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All the leading companies profiled.

Markets
End user markets and products.

Materials
Nanomaterials used in sol-gel nano coatings.

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Forecast from 2010 to 2024
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nanotechnology is a key driver for new and innovative coating applications and nanocoatings have shown substantial growth in recent years. The nanocoatings industry is conservatively estimated to be $2 billion in 2012, growing to over $9.7 billion in 2024. In the coating sector, high transparency, new functionalities and high-quality performance are increasingly important requirements. The key element that nanostructured coatings provide however is protection-from ice, pollutant, UV, fire, heat, bacteria, marine life, touch and corrosion. These factors cost global industry billions in maintenance, loss and downtime each year and can pose a significant public health hazard. For example, direct corrosion costs account for 3-4% of a country’s GDP worldwide. Nanocoatings can significantly increase the cost/benefit ratio of products, providing cost effective solutions and improved performances. Moreover, nanomaterials lead to new functionalities, completely innovative characteristics and the possibility to achieve multifunctional coatings and smart coatings.

Market drivers
Main market drivers are as follows:
• constantly increasing requirements on the performance of protective coatings
• rising cost awareness
• increasing environmental attention related to the reduction of solvent content
• growing application of surface tolerant protective coatings systems or coatings providing universal adhesion
• replacement of toxic inhibitors.

Exceptional properties
Thin films, nanoscale coatings and nanostructured surfaces are widely applied in different industry sectors and provide prime examples of how nanotechnology can improve or disrupt the existing technology sectors or create new ones. Nanocoatings display significant performance advantages over traditional coatings as well as being more cost-effective in the medium- to long-term. Properties such as antimicrobialism, product longevity, thermal insulation, gloss retention, dirt and water repellency, hardness, corrosion resistance, flame retardancy, ultraviolet radiation stability, improved energy efficiency, anti-graffiti, self-cleaning, moisture absorbing, gloss retention and chemical and mechanical properties are improved significantly using nanostructured materials.

Global revenues
The global coatings market is estimated at over $95 billion in 2012. Global commercial and manufacturing institutions are turning to nanocoating technologies to further enhance current commercial products or add completely new properties to existing technology. Automotive, construction, polymer, solar, glass, oil and gas organizations understand that nanocomposite-based
coatings offer significant product performance and cost-saving advantages.

Asian market growing
The market will be driven by increased demand in the Asian and developing countries markets. The Chinese market is growing rapidly and photocatalytic TiO2 nanoparticles for self-cleaning and deodorizing effect are in strong demand in the rest of Asia. These coatings represent a $900 million plus market in Japan alone. There is strong government support for nanotechnology in these regions and a large number of multi-nationals and innovative companies developing products and processes based on nanoparticles.

Main markets
Main markets for nanostructured coatings are:
• Medical (Short term disposables and Long-term reusables).
• Food manufacturing.
• Textiles/leather.
• Marine Coatings.
• Water treatment.
• Electronics.
• Household care.
• Construction.
• Automotive/Transport.
• Tools & Engineering.
• Energy.

Nanocoatings in aerospace & aviation
Aerospace and aviation coatings are generally used for protecting the structures and surfaces of the aircraft from harsh environments. Increasing requirementssuch as resistance to extreme temperatures, extreme climates, corrosion, abrasion and wear of engine parts have resulted in an increased demand for more reliable high performance coatings. A number of aerospace companies and agencies are beginning to use, or investigate the use of, nanostructured coatings to add special characteristics to aircraft frames and interior and engine parts and component surfaces, which can include properties such as: self-cleaning; improved hardness; wear and corrosion resistance; improvement in fuel efficiency; and improved thermal performance and flame retardancy.

Advantages of using nanocoatings in aerospace and aviation include reduced carbon footprint, fewer cleaning and maintenance costs, protection against corrosion and erosion and reduced ice accretion.

Nanocoatings are also allowing for fuel-burn savings through drag reduction. Aviation, especially military aviation suffers high maintenance costs which can be alleviated with the use of anti-corrosion nanocoatings. Multilayer structure, temperatures resistant, thermal shock, corrosive and erosive wear-resistant nanocoatings are also increasing in application in turboengines, increasing their service life considerably. Nanoparticle coatings can also facilitate crack healing, resulting in improved high-temperature, strength and creep resistance.

Medical nanocoatings
The global medical device industry has experienced significant growth over the past 5 years. The medical devices coatings market is estimates to be worth over $5 billion. Challenges in medical device coatings include:
• biocompatibility;
• coating adhesion;
• uniform coverage over challenging shapes;
• strength;
• durability.

