium hydroxide.
US6197757 (2001-03-06)	BD	Particles, especially microparticles or nanoparticles, of crosslinked monosaccharides and oligosaccharides, processes for their preparation and cosmetic, pharmaceutical or food compositions in which they are present.
EP1355537A1 (2003-10-29) Kraft Foods	BD	Production of capsules and particles for improvement of food products.
US5891907 (1999-04-06) BASF	BD FA	Stable aqueous solubilizates are disclosed suitable for parenteral administration, of carotenoids and vitamins or vitamin derivatives, in which the carotenoid and the water-insoluble vitamins are, with the aid of a nonionic emulsifier, in the form of a micellar solution, the micelles being smaller than 100 nm.
US5968251 (1999-10-19) BASF	FA	Carotenoid preparations in the form of coldwater-dispersible powders are produced by preparing a molecular-disperse solution of a carotenoid, with or without an emulsifier and/or an edible oil, in a volatile, water-miscible, organic solvent at elevated temperature and adding therein an aqueous solution of a protective colloid, whereupon the hydrophilic solvent component is transferred into the aqueous phase, and the hydrophobic phase of the carotenoid results as nanodisperse phase.
EP1447074A2 (2004-08-18) Rohm and Haas	BD	Polymeric nanoparticles in consumer products. Crosslinked polymeric nanoparticles having a diameter of 1-10 nm comprising skin care ingredients and food ingredients.

WO04063267A1 (2004-07-29)	FP	Article comprising stretched polymer composition with nanofillers: Polymer article (e.g. film for food packaging), comprises polymer composition containing polyolefin matrix and nanofiller dispersed in the matrix.
Borealis Technology, Finland		
WO04030649A2 (2004-04-15)	BD	Microcapsules or nanocapsules containing sparingly water-soluble active agent, useful e.g. for rapid drug release on oral administration, having permeable shell containing polyelectrolyte and counter-ion.
Cap-Solution Nanoscience Ag, Germany		
WO04016696A1 (2004-02-26)	FA	A method for the manufacture of patterned microparticles comprises immobilising microparticles, including nanoparticles, to be patterned on a surface of a porous membrane, causing an inorganic or organic coating material which can bind to exposed surfaces of said microparticles. The patterned microparticles produced can be used in wide range of applications in health, information and communication, and sustainable environment such as shelter, clothing, energy, food, transport and security.
University College Dublin, National University of Ireland, Dublin		
WO03095085A1 (2003-11-20)	BD	Colloidal dispersions of calcium phosphate nanoparticles and at least one protein, the size of said nanoparticles ranging between 50 and 300 nm, and the morphology of said nanoparticles being spherical. The invention can be used in the food, cosmetic, pharmacological industries.
Rhodia Chimie, Boulogne-Billancourt Cedex, France		
CN1454939A (2003-11-12)	FP	The preparation method of nano titanium dioxide granule whose surface is coated with aluminium oxide. The grain diameter of the prepared nano titanium dioxide is 10-100 nm, its surface is coated with aluminium oxide membrane. Nano titanium dioxide coated with aluminium dioxide has good dispersion property, can implement single granule dispersion, can be used as excellent UV-ray screening agent, and can be used in the fields of paint, rubber, fibre, coating material, sun protection products, printing ink and food package, etc.
Shanxi Coal Chemistry Inst., Chinese Academy of Sciences, China		
DE10310021A1 (2003-10-23)	FA	Micro- or nanoparticles of biomass of lipid-containing marine organisms, useful as pharmaceutical or cosmetic active agents or food additives, e.g. for preventing binding of bacteria to skin or tissue.
CN1448427A (2003-10-15)	FA	Water dispersible nanometer avicel, its prep. and colloid therefrom: The nanometer microcrystal cellulose powder is surface modified nanometer microcrystal cellulose with added hydrophilic colloid in the amount of 5-150 wt% of nanometer microcrystal cellulose and has grain size of 6.3-100 nanometers. During its preparation, hydrophilic colloid is dispersed homogeneously into water dispersed medium of surface modified nanometer microcrystal cellulose and the mixture is then dried and crushed. The nanometer microcrystal cellulose is easy to be water dispersed to form colloid, which is homogeneous and high in gluing strength and has the small size of microcrystal cellulose maintained, so that it has wide and unique application foreground in food production, medicine, papermaking, textile, new material preparation and other fields.
Guan-Gzhou Institute Of Chemistry, Chinese Academy Of Sciences		
CN1439768A (2003-09-03)	FA, BD	Nano feather powder and its processing method and use: A nano-class feather down powder used as the functional and health-care additive of food, feed cosmetics, medicine, or chemical fibres is prepared from the feather down of duck, goose, birds, etc through water washing, screening, shearing pulverizing, immersing in alcohol, centrifugal drying, microwave oscillating, quick cooling, low-temp pulverizing and sieving. Its advantages are no loss of active components, high specific surface area, molecular activity and affinity to human body and higher health-care effect."
Zhang Liwen, China		
WO03055804A1 (2003-07-10)		Calcium carbonate of different shapes including spindle, petal, whisker, needle, flake, ball and fibre. The calcium carbonate has an average particle size in the range of 10 nm - 2.5 µm and can be utilized in various fields such as rubber, plastics, papermaking, coatings, building materials, inks, paintings, food, medicine, domestic chemical industry, textile and feed."
Nano-Materials Technology Pte Ltd., Singapore Beijing University Of Chemical Technology		
US20030129403A1 (2003-07-10)	FP	Barrier material with nanosize metal particles as coating of plastic diaper or for food-contact packaging materials, comprises particles

