ACHEMA 2006
28. međunarodni sajam i kongres za hemijsko inženjerstvo, zaštitu okoline i biotehnologiju

U Frankfurtu je u periodu od 15. do 19. maja 2006., održan 28. međunarodni sajam i kongres za hemijsko inženjerstvo, zaštitu okoline i biotehnologiju, ACHEMA 2006. Nemačko društvo za hemijsko inženjerstvo i biotehnologiju, DECHEMA (www.dechema.de) prati ovaj sajam i kongres, objavljivanjem izvešaja o pravcima razvoja novih proizvoda i tehnologija. Kao i ranijih godina, počev od broja 5–6 (Hemijska industrija, vol. 60, no. 5–6) ovi izveštaji, u nešto skraćem obliku, objavljuju se i u našem časopisu.

NANOTECHNOLOGY CONTINUES TO BROADEN ITS REACH: • SMALL PARTICLES – GREAT EFFECTS

The majority of current innovations focus on materials and surfaces. It is the new developments in this field that have made countless innovative products with novel functions possible in the first place. From additives for varnishes or plastics to catalysts, membranes, therapeutic agents and diagnostic applications – a wide gamut of fields profit from these innovations. Here nanotechnology, the pacemaker for new developments, plays a key role.

Over the past two decades, there has been an explosion of research and development activities in nanotechnology, with considerable investment and effort worldwide, by universities, companies ranging from small entrepreneurial start–up businesses to leading corporations in all segments of the chemical process industries, and government and military research organizations.

Nanotechnology is now widely regarded as a key technology of the 21st century. Nanoscaled materials and nanotechnology manufacturing techniques are already being used to produce composite materials with improved electro conductivity, catalytic activity, hardness, scratch resistance and self–cleaning capabilities, and consumer products (such as cosmetics and sunscreens) that have improved aesthetic appeal and efficiency.

Nanotechnology applications are also being developed to improve the performance of gas sensors and other industrial monitoring devices, to increase the activity of various catalysts, to produce improved fuel cells and lighter weight and longer–lasting batteries. In the medical arena, an imaginative array of nanoscaled particles are being investigated to employ potent cancer–killing drugs more effectively in the human body, so they accumulate preferentially within tumors and other cancerous cells, to spare healthy surrounding tissue and minimize the devastating side effects often associated with chemotherapy and radiation–based cancer treatments.

Mind boggling dimensions

In recent years, working with countless materials, the scientific, engineering and medical communities have verified the novel, size–dependent properties and phenomena that occur in the nanometer–range, and they continue working to perfect the techniques needed to reliably produce or manufacture these tiny structures.

The German government has funded nanotechnology research since 1998. In 2004 more than EUR 270 million were contributed by the federal ministries in Germany, which has a leading position in the EU nanotechnology research (EUR 1,380 million in the whole EU in 2004). The German government plans to invest about EUR 320 million in nanotechnology in 2006. Money will be allocated via the Ministry of Education and Research as well as the Ministry of Economics and Technology. Not only pure scientific research was and is funded, but also structural measures such as the formation of nanotechnology competence centers (e.g. in chemistry, optics, ultra–precise surface manufacturing etc.).

In the USA, a primary unifying force has been the National Nanotechnology Initiative (NNI), a long–term research and development program that coordinates the nanotechnology activities of 22 departments of the US government, such as the National Science Foundation, Dept. of Defense, Dept. of Energy, National Institute of Health, National Institute of Standards, and National Aeronautical Space Administration, and other independent agencies. It was first proposed in 2000, during the Clinton Administration, and was signed into law in 2003 by President George H.W. Bush (The "21st Century Nanotechnology R&D Act").

Nanotechnology spending by the NNI members in 2005 is estimated to be US–$ 1,081 million, according to the NNI. For the FY 2006 federal budget, President George W. Bush requested US–$ 1,081 million for nanotechnology R&D across all of the agencies that participate in the NNI. Since the NNI was established, more than 40 other countries have announced priority nanotechnology programs, including Japan, Germany, China, Taiwan and Korea.