The ability of nanocoatings to meet these needs explains why they are under development for medical device applications. Nanocoating technology has already been widely applied in hearing aid coatings. Nanoparticle coatings are being increasingly applied in protective coatings for medical electronics, biocompatible coatings on implantable devices, and lubricious coatings on medical devices.

Bacterial infection from medical devices is a major problem and accounts for an increasing number of deaths as well as high medical costs. The anti-microbial efficacy of nanoparticle coatings is leading to significant market growth in this application area. MRSA is a global problem in healthcare facilities, responsible for up to 50% of hospital infections in the USA and UK. During the past 20 years it has been reported that between 6 and 14% of patients that enter general hospitals develop a nosocomial infection (Vazquez-Argon et al., 2003), i.e., an infection that was not present or incubating at the moment of patient admission at a hospital. Nanoparticle coatings have been proven to reduce germ concentration and adhesion on medical devices. The application of nanoparticles on the surface of medical devices has been used to prevent bacterial adhesion and subsequent biofilm formation. The nanoparticles are either deposited directly on the device surface, or applied in a polymeric surface coating. The nanoparticle is slowly released from the surface, thereby killing the
bacteria present near the surface. There are significant market opportunities in this sector with the catheter market alone projected to reach $22 billion globally by 2012 (ORNL). 10% of patients in ICU’s develop catheter related infections, and 40% of these are acquired during their stay. The market will continue to grow as an aging population will drive more hospital stays and infectious agents (bacteria/fungi) continue to evolve quickly and become less susceptible to antibiotic treatments.

**Nanocoatings in the automotive industry**

Surface protection is a key area in the luxury car market both for protection from UV, wear, heat; promotion of adhesion; and reduction of engine friction. The overall world automotive paints and coatings market was estimated to be $7.75 billion in 2010 and nanomaterials will play a key role in future growth. Many automotive parts have a protective coating applied to improve the appearance or provide additional durability to the substrate which can be enhanced by the incorporation of nanomaterials. Coatings containing nanoscale carbides, nitrides, metals or ceramics play a key role in the performance of internal mechanical components of a vehicle, such as the engine. Desirable functional properties for the automotive coatings industry afforded by nanomaterials include:

- Scratch resistance (alumina and silica nanoparticles)
- Anti-fingerprint
- Self-cleaning (Nano-Tio2, nanosilica)
- Chemical resistance
- UV resistance (zinc oxide, cerium oxide, titanium oxide, iron oxide nanoparticles)
- Abrasion resistance (silica and aluminium oxide nanoparticles).

By reducing wear and friction, nanostructured coatings increase the lifetime of the working material at the same time that they reduce the dissipation of energy as heat, thus increasing the efficiency of the vehicle. Nano-composite coatings offer improved solvent, fuel and gas barriers, and have heightened flame resistance, stiffness, and other mechanical properties. These coatings can increase tool productivity (longer tool life, higher cycle frequencies, less work piece finishing), reduce manufacturing costs, improve the quality of products (due to smoother surfaces, better dimensional stability, higher degrees of metal deformation and fewer manufacturing steps) and reduce lubricant consumption. Current applications in the automotive industry are for oxide scale protection and easy to clean coatings for automotive glass. Volkswagen, BMW, Toyota and Subaru all utilise nanomaterials in these areas. Mercedes-Benz have introduced ceramic scratch-resistant nanocoatings to automobiles. These nanoparticle clearcoats display significantly greater scratch resistance and enhanced paint gloss compared to vehicles with conventional paintwork.

Consumers desire a permanent, scratch-free finish on all parts of automobiles, and scratch performance is the highest rated customer concern for automotive paint systems and displays. Nanocoatings provide protection against scratches caused by mechanical car-washes, for example ensure visibly enhanced gloss over an extended period of time. Aluminium oxide nanocomposite scratch resistance coatings have been applied as automotive finishes. When the additives are blended into resins and coatings at very low 1.5 to 6 percent concentrations, scratch resistance increases dramatically. Bayer and Nissan (Scratch Guard Coat) have produced self-healing coatings and nanoparticles additives are improving the improve the scratch/mar resistance of clearcoats. Alumina and silica nanoparticles increase the surface hardness and resistance to indentation. Aluminium Oxide nanoparticles incorporated into surface coatings and films to provide long-term scratch resistance without significantly impacting optical clarity, gloss, colour, or physical properties. UV-curable, highly crosslinked polymer coating systems containing both hydrophobic and hydrophilic nanodomains are utilized in anti-fogging coatings. Surfaces coated are capable of spreading water and thus preventing fog formation on a variety of optical substrates such as automotive plastic and glass, including the headlamp covers of automobiles. Hydrophobic and oleophobic glass allowing greatly improved visibility in the rain, and reduces the adherence of dirt and contaminants to a treated surface.

