ObservatoryNANO

Coatings, adhesives and sealants for the transport industry

April 2010

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Executive Summary

Potential applications of nanotechnology in the transport sector are enormous. The match between the advantages derived from using nanotechnology, such as new, improved or tailored properties, and the market needs in the transport sector, such as more sustainable, safer and economic transport modes, has triggered huge public and private investments in the field.

As a result, a small percentage of today's new cars and aircrafts already incorporate nanotechnology. From nanotubes in cars' fuel lines, to nanoparticles in scratch resistant glass coatings, or as fuel additives to improve fuel combustion efficiency, nanotechnology has started to enter the transport sector. Cars and aircraft have benefited from the development of nanomaterials production technologies (for example providing benefit/cost attractive nanoparticles) and from better characterisation tools and control of processes that are already widely established in industries (e.g. PVD and CVD processes for coatings).

However, nanotechnology has not significantly contributed to lighter vehicle structures and powertrain systems nor to more efficient or alternative propulsion systems. Failing to meet the full set of industrial requirements (e.g. production volumes, automation and/or quality assurance) is preventing further deployment into mass-markets. Maintaining stringent performance requirements (e.g. stiffness, strength, wear-resistance) at a reasonable cost has also limited the application of nanotechnologies to vehicle parts such as windows or bumpers. Rigorous safety regulation in addition to long development times and costs (especially relevant to the aeronautics sector) do not ease the situation.

Looking into the future, nanotechnology will continue to penetrate into the transport sector providing it delivers clear advantages as compared to competing solutions that still offer room for significant improvements. Despite the long lifetimes of transport vehicles (from 10 to more than 30 years) which results in a slow market penetration rate, there are potentially huge advantages that could justify investment in new materials, processes or tools.

Specifically, coatings and surface treatments are likely to continue to be the fastest growing nanotechnology applications both in vehicles' parts and in tooling and production equipment. Coating technologies can benefit from developments in other sectors and can offer clear benefits in the short term; for example increased tooling lifetime). Adhesives and sealants can also be improved with nanotechnology to gain control over the process and to provide special properties to the final result.

Chapter 1 Introduction

1.1 Definition

The following definitions are as reported in the proposed ISO/DTS or ISO/DTR 12802, and ISO/DTS 11751, or as generally reported in the literature.

- Nanotechnology - The application of scientific knowledge to control and utilize matter at the nanoscale, where size related properties and phenomena can emerge.
- Nanoscale - Size range to approximately 1 nm to 100 nm.
- Nano-object or Nanostructure- Material with one, two or three external dimensions in the nanoscale
- Nanoparticle - Nano-object with all three external dimensions in the nanoscale.
- Nanofibre - Nano-object with two external dimensions in the nanoscale and the third dimension significantly larger.
- Nanotube - Hollow nanofibre
- Nanoporous - Structure with pore sizes in the nanoscale.
- Nanoclays - Layered silicates, as for example montmorillonite, in the nanoscale
- Nanocomposite - A composite of different materials or chemical substances in which at least one component includes a nanoparticle or other nanostructure

1.2 Keywords

Nanocoatings, nanoadhesives, nanosealants, automotive, aeronautics, tribological coatings, surface treatments, antiscratch, corrosion resistant, hydrophobia, hydrophilia.temperature protection, antireflecting, photochromic, electrochromic, powertrain, propulsion sytems, structural parts, glass, fuel efficiency, safety and confort, production costs,

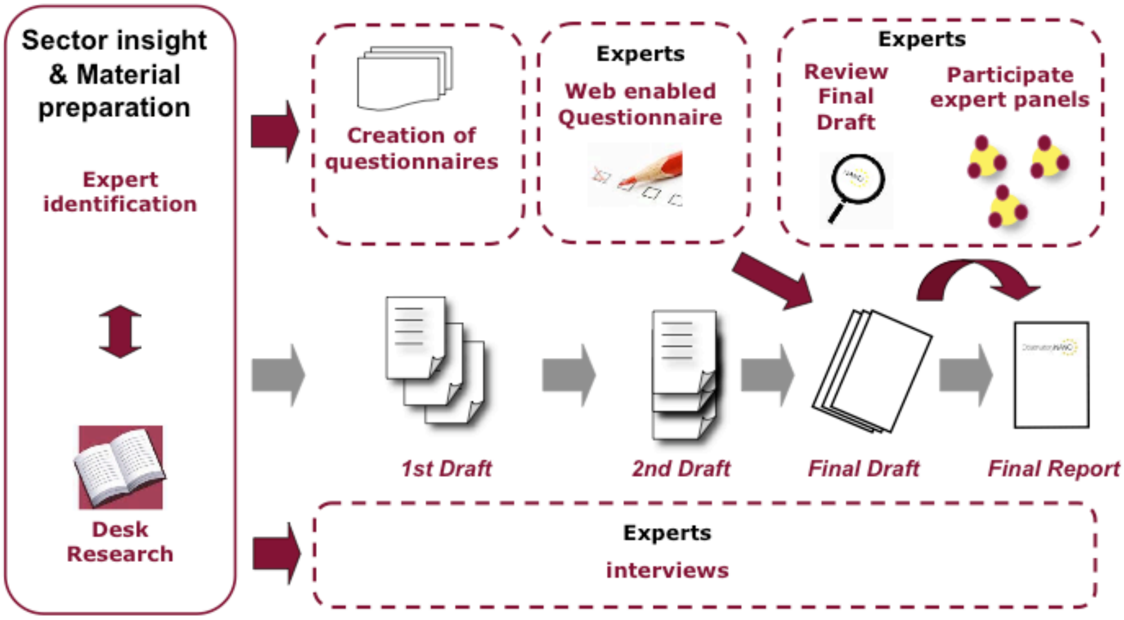
1.3 Overview and scope

In the frame of the ObservatoryNANO project a general overview of the applications and perspectives of the nanotechnology-related products in the tranport was published in 2009. This second report is devoted to the analysis of specific segments where such innovative technologies have a wider potential, namely coatings, adhesives and sealants.

1.4 Methodology

The content of this report is the result of a desk analysis of information from publicly available documents. For an analysis of the present status, future visions and economic perspectives of nanotechnology, expert interviews either personally or via on-line questionnaires were also carried out (These answers to the future predictions and future products are at least regarded as a good indicator of future developments from the present point of view). The final conclusions were also crosschecked with well renowned experts.

The final version of the report was reviewed by a pool of experts selected based on their background and experience.