Improved material properties bring performance advantages

As a result of the inverse relationship between particle size and surface area, drastically size–reduced nanoparticles have an extraordinary amount of available surface area, and many materials – including metals, metal oxides, various forms of silica, clays and novel carbon compounds – demonstrate a range of favorable physical properties and characteristics compared to macroscopic particles of the same material.

Carbon nanotubes

One particular type of nanometer–scaled structure that is generating considerable interest is the carbon nanotube. Pioneered by chemical engineering researchers at Houston?s Rice University in the early 1990s, carbon nanotubes are now being investigated by countless universities and companies – including Hyperion Catalysis International, Carbon Nanotechnologies, Showa Denko K.K., Mitsui & Co., Japan's National Institute of Advanced Industrial Science and Technology, and Tokyo Institute of Technology and others – which are working to develop and perfect commercially viable routes to produce carbon nanotubes, and novel applications that take advantage of their unprecedented structural, mechanical and electronic properties. However a German company will most probably be the first to produce carbon nanotubes (CNT) commercially in a large scale: Bayer MaterialScience and Bayer Technology Services have succeeded in producing CNTs in a more cost efficient way. They are on their way to scaling up production (see www.baytubes.com). The French Arkema group produces about 5 tons of multi–walled carbon nanotubes per year.

Carbon nanotubes are seamless cylinders composed of carbon atoms in a regular hexagonal arrangement, closed at both ends by hemispherical end caps, whose diameters are measured in tens of nanometers. They can be produced as single–wall nanotubes (SWNT) or multi–wall nanotubes (MWNT). In general, carbon nanotubes have a surface area of up to 1,500 m^2/g and a density of 1.33–1.40 g/cm^3. Depending on their structure, they can function as either conductors or semiconductors of both electricity and heat. They exhibit extremely high thermal and chemical stability, are extremely elastic (with a modulus of elasticity of the order of 1,000 Gigapascals), and can withstand 10–30 % elongation before breakage.

Perhaps their most prized attribute is their tensile strength, which can be greater than 65 GPa (with predicted value as high as 200 GPa). A widely cited comparison is that carbon nanotubes have a tensile strength 100 times that of steel, but at only one–sixth its weight. This remarkable suite of material properties opens the door for countless industrial applications.

Researchers are also working to investigate a variety of competing production routes, develop and scale up proven processes that allow carbon nanotubes to be cost–effectively produced (and mass produced). The key challenge is to produce nanotubes that have predictable, consistent dimensions, acceptable purity levels and minimal structural defects (since these can drastically alter the anticipated behavior of the nanoscaled particles).

Today, carbon nanotubes are being incorporated into various matrices, including fluoropolymers such as ethylene tetrafluoroethylene (ETFE) and polyvinylidene fluoride (PVDF), to produce ultra–lightweight composite materials that have exceptional strength and other functional advantages over conventional materials, and to create advanced thin–film membranes, fibers, foams and coatings. Such advanced composites are already being used in various automotive, electronics and materials–handling applications – particularly those that require precise control of static electricity, improved chemical resistance, a higher barrier to chemical permeation, inherent lubrication properties, and better resistance to sloughing compared to the conventional, non–nanotube–reinforced materials. They are also being investigated as key components in tomorrow's advanced sensors, electronic and optical devices, catalysts, batteries and fuel cells. In fuel cell applications, for example, the use of carbon nanotubes has been shown to improve the performance of industrial fuel cells while greatly reducing the amount of platinum catalyst required.

Researchers at the US National Aeronautical and Space Administration (NASA) are also developing polyimide nanocomposites that incorporate SWNTs to improve radiation and tear resistance, and thermal and electrical conductivity ? all of which are important for aircraft and spacecraft construction.