Nanostructured coatings can significantly increase engine power thereby decreasing fuel consumption and increasing the exhaust gas temperature. They show better thermal resistance and reduced thermal conductivity compared to coarse grained coatings. Protective thermal coatings containing on CNTs have been developed which can reduce insulation weight in automotive applications. Their high thermal conductivity, damage resistance, and reported optical-absorption efficiency also make them promising candidates as coatings for thermal detectors. Graphene is also being developed in this application area by a number of automotive companies.
There is also a high demand in the automotive industry for clean surfaces presenting a perfect, hygienic optical appearance insensitive to fingerprints, especially with the increasing incorporation of touch panel displays.

**Nanocoatings in construction and exterior protection**

Nanomaterials are particularly suited to protecting the surface of various construction materials such as glass, concrete, sand limestone or marble from environmental influences like water staining, moss, algae as well as soot and oil stains; and also function as corrosion inhibitors for reinforced steel. Paints and surface coatings are commercially available that create a low energy facing thus rendering a building surface highly hydro- and oleophobic, thereby helping to prolong maintenance cycles and reduce cleaning.

Dirt repellent protective paints and photocatalytic coatings are the most prominent applications in the construction and exterior protection industry. Dirt collection (accumulation) in building exteriors poses considerable problems for building maintenance. Cleaning such building surfaces is generally done by using detergents accompanied with scrubbing, wiping and high-pressure water jets. These processes have several shortcomings such as use of chemical detergents, high consumption of energy and labour cost. This naturally leads to high maintenance costs; therefore, an effective self-cleaning coating is desirable.

A number of large multinationals, including Evonik Degussa, Dupont, Schott, 3M and Corning produce anti-fouling and easy-to-clean coatings for a variety of markets.

In recent years, self-cleaning coatings using photocatalytic Titanium Dioxide (TiO2) have gained considerable industry attention. With assistance of little UV light from fluorescence source or sunlight, TiO2 offers two unique properties: (a) strong oxidation power, and (b) super-hydrophilicity. Strong oxidation power can be used to kill bacteria attached on the wall, or oxidize/remove foul smells from stains in toilets (e.g., TiO2-coated tile and TiO2-coated glass are commercially available). Super-hydrophilic properties allow dirt and stains to be easily washed away with water or by rainfall when such a coating is applied to exterior surfaces. Nanoparticle TiO2 self-cleaning coating greatly benefit building maintenance, especially for skyscrapers, as they reduce the need for costly surface cleaning. Photocatalyst coatings are also used to improve indoor air quality by reducing the amount of volatile organic compound and other toxic chemicals people are exposed to in hotels, restaurants, commercial business facilities, university laboratories, hospitals and residences.

Anti-stick properties of nanocoatings leads to less staining and easy-cleaning-effect on exterior and interior surfaces. Anti-graffiti properties mean that stubborn stains such as graffiti, which in the past called for intensive cleaning efforts can be washed away simply with a high pressure hose. Water-based, VOC-free, clear impregnating nanoparticle wood coatings containing nanoscale UV absorbers have been commercialised. They are designed for use on masonry and concrete surfaces, provides superior water repellency, reduces efflorescence, and provides significantly improved abrasion resistance.

**Nanocoatings in electronics**

Nanotechnology is making a significant impact on the electronics sector, driven by consumer electronics requirements and the need to enhance the speed and performance of computing components while reducing their size. A number of electronic products made with nanomaterials are already commercially available and more are coming onto the market in 2014, especially in consumer electronics. Liquid repellent, thermal, conductive, magnetic and anti-corrosive nanocoatings have been applied inside and outside electronic devices. Graphene, carbon nanotubes, silver nanoparticles and nanowires and quantum dots are finding their way into the displays and touchscreens markets.

**Economic impact**

Micro- and nanoelectronics underpin a significant part of the global economy.