CHAPTER 2 S&T Aspects

Nanotechnology has proved that it can contribute to materials development, overcoming barriers that could not be controlled before, for example achieving stronger metals or self-cleaning textiles. With the existing applications and the potential ones, nanotechnology can bring an important value to the transport industries, mainly the automotive and aeronautics sectors.

The transport industries are indeed among the innovation drivers in Europe. Statistics published recently by ACEA (European Automobile Manufacturers' Association), position the automotive industry as the largest private investor in R&D in the EU, with €32.8 billion of annual investment in 2008. The aeronautics sector is also a R&D-intensive industry, spending an important part of its turnover in research and development activities, reaching 14.4% in 2007.

This is why many nanotechnology developments are or should be aimed at transport applications, and many companies in the sector are actively promoting research or even developing their own in-house research groups.

Note: The terms, as the functionalities, are often mixed:

It is common that a nano-enabled coating can offer combined properties, also mixing coating, sealant and adhesive properties. For example, certain nanocoatings that serve to functionalize the bare surfaces of given material, making it more receptive to further modification, may also function as an adhesive undercoat. A second example would be special additives in adhesives used for automotive assembly, that can offer both more control on the curing process and corrosion resistance.

That is why often it might be difficult to categorise into nanoadhesives, nanosealants or nanocoatings and they would be rather united under the umbrella of the **nano-enabled surface treatment coatings**.

2.1 State of R&D and nanotechnology impact

Nano-enabled surface treatments, such as **nanocoatings, nanoadhesives and nanosealants** can change the surface qualitites of the materials, addressing technological improvements for the tranport industries.

The R&D in nanotechnology for automotive and aeronautics, such as any application aimed at these sectors, has to contribute to one of more of these objectives:

1. Increase fuel efficiency and reduce environmental footprint;
2. Increase safety and comfort;
3. Reduce production costs; and
4. Develop new, competitive products (e.g. hybrid vehicles, fuel cells, electric cars, etc.)

The developments with the objective of improving the **fuel efficiency and environmental footprint** are mostly technologies which reduce the vehicles' overall weight or minimize the mechanical losses in the transmissions. The most important of these technological developments, which may be addressed with coatings and other surface treatments, is to increase the mechanical properties of materials in the vehicles' powertrains in order to avoid energy losses. This can be achieved in the surfaces using **nanoscale layers such as metal carbides and nitrides, diamond-like layers** (also known as DLC) **nanostructured thermal spray coatings** or **sol-gel coatings**, increasing the scratch resistance, the hardness, and the tribological properties of the materials. Additionally, for applications where thermal and chemical properties are necessary, **nanoscale layers of coatings with metal oxides, carbides and nitrides or organic self-assembled monolayers** can offer solutions. For the automotive and the aeronautics sector, these coatings are especially relevant to prevent corrosion for metal surfaces (e.g. steel) and high temperature protection in engines and turbines.

There are also a number of developments aimed at increasing the passengers **safety and comfort.** The two most important, where nanotechnology-enabled surface treatments can contribute, are related to increasing visibility and the visual comfort of drivers; **nano-coatings based on fluorinated hydrocarbons and fluoroalcylilane** applied on surfaces make them acquire wetting reaction properties such as hydrophobia or hydrophilia. For enhancing the optical properties, **solutions based on nanoporous silicon dioxide layers or tungsten trioxide layers** can transform surfaces into anti-reflecting, photochromic or electrochromic; these properties are useful in panes or even solar cells for example.

Regarding the **reduction in production costs**, nanotechnological coatings can be applied to harden cutting tools, moulds and dies used in materials' processing machines, thus increasing their lifetime. The technologies for this use are mainly **nanoscale layers such as metal carbides and nitrides, diamond like layers**, nanostructured thermal spray coatings such as in the scratch-resistant coatings mentioned above. To optimise the joining processes (for example in the assembly lines of the automotive industry), nanotechnological developments can be used, such as **nanoscale coatings with iron oxides** to increase the control over adhesives. These surface treatments can achieve, for example, bonding and debonding on command. Additionally, **nanoclays' layers** can be used **as barrier films for adhesives and sealants**.

Last but not least, there is also nanotechnology-treatment research to be applied in **new products for the transport industries**. The most discussed new product in the sector automotive are electric vehicles, which are expected to burst into the market over the next few years. The electric components in the electric vehicles have to be extremely effective and the electromagnetic compatibilities and risks have to be controlled. **Nano-enabled coatings with metal multilayers, indium-tin-oxide-coats or silicon dioxide** can provide electronic, electric and magnetic properties, where they would be necessary. Indium oxide applied in windows or display screens, for example, would be transparent and can have an anti-static effect. It is also reported that adding nanotubes or other metallic nanoparticles, and even polimeric coatings, the magnetic properties can be tailored to the specific requirements. For aesthetic purposes, several **nano metal oxides** can be also used as pigment for coatings.

Summary of main functionalities of nano-enabled adhesives, sealants and coatings in transport:

- Improved mechanical properties
- Improved wear resistance
- Corrosion resistance
- Temperature resistance
- Conductive shielding
- Fire/flame retardant properties
- High performance, structural adhesives
- Optical properties in surfaces
- Special colours and visual properties
- Transparent sealants

2.2 Additional demand for research

The most important challenge of nano-enabled surface treatments for their application in the transport industry is technology for scaling-up of production, from the lab to industrial use. Namely, the two most important issues that the industry demands to be improved are production volume and cost.