Commercial–scale applications of nanotechnology

Polymeric composites

In addition to carbon nanotubes, nanoparticles of various other materials are being used as functional additives in the production of a range of advanced composites. By blending small quantities of these tiny particles into various polymeric resins, the resulting advanced composite materials demonstrate a range of improved material characteristics, such as electrical conductivity, catalytic activity, hardness and scratch resistance, fire retardant properties, diffusion–barrier characteristics, and even self–cleaning (or easy to clean) capabilities and anti–microbial properties. DuPont, BASF, Degussa, Toyobo and others are leading the way in this area.

The use of nanoscaled particles as functional additives allows much lower loadings to be used, compared to conventional additives. For instance, a nanocomposite typically contains just 3–5 wt.% nanosized clay or other nanoparticles, while conventional reinforced composites typically require the addition of 20–40 wt.% micrometer–sized fillers, such as talc, mica, calcium carbonate, asbestos, graphite, and various oxides. Such relatively high loading rates lead to tradeoffs, such as decreased polymer clarity (micrometer–sized inclusions lead to a loss of transparency because they scatter light), increased brittleness and higher density. This is not the case when relatively minute proportions of nanoscaled particles are used instead.

Advanced ceramics

Traditionally, high–performance ceramics have been made from powders whose constituent particles have a diameter of just under one micrometer, or 1,000 nanometers. However, while finished ceramic components are typically resistant to high temperatures and corrosion, they are also brittle and hard to work with. In recent years, improvements have been demonstrated by producing ceramics from powders consisting of much smaller particles – say, 100 nanometers in diameter or less.

For instance, nanoscaled powders of zirconia (ZrO_2) and alumina (Al_2O_3) are being used as a component in structural ceramics, to improve toughness and resistance to fracture and chipping. Such improved ceramics are increasingly making their way into industrial equipment that tends to experience high temperatures, harsh operating conditions and excessive wear, such as pump components, cutting tools and extrusion dies, bearings and seals, high–temperature filters and membranes, refractory materials, catalysts, advanced sensors, electronic components, and automotive engine components.

Another benefit arises from the use of nanoscaled ceramic powders. Since there is a strong relationship between sintering temperature and particle size, the ability to reduce the particle size of the initial material to about 20 nanometers has been shown to reduce the sintering temperature for zirconia, from 1,400 oooC to 1,110 oooC.

Degussa's Separion® improves safety of Li–ion batteries: if a conventional Li–ion battery ruptures, it may catch fire. Separion limits that effect to a very small range, so only a very small and not very dangerous cloud comes out of the battery; no extensive heat production occurs. Furthermore Degussa has developed a ceramic wall covering in its science to business center "Nanotronics" that will be brought onto the market shortly.

Consumer products

Makers of sunscreens, cosmetics and other personal care products have discovered that the use of nanometer–scaled versions of common additives can improve the effectiveness and aesthetic appeal of many products, compared to conventional formulations. For instance, with the advent of affordable methods to produce and use nanoscaled particles of the common ultraviolet–light blockers titanium dioxide (TiO_2) and zinc oxide (ZnO), sunscreen manufacturers can now use these broad–spectrum UV–blocking agents to produce transparent lotions that are aesthetically superior to the opaque white oxide creams that are the hallmark of surfers and lifeguards. Similarly, nanoparticles of TiO_2 are also being used to add UV–blocking functionality to varnishes, textile fibers and packaging films. Merck produces nanoparticles that improve the look of a wrinkled skin. These nanoparticles reflect light and if applied to a wrinkle they illuminate the interior of the wrinkle. It gives the impression that the wrinkle is not so deep as before (or has even disappeared).

Semiconductor–polishing slurries

A well–established use for nanoparticles is during chemical mechanical planarization (CMP), an extremely precise polishing process that is used during the production of integrated circuits on semiconductor chips. During CMP, nanoscaled particles of abrasive materials – typically oxides of aluminum and zirconium, colloidal or fumed silica, and cerium with diameters of 20–300 nm – are formulated in a polishing slurry that is used to make the metal and dielectric layers on silicon wafers smooth and defect–free. Polishing surfaces for optical applications with nanoparticles is a research area of the German Competence Center for Ultra Precise Surfaces in Braunschweig (www.upob.de).