Cellresin Technologies, LLC		of zinc or similar reacting metal or metal alloy, dispersed in matrix material.
US6579929 (2003-06-17)	FA	Stabilized silica and method of making and using the same: A surface stabilized, non-agglomerated silica is provided, it has a size in the nanometer range. The surface stabilized, non-agglomerated silica can be used as an additive in any application that uses silica, such as reinforcing fillers for elastomeric compositions, foods, drugs, dentifrices, inks, toners, coatings and abrasives.
Bridgestone Corporation, Tokyo, Japan		
WO03028700A3 (2003-04-10)	BD, FA	Water soluble nanoparticles of hydrophilic and hydrophobic active materials: This invention provides a soluble nano-sized particles formed of a core (Water-insoluble lipophilic)compound or hydrophilic compound and an amphiphilic polymer and which demonstrated improved solubility and/or stability. The lipophilic compound within the soluble nano-sized soluble ("Solu-nanoparticles") may consist of pharmaceutical compounds, food additives, cosmetics, agricultural products and veterinary products.
Solubest Ltd., Rehovot, Israel		
WO03024583A1 (2003-03-27)	BD	Novel Calixarene Based Dispersible Colloidal Systems in the Form Of Nanoparticles for medical, biological, veterinary, cosmetic and alimentary use, includes nanoparticles comprising amphiphilically modified calixarene.
Central P BV, Naarden, Netherlands		
WO03011040A1 (2003-02-13)	potravina	A novel process for preparing a gelled aqueous composition, which process employs a gel-forming globular protein such as whey protein, ovalbumin or soy protein. The invention also relates to products obtainable by the above process.
Wageningen Centre For Food Sciences, Netherlands		
WO02060591A1 (2002-08-08)	BD, FA	Device and method for producing stationary multi-component liquid capillary streams and micrometric and nanometric sized capsules, the diameter of which may range from tens of nanometers to hundreds of microns and to a relatively monodispersed aerosol of electrically charged multi-component droplets generated by rupture of the streams due to capillary instabilities. The device and method can be used in fields such as materials science and food technology, wherever generation and controlled handling of structured micrometric and nanometric sized streams is an essential part of the process.
University of Seville, University of Málaga, Spain		
US5741505 (1998-04-21)	FA	A coated edible product comprising edible material and a substantially continuous inorganic coating on a surface of the edible material, wherein said coating covers at least a portion of the edible material and said coating has a thickness ranging from 0.0001 to 0.5 microns.
Mars, Inc.		
US6379712 (2002-04-30)	FA(preservative)	The invention relates to nanosilver-containing antibacterial and antifungal granules ("NAGs"). The NAGs have longlasting inhibitory effect on a broad-spectrum of bacteria and fungi. The NAGs can be used in a variety of healthcare and industrial products. Examples of industrial products include, but are not limited to, food preservatives, water disinfectants, paper disinfectants, construction filling materials (to prevent mold formation).
Globoasia, L.L.C., Hanover, Md.		
US6352737 (2002-03-05)	FA	The use of nanoscale sterols and/or sterol esters with particle diameters of 10 to 300 nm as food additives and as active substances for the production of hypocholesterolemic agents. The particular fineness of the particles promotes more rapid absorption by the blood serum after oral ingestion by comparison with conventional sterols and sterol esters.
Cognis Deutschland		
DE10027948A1 (2001-12-20)	FA	Production of suspension of undecomposed meltable material used in e.g. the pharmaceuticals, cosmetics, and food industries comprises preparing emulsion from material, liquid phase and surface modifying agent, and cooling
Henkel Kgaa, Germany		
US6303150 (2001-10-16)	BD	Method for producing nanocapsules with crosslinked protein-based walls nanocapsules thereby obtained and cosmetic, pharmaceutical and food compositions using same.
Coletica, France		
CN1298902A (2001-06-13)	Packaging	Process for preparing antibacterial plastics for food or beverage containers using nanoscale antibacterial powder.
Lu Bingkun, China		
DE19937117A1 (2001-02-08)	Packaging	Film, useful for the packaging of food stuffs, contains at least one copolyamide layer comprising 10-2000 ppm dispersed nanoscale

Wolff Walsrode Ag, Germany		nucleating particles.
US6117541 (2000-09-12)	Packaging	Polyolefin material integrated with nanophase particles: Packaging laminate, used in a container for fluid foods e.g. milk or juice – comprising a layer of polyolefin interspersed with nanometer size clay particles for gas barrier properties.
Tetra Laval Holdings & Finance S.A.		
US5946930 (2001-02-08)	Packaging	Self-cooling beverage and food container using fullerene nanotubes.

*) FP = food packaging, FA = food additives, BD = bio-delivery

Source: *Down on the Farm. The Impact of Nano-scale Technologies on Food and Agriculture. ETC Group. November 2004.* http://www.etcgroup.org/documents/ETC_DOTFarm2004.pdf