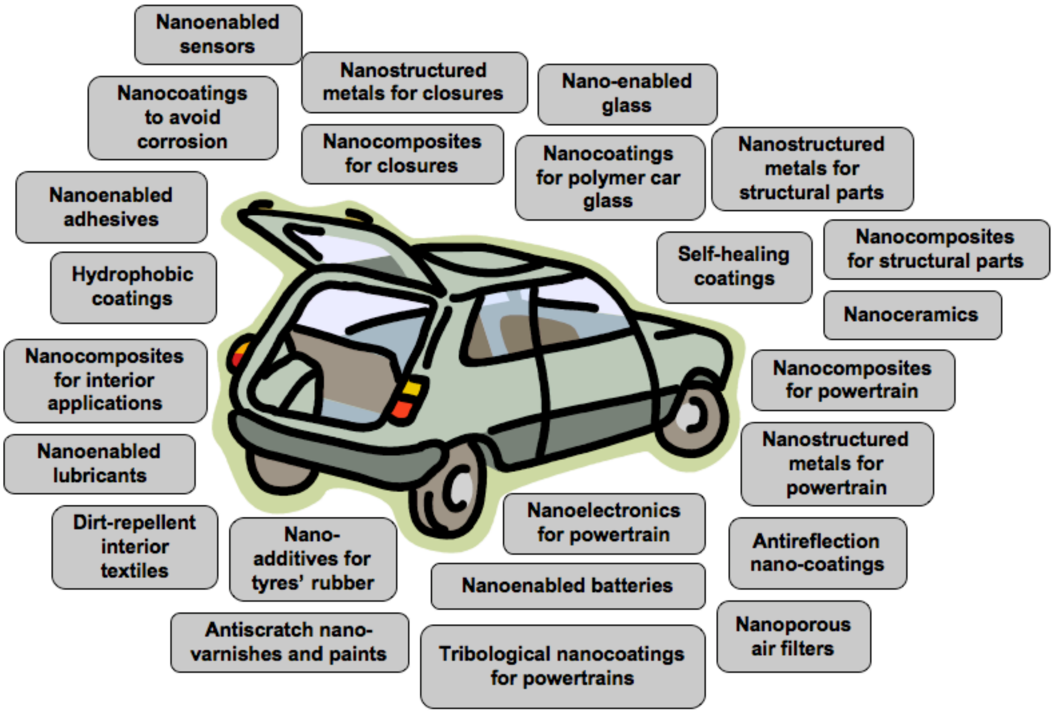
> Production volume is especially relevant for the automotive industry, where large numbers of parts have to be produced, often of more than 1 thousand/day (for example the best seller in 2007, the Peugeout 207, sold 437.505 units that year).
>
> In aeronautics, regarding the parts' sizes and production volumes there are of course differences between business jets/small aircrafts and large civil aircrafts. While companies such as Airbus and Boeing may produce around 400 – 500 aircrafts per year, business jet companies may produce two to three times this number. In the aeronautic sector, the size of the parts to be treated is significantly big. In order to coat or apply surface treatments in these parts, large equipment and special rooms are necessary, often with special condicions of temperature, pressure (even vacuum). This implies that in many cases the process is simply not possible, and in others the costs of the investments are excessive for most budgets.
>
> Additionally, new production technologies to apply the nano-enabled surface coatings have to reduce the extra cost the treatment is adding to the final part. The automotive industry is known for dealing with big volumes, having high efficiency, but maintaining low production costs. In order to introduce successfully nano-enabled products in tomorrow's cars, they have to ensure all these qualities.

Advanced modelling tools are also required for these processes. Specific software that can simulate and model precisely the processes remains necessary, to be able to optimise all the parameters for each specific case. Such tools are often also involved in the standardisation processes of governments or companies to allow for the acceptance or adoption of products; therefore they have the potential to accelerate the market penetration of the nano-enabled products.

3.1. Applications and perspectives

As mentioned in the previous chapter, the transport industries aim at decreasing weight while increasing engine efficiency and overall performance of the vehicles in order to reduce their CO_2 footprint and therefore, energy consumption. Consequently, research activities and new applications are focused on using lighter materials with improved performance for lighter vehicle components, increasing engine efficiency via reducing energy losses due to friction, or developing more efficient combustion systems, and also increasing the safety via improving the mechanical properties of various parts, etc.

The application of nanotechnology in vehicles can be present in almost all the systems and parts: advanced powertrain; using new energ; reducing car weight; enhancing material functions; increasing comfort degree & flexibility; and raising cost efficiency. The figure below shows some examples of possible applications of nanotechnology in a car, including several types of surface coatings.



Surface treatments are key in both the automotive and aeronautic sectors. Nano-enabled solutions can contribute to improved safety, comfort, and competitiveness of many vital parts in cars and aircrafts.

In **exterior parts**, nanocoatings can be used with different purposes. One of the most appreciated functionalities of nano-enabled paints or coatings is the fact that they can reduce the manteinance costs, increase the safety, and even increase the aerodynamic properties. For instance, Air Canada explored replacing paints by nanocoatings and expected a weight reduction of about 350 pounds resulting in fuel saving costs of more than $25,000 per year. One important issue is that the appropriate coatings can reduce the manteinance and operations cost. For example preventing the ice formation in the aircrafts and the the use of (ceramic) pigments, which do not degrade due to UV radiation (thus avoiding the need for aircraft re-painting).

Regarding the prevention of ice formation (with each de-icing procedure costing around $10.000), nanostructured coatings have been reported (though not marketed) that can repel water, prevent corrosion, and reduce ice formation on optical elements and aircrafts.

In **powertrains and propulsion systems,** nano-enabled coatings can upgrade the surface properties of the parts; for example improving their corrosion and wear resistance. This has an impact on the durability of the partsresulting in a reduced energy loss.

Besides improving materials performance, nanotechnology can also provide alternative solutions (e.g. aluminium nanostructured coatings) to well-established, but not environmentally friendly, coatings such as coatings such as hard chrome electroplating, produced from a plating bath that contains hexavalent chromium, used for corrosion protection in aeronautics.

Coating also find applications in the **interiors,** especially in the **textiles**, as they can upgrade them with properties such as flame-retardation, dirt-repellence, air-filtering, etc. These properties have impact in the safety and the comfort of the users/clients.

The **glass** parts assembled in cars and aircrafts can also be improved thanks to nanotechnology surface treatments:

In car glass nanotechnology-enabled coatings can have an important impact; for example with electrochromic, antiglare coatings for mirrors, dash panels and glasses, hydrophobic (anti-fog) coatings for mirrors and glasses, solar heat control glass, switchable glasses (for sun roofs that can select the transparency of the glass), and self cleaning glass. An important driver in the transport sector is weight reduction and here nanotechnology is also contributing to make possible the substitution of mineral glass by polymer glass, especially polycarbonate, which could reduce a car's overall weight by up to 20 kg, depending on the car. Nanocoatings could protect the surfaces from scratching, abrasion and climate influence (e.g. extremely hard aluminium oxide nanoparticles coating).

The aeronautics sector is also expecting to benefit (or lead) these developments but will also have higher requirements (which may justify cost increases not acceptable in other sectors). Moreover, developments in this area could benefit from developments in windows protecting infrared sensors in missiles.