Gas sensors and other analytical devices

The research community is also hard at work to exploit the extraordinary surface area, and increased reactivity and catalytic properties, of many nanoscaled materials to develop highly sensitive gas sensors and other analytical devices, such as those used to check food quality, improve disease detection, and monitor potential chemical, biological, radiological and nuclear hazards.

Resistive, metal oxide gas sensors (using, for example, nanoscaled oxides of zinc, tin, titanium and iron) rely on a change in electrical conductivity at the surface of the sensor, as it comes in contact with the target gas. The use of nanoscaled particles of key materials can greatly increase gas detection sensitivity, selectivity and response time by drastically increasing the amount of reactive surface area on the probe tip.

Similar advances are being pursued in gas chromatography. For instance, up to now, miniaturized gas chromatography (GC) modules for gas analyzers have been limited to applications involving the measurement of organic compounds. Recently, SLS Microtechnology GmbH and researchers from the Technical University of Hamburg–Harburg, have developed miniature GC columns (the size of a credit card) that are packed with singled–walled carbon nanotubes on a silicon wafer. The new system makes it possible to resolve inorganic gases such as CO_2, NO_x and O_2, say researchers.

Catalytic and photocatalytic applications

The development of highly effective catalysts also benefits from the enormous surface area advantage of nanoscaled particles. In one example, gold nanoparticles are used to enhance low–temperature oxidation processes, including carbon monoxide oxidation in a hydrogen stream, selective oxidation of propene to propylene, and the oxidation of nitrogen–containing chemicals.

Similarly, when exposed to ultraviolet (UV) light, photocatalytic substances such as the anatase form of titanium dioxide (TiO_2), strongly absorb UV radiation. In the presence of water, oxygen and UV light, such substances generate free radicals that decompose unwanted chemical substances, and reduce the adhesive forces that bind dirt and algae to various surfaces. This photocatalytic effect is being exploited for various commercial applications, such as water and air purification, or to impart self–cleaning, anti–microbial and anti–algae properties to various surfaces. It has been applied to decompose soot on walls in motorway tunnels in Japan.

Drug–delivery mechanisms and medical therapeutics

Ongoing nanotechnology developments in medicine have the potential to revolutionize medicine and healthcare. Today, a host of biocompatible nanomaterials are being pursued to allow for the development of more robust artificial tissues and organs, and hip– and knee–replacement materials. For example, researchers at GfE Medizintechnik GmbH, Nürnberg, Germany have developed a nanotechnology–based coating process to improve the biocompatibility of conventional polymer–based implant materials (which are prone to inflammation and rejection), by adding a coating of titanium just 30–50 nm thick.

In a related development, researchers at Purdue University have discovered a way to coat artificial joints made of titanium with a thick coat of nanotubes made from self–assembled rings of deoxyribonucleic acid (DNA), to make medical implants such as hip replacements less irritating to the human body. The nanotubes are composed of guanine and cytosine, two of the molecules that are basic components of genes.

Meanwhile, one of the most promising nanotechnology–based developments in the medical arena is the use of nanoscaled materials and devices to improve cancer diagnosis, and create new ways to target the delivery of potent, often–toxic chemotherapy drugs and reduce their dose–limiting effects.

The prevailing wisdom in cancer care is that when they are detected early, many cancers are treatable, and early intervention leads to better outcomes. As a result, devising more–effective strategies to detect cancer ? on a molecular level, before advanced–stage tumors have formed ? is also an ongoing area of interest for nano–related medical researchers.

Medical diagnostics

Over the last two decades, the evolution of fluorescent semiconductor nanocrystals known as quantum dots has ushered in a new era in medical and laboratory diagnostics. These nanocrystals are typically made of cadmium selenide, cadmium sulfide or cadmium telluride, and have an inert polymer coating that both safeguards human cells from potential cadmium toxicity, and allows drug developers to attach a variety of molecules that facilitate preferential uptake of the quantum dots (and other nanoparticles) by targeted cells.