Last but not least, the **production technologies** can also benefit from the advances in nano-enabled surface treatments. Cutting tools, and other material processing technologies tools such as moulds and dies, can have their surfaces enhanced to allow for a longer lifetime, thus avoiding the costs for new ones and reducing the down-times necessary for exchange, and increasing the quality of the parts producted. Also in the assembly processes, special treatments and adhesives can provide exra control over the results of the processes and for example reduce the costs of inspection.

3.1.1 Tribological coatings

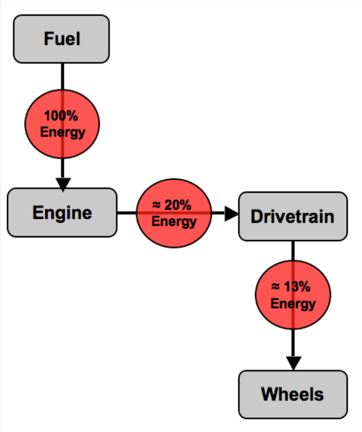
Tribological coatings are coatings that are applied to the surface of a component in order to control its friction and wear. They can be single phase, multi-phase or composite coatings consisting of materials such as carbides (e.g. WC, TiC, SiC), nitrides (e.g. TiN, CrN), metals (e.g. W, Ti, Mo) or ceramics (e.g. Al_2O_3, Cr_2O_3). These coatings can be applied to all kinds of substrates (most of the substrates to be protected are usually metallic and/or ceramic). These coatings can be processed mainly by two different methods, thermal spraying and vapour deposition processes.

Tribological coatings play a key role in the performance of internal mechanical components of a vehicle, such as the engine and power train. Besides, they are also key elements of cutting tools, moulds, dyes, and machinery in general. By reducing wear and friction tribological coatings increase the lifetime of the working material at the same time they reduce the dissipation of energy as heat, thus increasing the efficiency of the vehicle.

When applied to machinery and tools, tribological coatings can reduce (or eliminate) the need for lubricants (dry machining), enable higher material removal rates, increase cutting speeds, reduce maintenance cost or reduce processing cycle times (e.g moulds).

Nanotechnology and use of new materials for tribological coatings would bring further improvement in lifetime, reliability, damage tolerance and safety via self-sensing and self-healing.

> The importance of friction losses in the car's driveline
>
> As shown in the figure below only about 13% of the energy available in the fuel is available to drive the wheels. The losses are mainly due to engine inefficiencies and mechanical losses in the driveline.



There are technologies, mainly **coatings**, which can reduce the friction and therefore the energy losses. One example would be carbide-based wear-resistance coatings for cylinder walls, pistons, bearings and other engine components (crankshaft, valve train, etc.).

The applicability of specific coatings in these complicated parts is sometimes associated with manufacturability problems. For example, in the pistons, it has to be taken into account that their different rings need different types of coating: while the top compression ring usually has a wear resistance coating such as flame-sprayed molybdenum, the second compression ring is not normally coated and the bottom ring used to have a chromium plating, to improve the oil retention. Another example in the powertrain is cylinder bores: most of them have inner radius of 70-110 mm and such dimensions call for special tooling for applying the coating.

Reducing friction and wear in engine and drive train components is a vital issue for automotive manufactures, and it is estimated that could save the US economy as much as US $120 billion per year.

Thermal spraying processes, such as atmospheric plasma spraying and high velocity oxygen fuel, and vapour deposition processes, such as physical vapour deposition (PVD) and chemical vapor deposition (CVD) processes, are the common processing technologies for tribological coatings. The most important challenge to overcome in relation to application of tribological coatings on vehicle parts is the chamber sizes for large parts and accordingly long processing times where vacuum is required.

3.1.2 Adhesives and sealants

Adhesives and sealants are two chemical specialities similar in formulation but by definition different in functionality:

Adhesives are substances used to join two or more surfaces. Compared with the different joint techniques in the automotive and the aeronautic industry, adhesive bonding offer several advantages; it reduces steps in the manufacturing processes, which ultimately results in reduced cost and ofen adds other necessary properties, such as corrosion protection (very important when joining disimilar materials) or sealing. In fact, they are routinely used in both structural and non-structural automotive applications.

Nanotechnology can offer more control over the adhesive application process, and improved properties of the final product. As example, iron oxides nanoparticles have been reported to be developed by Degussa (today Evonik) for additives in adhesive formulations to allow for bonding and debonding on command.

Nanoadhesives inspired by nature

During decades investigators have tried to mimic some of the solutions found in nature to achieve reversible adhesive properties.

For dry adhesion, the key animal taken into consideration is the gecko, as they have the highest adhesion forces. The ability to climb stiff walls comes from the micro and nanoscale elements found in their feet. On the sole of the gecko's toes there are some one billion tiny adhesive hairs, about 200 nanometers in both leght and width. The scientists have studied how these feet have evolved, to be able to replicate it. The application field is mainly in protective foils, packaging and reusable adhesive fixtures, in a diverse range of surfaces.

For wet adhesion research mussels provide an example, as they can be found in water environments, adhered to rock and many different surfaces. And as with the gecko, the property is reversible. The studies have established that the mussel secretes specific proteins with unique adhesion properties. In a report in the Nature magazine it was reported that in coatings with nanopatterns mimicking the gecko with a mussel-mimicked polymer coating, the adhesion was significantly improved.

Sealants are applied to the surfaces of other materials to prevent or minimise the absortion or penetration of liquid or gases. In transport, the sealant properties are often combined with others (e.g. adhesives, water-repellent, anticorrosives, etc.) and therefore often treated as surface treatments in general.

The rheology in the sealants is strongly affected by the particle size and distribution. That is why nanotechnogy can offer important improvement opportunities for these products. Most nanosealants developed take the form of nanocoatings, nanofilms or nanopaints, others are in the form of polymer-matrix nanocomposites. Another important property, very useful for the use in car glass for example, is that nanosealants can be made totally transparent or translucent due to the small size of their particles (the waveleghts of visible light are 400-70 nm).

2.3 Current situation within the EU

Europe's position in the development of nanocoatings, nanoadhesives and nanosealants is strong, and only comparable with the United States of America. There are important research groups and companies in the EU developing nanocoatings and nano-enhanced surface treatments for transport, Further, important European companies, such as BASF or Henkel are often leading developments and applying nanotechnolgy in their products.

Some relevant EU projects:

CORRAL (FP7 2008-2011)

Corrosion protection with perfect atomic layers (CORRAL) aims to develop high density defect-free ultra-thin sealing coatings with excellent barrier properties and improved corrosion resistance. The application areas include high precision mechanical parts, aerospace components and gas handling components.

MUST (FP7 2008 – 2012)

Multi-level protection of materials for vehicles by smart nanocontainers (MUST) is a project which aims to provide new technologies based on active-multilevel protective systems for future vehicle materials. A multi-level self-healing approach will combine - in a same system - several damage prevention and reparation mechanisms, which will be activated in response to environmental conditions. For details please visit http://www.sintef.no/Projectweb/MUST/

APPLICMA (FP7 2008-2011)

APPLICMA is the acronym for the FP7 project called Development of wear resistant coatings based on complex alloys for multifunctional applications. Please visit http://www.applicma.eu/applicma/ to get detailed information about this project.

MATECO (FP6 2004-2007)

Within the scope of this project (New Coatings Based by PACVD for Corrosion protection) smart multifunctional coatings based on [Is-O-N] materials have been developed.

Nano-enabled coatings, sealants and adhesives for the transport industries are often developed in parallel to their applications in other sectors (e.g. construction, textiles, etc.). For example, self-cleaning nanocoating products for the automotive industry are likely to be specifically formulated for this sector, and will exhibit properties that are different from the self-cleaning nanocoating products designed for construction/architectural applications.

This is why it is important to understand the sectors in general, with their drivers and their boundary conditions:

2.4 General market description

Automotive and aeronautics industry are linked in their basic objective; they both develop products mainly targeted at transporting persons and goods. Because of this, both sectors share the following characteristics:

- Performance requirements (e.g. stiffness, strength, wear-resistance);
- Stringent certification requirements derived from transporting human beings;
- Industrial requirements (e.g. production volumes, automation and/or quality assurance); and
- Long development times and costs.

While performance requirements may be the main driver for the introduction of nanotechnology in these industries, the other characteristics are often challenges to be overcome in future developments.

2.4.1 Automotive

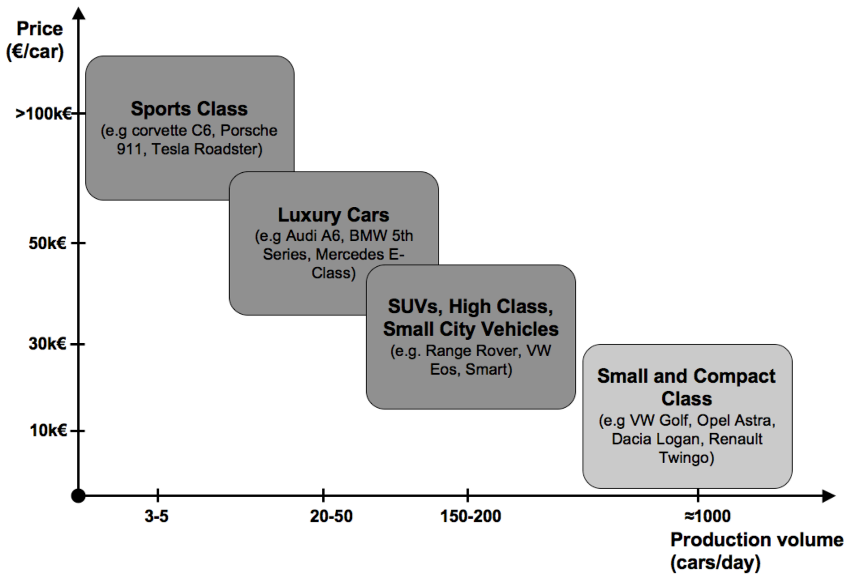
The turnover of the world automotive industry approached a peak of €2 trillion in 2004, equivalent to the 6th largest economy in the world (OICA International Organisation of Motor Vehicles Manufacturers). In Europe, the automotive industry is without any doubt a powerful major contributor to the economy, generating turnover of €551 billion in 2008, representing around 5% of the Europe’s gross domestic product (GDP).

The European automotive industry produced 17.1 million passenger cars in 2008, equating to 32% of the worldwide vehicle manufacturing (ACEA). This number has to be compared with the total number of vehicles in use in Europe, estimated at 260 million (Lux Research, 2008).

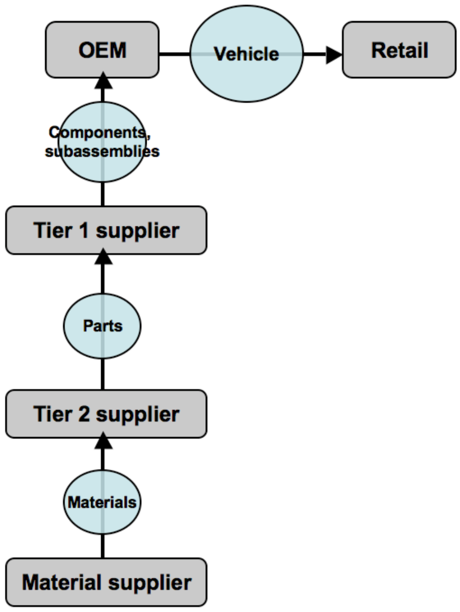
The growth of European automotive markets has been flat in recent years (with the exception of the new Member States). On top of that, since the first half of 2008, when a total of 8,5 million cars and light commercial vehicles were sold in Europe, the production and sales have dropped drastically. The global financial economic crisis has had a dramatic effect on the European automotive industry; new passenger car registrations in Europe fell by 7.8% to 14,712,158 units in 2008, recording the sharpest decline since 1993. The common opinion is not optimistic in general and accepts that this declining situation will continue over into 2011 at least.

Regarding the markets for the cars produced in Europe; in January 2009 there was a shift when China overpassed USA with 130.000 units becoming the largest automotive market for the first time in history (Goutai Junan Consulting, 2009). China has not only become a location for low production costs but also the most important market, because even though the motorisation index is 10 times lower than in Western countries (e.g. in China 60 cars/1000 inh. while in USA 750/1000 inh.) it has a population of greater than 1300 million.

The main products of the automotive industry, that is the vehicles, can be divided according to the differences in terms of prices and production volumes, as simplified in the following figure:



Most of the vehicle parts are manufactured by specialised suppliers. These suppliers are organised in multiple tiers, as in shown the Figure below. While Tier-1 suppliers take responsibility for developing, producing and refining complete components or modules of the car (e.g. cooling, seating, tyres), Tier-2 provide them with the parts required to manufacture the components (e.g. cables, connectors) and Tier-3 provide them with the necessary materials (e.g. aluminium sheets, steel profiles). The car manufacturers, usually known as OEMs, assemble the vehicles and produce some strategic parts.