By changing the diameter of quantum dots, they can be made to absorb and emit light of different wavelengths, and thus they can be color coded. As a result, quantum dots can be used to color–code and track different cell processes, different cancers or different stages of the same cancer. For instance, researchers at UCLA and Stanford University have labeled quantum dots with a positron–emitting isotope and injected them into mice. Then, using positron emission tomography (PET) scanning, the researchers were able to watch over time as the quantum dots made their way through the vascular system and to the liver. Prof. Weller from the University of Hamburg, Germany, has synthesized nanoparticles and is testing a broad range of applications.

Meanwhile, researchers at the University of Texas at Austin, and Houston's MD Anderson Cancer Center have developed a water–soluble formulation of fluorescent quantum dots that are labeled with a monoclonal antibody that binds to epidermal growth factor receptor (EGFR), which is thought to be an early predictive marker for cervical cancer. Using the labeled quantum dots, which fluoresce strongly when irradiated with white light, the Texas investigators were able to distinguish between cultured cells that overproduce EGFR and those that do not.

Researchers at Vanderbilt University have found a way to modify quantum dots by attaching short pieces of the biocompatible polymer polyethylene glycol (PEG) to substantially reduce nonspecific binding to various cell types. Companies involved with producing and using quantum dots include Evident Technologies and Invitrogen Corp. (which recently acquired both Quantum Dot Corp. and the BioPixels business unit of BioCrystal, Ltd.).

Trying to improve the efficiency of magnetic resonance imaging (MRI), researchers at Yonsei University in Seoul, South Korea, found that when they injected a formulation of magnetic nanocrystals labeled with a particular antibody (one that binds tightly to breast cancer cells) into mice, the formulation traveled quickly to the site of tumors, allowing the tumor cells to be detected using an MRI scan within one hour of injection. Alnis BioSciences also has also developed a magnetic nanoparticle formulation to improve tumor detection using MRI.

Researchers at Purdue University are relying on tiny "nanorods" of gold, which are roughly 200 times smaller than a red blood cell, to create an ultra–sensitive medical imaging technique for cells. By injecting the rods into the bloodstream of mice and shining a laser through the skin, these researchers produced images nearly 60 times brighter than those made using conventional fluorescent dyes.

Meanwhile, by inserting gadolinium into carbon nanotubes, scientists from Rice University have been able to produce improved contrasting agents for high–resolution MRI. Schering is selling their Gadomer–contrast agent that contains gadolinium complexed with dendrimers (tree–shaped organic nanoparticles, that are built up from scratch).

Targeted drug delivery

Today's nanotech pioneers are working to synthesize and deploy a diverse array of nanoscaled structures in order to dramatically improve the way in which highly effective therapeutic agents are administered. These include biodegradable and biocompatible polymeric nanoparticles and dendrimers, and silica–gold nanoshells, which can smuggle tiny payloads of anticancer drugs or imaging agents into cancer cells. Prof. Kreuter, University of Frankfurt/Main, has developed a nano encapsulated drug for treatment of glioblastomas, a kind of brain cancer. Glioblastomas are not removable by surgery because they form a sort of spider's web in the brain. Thus at present glioblastomas are 100% lethal. As normal therapeutic pharmaceuticals for cancer cannot pass the blood brain barrier, treatment with these conventional drugs fails. Encapsulating the therapeutics pharmaceuticals in a capsule of "brain–food" makes the body believe it is transporting only nutrients into the brain, but the therapeutic agent is transported as well.

For most nanoscaled drug–delivery applications, encapsulating the cancer drug or imaging agent represents only half the battle. To get the tiny particles to accumulate preferentially within target cells, researchers are working to attach a variety of targeting ligands, such as peptides, proteins or antibodies, to nanoparticle surfaces.

Efforts are also underway to engineer effective triggering mechanisms to get these pint–sized Trojan horses, once accumulated within cancer cells, to release their payload on demand, either suddenly or in a sustained, time–release fashion.

In January 2005, American Bioscience, Inc., received final approval from the US Food and Drug Administration (FDA) of its drug Abraxane, for patients with metastatic breast cancer who have failed combination chemotherapy. Abraxane consists of nanoparticles made of albumin that contain the proven anticancer drug paclitaxel.

Compared to patients getting paclitaxel alone, Abraxane allows patients to safely receive 50% more paclitaxel per dose, according to its maker. And, clinical trials involving 454 patients with metastatic breast cancer showed, those receiving Abraxane achieved almost a doubling of tumor–response rate, compared to those receiving paclitaxel alone.

While Abraxane uses albumin–based nanoparticles, researchers at Rutgers University, Insert Therapeutics, National University of Singapore, Cardiff University in Wales, the University of Nebraska Medical Center, Alnis BioSciences, Access Pharmaceuticals, pSivida, MIV Therapeutics Limited, Elan Corp. and EntreMed among others, are all developing biocompatible polymer–based nanoparticles to improve the delivery of potent anticancer drugs.

Branch–shaped dendrimers are another class of novel nanoscaled structures that have emerged over the last decade, and their use is also being actively pursued for intracellular drug delivery. Synthesized from monomers, dendrimers have a three–dimensional, treelike configuration, about the size of an average protein, and their many branches offer extraordinary surface areas that makes it possible to attach tumor–targeting drugs, imaging agents, and targeting molecules to their branches.

Starpharma Holdings Ltd. has developed VivaGel – which is said to be the first dendrimer–based application submitted to the US Food and Drug Administration (FDA) for regulatory approval. VivaGel is a topical vaginal microbiocide developed to prevent the transmission of HIV, genital herpes, and other sexually transmitted diseases. It is currently entering Phase II clinical trials.

In January 2006, FDA granted "fast track" status to VivaGel, a designation that allows products that address serious or life–threatening conditions to move more quickly through the regulatory–approval process.

Researchers at Dendritic NanoTechnologies (DNT), the University of Michigan and Avidimer Therapeutics are also developing dendrimer–based anticancer therapies.

Getting nanocarriers to release their payload

An imaginative array of triggering mechanisms are being investigated to provide greater control over when and how a nanoscaled vehicle will release its drug payload inside a cell. For instance, researchers at Northwestern University and Massachusetts Institute of Technology (MIT) and University of Tokyo have developed pH–sensitive nanoparticles that dissolve when they encounter the acidic pH found inside cancer cells.

Researchers at the University of Melbourne are using gold linings to help their polymer–based nanoparticles to release their enzyme or drug payload on demand. Using a single nanosecond pulse of laser light (which is readily absorbed by the gold nanoparticles), the investigators were able to rupture the walls and release the contents.

Meanwhile, investigators at Washington University School of Medicine have shown that cultured melanoma cells, when subjected to ultrasound for five minutes, took up ten times more liquid perfluorocarbon nanoparticles compared to when no ultrasound was applied. The researchers hypothesize that exposure to ultrasound enhances the exchange of molecules between fat–soluble nanoparticles and lipids (fatty molecules) that make up cell membranes.

Thermal ablation

While novel drug–delivery platforms show great promise, another nanotechnology based method for treating cancer that is gaining a foothold among researchers is to target cancer cells non–invasively – not using drugs, but heat – to destroy malignant cells from the inside out. While the specific approaches vary, they all rely on a unifying concept – first, some type of magnetic nanoparticle is introduced to cancer cells or tumors, and then, an external energy source (i.e., activation via laser light or exposure to an oscillating magnetic field) is applied to generate cell–killing heat that destroys the diseased cells. Researchers are evaluating the use of carbon nanotubes, magnetic iron oxide nanoparticles, gold nanoshells and gold nanocages to function as such "thermal scalpels."