2.4.2 Aeronautics

The European aerospace industry is a high-tech industry which develops and manufactures a broad range of products: civil and military aircraft, aircraft-engines, helicopters, launchers and satellites, unmanned aerial vehicles, missiles, as well as systems and equipment. In 2004 the European aerospace industry employed about 445,200 directly and had a turnover of €77 billion. It invested about 14.4% of its turnover in research and development. Exporting more than half its output, the industry provided a positive trade balance of €31.8 billion for the EU as a whole.

Aircraft development and production is by far the largest component of the aerospace industry (with space activities accounting for less than 10% of the activities). In total, the European aerospace industry accounted for around € 26 billion value-added (out of above € 90 billion in production value) and around 2.200 enterprises in 2003. Nevertheless, the market is dominated by a small number of large firms with more than 1.000 employees that account for 3% of the total number of enterprises but for above 80% of the turnover while SMEs account for just 7% of the industry added-value.

The success of the industry depends on twin pillars, civil (64%) and defence (36%); they are both complimentary and mutually dependent. Operating in civil and defence markets allows companies to share know-how, skills and products, and benefit from the economies of a broad product range. Both areas rely on the application of advanced technologies while serving private and public customers with different needs. For the long-term, forecasts indicate an increase in overall growth in the civil market while the defence market growth is expected to be flat.

In Europe three countries (Germany, France and the UK) account for more than 80% of the added value and more than 85% of the turnover. The global aerospace sector was formerly dominated by US companies, who traditionally accounted for two thirds of the industry's global turnover. Largely due to the success of Airbus, this picture has changed in recent years in favour of the European aerospace industry, which accounted for 36.4% of the €284 billion in global sales in 2007 (US: 51.1%). Europe is claimed to be a world leader in large civil aircrafts, business jets, helicopters, aero-engines and defence electronics.

However, emerging markets such as China, Russia or India are expected to play an increasing role in civil aircraft manufacturing and assembly initially on the business jet sector and the single-aisle aircrafts lately. This growth will be fuelled by low-cost labour (leading to manufacturing costs around 20-25% cheaper for typical aircraft structures), the purchase of more than 3.500 planes (roughly 15% of global demand) over the next 20 years and the related offset requirements set by governments (by which local suppliers must be involved in aircraft manufacturing) and know-how gains derived from existing alliances between western OEMs and local suppliers.

2.5 Drivers and barriers

2.5.1 Drivers

Ecology and fuel efficiency

The pollution generated by transport has become an important concern for both citizens and the governments. In Europe, road travel is the second biggest source of greenhouse gas emissions, after power generation; passenger vehicles are responsible for releasing 12% of the EU's total CO_2 emissions into the atmosphere. Therefore, **reducing the environmental footprint of the vehicles** has become an important driver in the automotive industry.

Even with the significant improvements in fuel efficiency related technologies, the CO_2 emissions rose by 26% in the period 1990-2004, due to the traffic increase and bigger car sizes. This is driving the automotive innovations mainly towards reducing vehicle weight and new powertrain systems, mainly Plug-in Hybrid Electric Vehicles and "pure" Electric Vehicles.

ACARE's JTI Clean Sky has set a target of 50% CO_2 emission reduction to be achieved by 2020 breaking them down into improvements in several areas; about 20 to 25% should come from airframes (e.g. weight reduction and aerodynamics), about 15 to 20% from engines and 5-10% from air traffic management.

The environmental impact of aircraft and engine manufacturing are negligible as compared to the energy consumed during use. Airbus reported that energy consumption during use is more than 99% of the total energy consumption over the complete aircraft lifecycle. The A380, in service today, consumes less than three litres per 100 seat kilometres. In just the last 40 years, technological advances have reduced fuel consumption and CO_2 emissions by 70%, noise by 75%, and unburned hydrocarbons by 90%, while increasing the number of people moved per take-off or landing slot and setting unprecedented levels of comfort.

During flight aircraft engines emit CO_2, NO_x, SO_x, water vapour, hydrocarbons and particles (with particles basically consisting of sulphate from sulphur oxides and soot). Besides, the introduction of legislation to restrict the use of certain substances (e.g. CrVI, Lead or Cadmium) has led the aerospace sector to develop alternative (and environmentally friendly) materials.

Beyond purely environmental drivers for reducing CO_2 emissions, the fact that fuel is the largest cost for all airlines (between 30% and 50% of direct operating cost) is probably the strongest driver for lighter aircrafts and cleaner propulsion systems. As compared to the economical value of 1.5 to 3 US$ for pound saved in the automotive sector, the value of weight saving in the airborne commercial transport has been estimated at around US$ 300 per pound saved (getting to as much as US$ 3000 for fighter aircrafts).

Probably as important as the fuel economy, aircraft designs aim at maximising the payload in relation to cost. As an indication, the weight of a fully loaded aircraft taking off could be broken down as follows: 20% is payload, 40% is structural weight and 40% is fuel.

Safety and security

Reducing fatalities and increasing comfort is also an important driver for the automotive industry. The car users demand more and more safety control (even assisted to autonomous driving) and at the same time more comfort and commodities inside the vehicle mainly based on electronic systems.

From a safety and security point of view, the aeronautics business remains extremely conservative and risk averse making it difficult for nanotechnology applications to be integrated into new products. This is even more prominent for civil aircraft makers. Carrying passengers puts extreme demands on the qualification process of new technologies. The material has not only to prove its supremacy, but also its durability, whereby the physical properties are maintained under extreme conditions and on a long-term basis. In addition, a production process suitable for an industrial scale and a reasonable price/performance ratio is mandatory.

Competitiveness of the European industry

The automotive industry has always been very competitive. Suppliers fight to be able to produce a specific part, because due to the large production volumes, it can mean a big part of business for that company over many years. Since the end of 2008, **competitiveness** has become even more important with the global financial and economical crisis hitting the sector. Companies are pushed to innovate to ensure their position in the future market. Plants, companies and governments are competing to produce new products, largely electric cars or their associated systems

Finally, cost reduction is always an issue in such a cost-competitive industry; maintenance, Repair and Operation (MRO) represent a huge cost. According to the TATEM project, maintenance activities can account for as much as 20% of an operator's direct operating costs and have remained at this level for many years. For example, it has been estimated that line mechanics spend 30% of their time trying to access information to diagnose and rectify failures, and errors can impact aircraft safety; for example a standard de-icing procedure of a large aircraft could cost US$ 10.000.