Research institutions and companies involved in this arena include Rice University, Nanospectra Biosciences, MD Anderson Cancer Center, Oak Ridge National Laboratory, the University of California – San Francisco (UCSF), Georgia Institute of Technology, the University of Paris, Triton Biosystems, MagForce Nanotechnologies GmbH, Stanford University, the University of Delaware, and Kimmel Cancer Center at Thomas Jefferson University, among others.

When it comes to cancer, nanotechnology should not be viewed as a silver bullet, and only time will tell whether or not today's promising nanotechnology developments will be able to move successfully through proof–of–concept testing, to full–scale human clinical trials, into approved, commercially available therapies and clinical practice. Nonetheless, the ingenious application of nanotechnology–based concepts, materials and systems is bringing fresh excitement and a lot of hope to the cancer diagnosis and treatment arenas.

Production routes

A range of methods are available or under development to manufacture nanoparticles of various materials. In general, there are six widely used methods for producing nanoscaled particles – on the order of 1–100 nanometers in diameter – of various materials:

- Plasma–arc and flame–hydrolysis methods (including flame ionization), involving the use of a high–temperature plasma or flame–ionization reactor (involving both gas–to–particle and droplet–to–particle methods)
- Chemical vapor deposition (CVD), in which a starting material is vaporized and then condensed on a surface, usually under vacuum conditions
- Electrodeposition techniques, in which individual species are deposited from solution in a precisely controlled manner, to form a nanoscaled surface film
- Sol–gel synthesis, a wet–chemical method that allows high–purity, high–homogeneity nanoscale materials to be synthesized at lower temperatures and milder conditions compared to competing high–temperature methods. (The inorganic or "colloidal" route uses metal salts in aqueous solution, such as chloride, oxychloride nitrate, as raw materials; The metal–organic or "alkoxide" route employs metal alkoxides in organic solvents)
- Mechanical crushing via ball milling, which pulverizes conventional starting materials (such as metal oxides) using conventional high–energy ball mills
- Use of naturally occurring nanomaterials; certain naturally occurring materials, such as zeolites, can be synthesized and modified by conventional chemistry to produce particles with nanoscaled dimensions

In addition to the proven techniques discussed above, additional, promising technologies are emerging to produce nanoscaled particles of various materials. These include:

- Flame or jet–flame reactors, which introduce an additional flame behind the reaction zone, in order to transform the aggregates into spherical particles more effectively
- Improved plasma processes, which are designed to promote more rapid cooling, in order to produce fewer agglomerates
- Sonochemical processing routes, in which an acoustic cavitation process generates a transient localized hot zone with an extremely high–temperature gradient and pressure
- Hydrodynamic cavitation processes, in which nanoparticles are generated through creation and release of gas bubbles inside a sol–gel solution
- Microemulsion techniques, which show promise for the synthesis of metallic semiconductor silica, barium sulfate, magnetic and superconductor nanoparticles
- Bead technologies
- Molecular chemistry

Nanotechnology critics urge caution

Nanomaterials exhibit changed properties due to increased surface/volume ratio, a higher surface energy and a smaller particle size. These altered substance properties may possibly result in different toxicological and ecotoxicological properties to the bulk material. These possible changes in substance properties are currently giving rise to worldwide discussions whether existing exposure measurement technologies and methodologies and toxicological testing strategies are appropriate to assess potential hazards and thus are appropriate to analyze potential risks of nanomaterials. Nanomaterials must be safe for humans and the environment. To ensure responsible use of nanomaterials further safety research is necessary which is currently being undertaken intensively worldwide by industry and public research institutes.

The DECHEMA–VCI working group has already addressed safety issues of nanomaterials at a very early stage in a "roadmap" of safety research which is continuously updated and reviewed. The roadmap gave rise to joint safety research activities of industry and science, such as the EU FP6 project Nanosafe 2 as well as the new project NanoCare funded by the German Federal Ministry of Research and Education (BMBF). This project is studying the potential risks of nanoparticles. It is the most expensive project in the EU in the nanotechnology field with a total financial budget of more than EUR 7.5 million of which more than EUR 5 million comes from the Federal Ministry of Research and Education (BMBF).