Main drivers and their directions:

Drivers	Directions
Reduce environmental footprint	Fuel efficiency technologies Weight reduction New powertrain systems
Safety and comfort	Electronic systems to control safety and comfort
Competitiveness	Innovativeness New products, such as electric vehicles Cost reduction

2.5.2 Barriers

On the other side, there are barriers for the new technologies to be introduced in the automotive industry that have to be taken into account, such as stringent regulations, overcapacity in the automotive production plants, and the lack of the communication between the high-end scientific community and the industry.

Stringent standards and regulations

The automotive industry is highly regulated (over 90 European directives), particularly in the fields of safety and environment, and the stringency of such regulation is becoming a driver for technological change in the sector, although it also adds to the cost of production. Unlike in other markets, the cars to be sold in Europe have to pass stringent mechanical and chemical tests, and this has positive repercussions in the quality of the products and their safety, but also implies that the minimum time to develop a car passing all the regulations and standards in around 5 years.

Long development times required for the design and development of new aircrafts (approximately 10 years) and their production (10 years as well) lead to a significant delay between the development of conceptually new technologies and such developments entering the market. For new developments, the long-term orientation of R&D and the risk involved makes it hard for SMEs to compete with large firms (despite having more flexibility and, probably, creativity). The fact that aircrafts lifetime in western countries is of around 30 years (with many of them then being sold to airlines in developing countries) also hinders the penetration of new technologies into the market.

For aeronautics, one of the principal obstacles to the application of new materials noted by the aerospace industry are the long timeframes needed to test and validate their reliability. Given its stringent regulatory, quality and safety requirements, there are very detailed certification procedures to meet airworthiness standards for aircraft and components. In Europe, EASA can act as a single entity and take binding decisions. Given the importance of this issue for Europe's major aerospace companies, industry has been closely involved in setting up the new EASA structures. The certification process typically lasts 18 to 24 months.

Overcapacity in automotive plants

Another barrier is that the automotive production plants are normally designed to cover the maximum demand, which leads to an almost-always situation of **overcapacity**, especially since mid 2008 because of the reduction in production. As the overcapacity implies an important resistance to investments and product modifications, it affects the uptake of new technologies in the automotive industry.

Gap between scientific and industrial communities

As in any other industry susceptible to use high-end research products, there is sometimes a **lack of understanding between the industrial and the scientific communities**. This is because in the high-end research (e.g. biotechnology, nanotechnology), the research is often not intended to address any specific need, but driven by the researchers to find out "what is possible". This creates a big distance between the research and the market applications. This gap has normally to be overcome with specific programmes in the research centres.

Additionally, the lack of availability of nanomaterials for mass industrialisation (e.g. cost-effective, reliable, reproducible, etc.) may hinder their market penetration even if their added value is demonstrated in real components. Thus, industrialised production processes need to be developed thereby reducing overall costs through the increase of volume produced.

Another barrier identified concerns the still unknown effects of many nanomaterials on the environment. This covers workers health and safety, environmental impacts resulting from accidental damage, and recycling of materials containing nanomaterials

Main barriers and their effects:

Barriers	Effects

Stringent regulations	**Long development times**
Overcapacity	**Resistance to equipment investments**
	Delays in the adoption of high-end technologies
Gap scientific-industrial communities	**Processes not yet adapted to industrial use, regarding environmental and heath protection**

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2.6 Boundary conditions

The boundary conditions related to the parts produced for transport are mainly related to quality, recyclability and easy use and manteinance.

Quality and performance requirements

Both automotive and aeronautic industries demand from their suppliers high standards of quality. The quality relates mostly to supplier stability and performance requirements of the final product. The performance requirements will depend on the part or system being supplied. For example:

- For structural car parts stringent functional requirements such as crash resistance, fatigue and static performance are necessary to be able to comply with the European standards required to commercialise vehicles in the EU. All these standards and regulations respond to passenger protection measures, and are aimed at reducing the number of fatalities in the European roads.
- External car body parts also have to have high quality surfaces (Class A), corrosion resistant and be UV-light resistant.
- For large aircrafts flying at high altitudes, fuselage pressurization poses more stringent requirements to the airframe structure so as to ensure passengers comfort (and safety) during flight.
- For car hoods, pedestrian safety is as well an important boundary condition for design. In Japan and Europe, regulations have come into effect in recent years that place a limit on the severity of pedestrian head injury when struck by a motor vehicle. This is leading to more advanced hood designs.
- New aircraft adhesives, for example, must be qualified with long, stringent tests such as fluid immersion, accelerated ageing, high, low and cyclic temperature testing followed, if successful, by structural fatigue and static buckling tests on bonded structure.

Due to the stringent quality and performance requirements, the introduction of new materials needs to undergo a long and expensive certification processes, as explained in the previous chapter.

Recycling

Ensuring the recyclability of all the parts is more and more important in the transport industries, due to the stringent environment regulations surrounding them.

In some cases, the producer has to face the costs of recycling their own parts, and therefore the "design for recycling", that is designs targeted at allowing easy, economic material recovery are encouraged.

Repair and maintenance

Both for automotive and for aeronautics, an important boundary condition is to ensure proper and economic maintenance, repair and operation throughout the part or system lifetime.

Thus, in many cases, difficult access for inspection and repair will set much stronger requirements on the part (e.g. through fail-safe approaches) and possibly limit the potential benefits of introducing new materials (e.g the theoretical minimum thickness that would realize the required weight savings may not even be possible due to safety requirements).

2.7 Economic information and analysis

Surface treatments such as coatings, adhesives and sealants are widely used in tranport.

According to the recent publication in ReportLinker, **the current market of coatings in the automotive industry is estimated to around US$133million, rising to US$330 million by 2015.**

The total coating market for the aerospace sector had been estimated at about $ 150 million in 1999, $ 215 million in 2001 and expected to increase by 50% until 2010. Other sources claim that the paint market alone for commercial aircraft is around $ 300 million per year. In the U.S., commercial aviation accounted for more than 70% (including general aviation) of the market. OEMs accounted for 65% and refurbishers for the remaining 35% in the commercial aviation sector. Compared with the automotive, the market for aeronautics' coating could be less affected by the economic recession and aircraft production slowdown because existing aircrafts need to be periodically repainted (e.g. decorative coatings usually last between 5 to 6 years).

Adhesives are increasingly used in modern automotive production. In modern vehicle construction practically all components can be bonded using industrial structural adhesives. The benefits of structural adhesives are even more important when dealing with a mix of lightweight construction materials, where bonding would not be possible without adhesives, or could have other problems such as corrosion. Cost-saving, for example the replacement of mechanical fasteners with adhesives, provide an additional advantage. According to specialised sources, a medium-class vehicle requires welding at approximately 5,000 points, each costing around five cents. More than half of these can be replaced by adhesive joins, saving around €70 per vehicle. In addition, using one kilogram of adhesive reduces the vehicle weight by 25 kilograms and adhesive-bonded vehicle bodies are more rigid, allowing thinner sheet metal to be used.

In aeronautics, adhesive bonding of aircraft primary structures has been in use for over 50 years and is still in use on current aircraft projects as a direct alternative to riveting. Bonding of stringers to skins for both fuselage and wing construction and of metallic honeycomb to skins for elevators, ailerons, tabs and spoilers are the main uses for adhesives.

Nanotechnology market estimations in transport

Nanotechnology enabled products have an enormous market potential in the transport sector, even thought it might often be difficult to identify them as "nano".

For the automotive market, it is often estimated to be included in 70-80% of the total automotive applications by 2015. Regarding market forecasts, different estimations have been published in the recent years, and even though the broad range between the estimations, the lowest one (and probably the most accepted one) is the impressive amount of more than US $6 billion by 2015.

Several market forecasts regarding nanotechnology in automotive:

Source	Estimation
Lux Research (2004)	8.500 million US$ (2004)
Frost & Sullivan (2005)	1.276 million US$ (2008) 1.526 million US$ (2010) 6.460 million US$ (2015)
RNCOS (2006)	Close to 7 billion US$ (2015)
Helmut Kaiser Consultancy (2007)	8.600 million US$ (2007) 54.200 million US$ (2015) 137.400 million US$ (2020)
Institute of Nanotechnology (2007)	1.110 million US$ (2007) 6.460 million US$ (2015)

In fact, it is reported that only paints and coatings accounted in 2008 for about 43 per cent of the entire nanotechnology market in the automotive industry.

General market estimations for nanoadhesives and nanocoatings

The entire market of nanoadhesives and nanocoatings has been estimated by BCC Research in a report presented in 2010 as:

- 2010: Around 3.000 million US$ for nanocoatings and around 50-100 million US$ for nanoadhesives
- 2015: Around 18.000 million US$ for nanocoatings and around 1.000 million US$ for nanoadhesives

These estimations include nanosealants, as explained before, because they are normally involved in other categories due to their combined functionalities.

According to the results of the VDI TZ-Expert Panels in 2005/2006, the world market for nano-enabled tribological layers was estimated at €1-5 billion EUR in 2006, with a value of €1-5 billion EUR in 2006 also for corrosion protection nanocoatings.

Nanoadhesives and nanocoatings for transport

Among all possible applications of nanoadhesives and nanocoatings (construction, textiles, etc.) it is foreseen that the transport industries will have an important share. Automotive and aeronautic sectors are often also considered as early adopters of the nano-enabled surface treatments, as they are usual buyers of chemical additives and can pay relatively high prices (compared to other industries) for improvements in the functionality of the quality of the final product.

In aerospace, according to a recent report by ReportLinker, the market for nano-enabled coatings in 2010 is estimated to be around US$80million, rising to US$235million plus by 2015, driven by factors such as the demand for stronger, tougher, lighter and longer-lasting components that meet stringent qualifications and reduced fuel consumption and emissions.

However, nowadays only **very few nano-enabled coatings, sealants or adhesives are present in the current or planned cars and aircrafts**. While nanotechnology enabled products promise to reduce significantly weight and increase efficiency, at the moment **only products with relatively low market impact, mostly used in parts that do not compromise either safety or vehicle performance, have accessed the market**.

Example of marketed product for the automotive sector:

Glassylite™, is a restoration treatment for car's headlights. It is targeted directly at the consumers, not the automotive industry.

As shown in the advertisement below, this product uses nanotechnolgy in its publicity. It is self-declared a nanosealant, with advanced liquid glass nanotechnology.

Example of marketed product for the aeronautic sector:

Zyvex Performance Materials (ZPM) has developed Epovex Adhesive™ , line of two-part epoxy adhesives that are stronger and less expensive than conventional aerospace adhesives

"*By using Epovex Adhesives, our customers will experience fewer secondary bond failures and save money at the same time*" says Product Development Engineer Fred Meyer.

After them, the research is already driving to promising solutions to launch more nanotechnology-enabled products to the market in medium term (3-7 years), such as hydrophobic coatings, dirt-repellent coatings for interior textiles, nano-enabled glass, self-healing coatings, nanoenabled adhesives, nanocoatings to avoid corrosion and tribological nanocoatings to improve the efficiency of the powertrains.

The market penetration of these products for the automotive or aeronautic is expected to be slow though, as most of their production processes (and costs) have to be adapted to the industries' requirements.

2.8 Selected company profiles

- BASF

BASF is a German chemical company with revenues of € 62 billion that employs close to 100,000 people worldwide. For applications in the automotive sector, it is significantly involved in the development of nano metal oxides used for pigments used for metals and plastics.

www.basf.com

- Evonik

Evonik is a German industrial corporation that operates in the chemicals, energy and real estate businesses. Evonik is owned by the RAG Foundation, employs 43,000 people and carries out activities in more than 100 countries It is involved in the development of new adhesive additives, such as the nanoscale iron oxide particles, to allow bonding and debonding on command.

www.evonik.com

- Henkel

Henkel is a German company with revenues over €14 billion that operates in 125 countries and employs 50,000 employees worldwide. Henkel operates in three different business areas: Laundry & Home Care, Beauty & Home Care, and Adhesive, Sealants & Surface Treatments. World leader company in adhesives, sealants and surface treatments for consumers and industrial applications. It has several products based in nanotechnology targeted at the automotive sector.

www.henkel.com

- Nanogate

Nanogate has been in operation since 1999 and is an internationally leading enabler in the growth market of nanotechnology. Its sales in 2008 were €12.2 milion and, as of October 2009, it had 76 employees. The company provides solutions based on chemical nanotehcnology. Among other sectors, the company has worked for the automotive industry, applying for example wear-reduction coatings in powertrains.

www.nanogate.de

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