- The global turnover of the sector was $310 billion in 2012. The value of products comprising micro- and nanoelectronic components represents around $215 billion of value globally.
- Despite the recent financial and economic setbacks, the worldwide market for micro- and nanoelectronics has grown by 5% per year since 2000. Further growth of at least the same magnitude is predicted for the remaining part of the current decade.
- The pace of innovation in the field is one of the main drivers behind the high growth rates of the whole digital sector which today has a total value of around $4050 billion worldwide. Dow Chemical estimate the current addressable electronics market to be $95 billion with annual growth of 5%-7%.
- The impact of micro- and nanoelectronics on the whole economy is estimated at 10% of the worldwide
Drivers

Shrinking semiconductor device sizes have increased demand for more sophisticated materials, primarily nanomaterials. Demand is increasing for smaller, more highly integrated electronic products. This has led to ever higher performance and more complex semiconductor devices. As these devices become more highly integrated and incorporate more advanced functions, manufacturing processes are becoming more miniaturized and complex, and include diverse reliability factors. Nanomaterials are candidates to replace or complement traditional semiconductors in both high-performance and low-cost devices. Nanomaterials will potentially meet a wide range of memory device needs including speed, power consumption, density, reliability, non-volatility, and cost. CNTs and nanoparticles are utilized for their radiation and temperature intolerance, high speed capabilities and long-term scaling potential.

Trends in 2014

• Indium tin oxide (ITO) replacement is a key theme among product development. Carbon nanotubes (CNTs) and graphene may allow for the replacement of existing electrically conductive that are in short supply, expensive and limited in their use with flexible substrates.
• Quantum dots, nanoparticle silver, silver nanowires, graphene enabled consumer electronics products are on the market in 2014.
• Increased focus on 2-D nanomaterials in nanoelectronics.
• Companies are mainly targeting the small/medium size flat panel display market. This is estimated to be $130 billion and will reach $150 billion in next few years, driven by the exploding consumer demand for portable display-based electronics such as smartphones, cameras, iPads, netbooks, and similar devices. For such applications, low-cost, high image quality, low-power consumption display screens are already sought-after and will be in high demand.
• Most product development has resulted from strategic partnerships.
• Nanomaterials are driving developments in printable and flexible electronics.
• Competition from silicon in semiconductors and sensors for nanomaterials is significant. Graphene, silver nanowires and carbon nanotubes are likely to become increasingly competitive as well as other 2-D materials such as boron nitride, molybdenum disulfide, tungsten disulfide and germanane.

Nanocoatings in household care

Nanoparticles have been added to construction ceramics, which include floor and wall tiles, countertop ceramics and sanitary ware products. They have found a place on the market with self-cleaning, anti-bacterialism hygienic and scratch resistant features. Nanoparticle coatings reduced the contact area between water and surface to a minimum and decrease the forces of adhesion.

They add new functional properties to a number of surfaces inside the home, for example, preventing lime-scale in the bathroom, keeping windows and sanitary surfaces clean as well as providing algae and moss resistance on outdoor furniture. They have been widely applied, especially in Asia on glass surfaces in sanitary areas (showers, mirrors) and glazed ceramic surfaces (toilets, sinks, glazed tiles). As well as displaying strong hydrophobicity, strong anti-stick properties and excellent easy-clean performance on contamination and lime-scale, other properties include:
• Food-safe (inert).
• Invisible to the human eye (coating thickness: 100-150 nm).
• Permanent (UV-stable, huge abrasion-resistance).
• Resistant to temperature change.
• Breathable.
• Simple application (do-it-yourself).
• Chemical-resistant (except for pH value of 13 or 14).
### Table 1: Global market for nanocoatings 2012-2024

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Anti-fingerprint</td>
<td>$85</td>
<td>12%</td>
<td>$10.2</td>
<td>$213</td>
<td>65%</td>
<td>$138</td>
<td>$310</td>
<td>68%</td>
<td>$210</td>
</tr>
<tr>
<td>Anti-microbial</td>
<td>$6,500</td>
<td>5.5%</td>
<td>$357</td>
<td>$8,700</td>
<td>13.5%</td>
<td>$1,170</td>
<td>$9,150</td>
<td>18%</td>
<td>$1,647</td>
</tr>
<tr>
<td>Conductive</td>
<td>$2,500</td>
<td>2.5%</td>
<td>$62.5</td>
<td>$4,000</td>
<td>22.5%</td>
<td>$900</td>
<td>$4,960</td>
<td>31%</td>
<td>$1,537</td>
</tr>
<tr>
<td>Anti-corrosion</td>
<td>$3,000</td>
<td>1.9%</td>
<td>$57</td>
<td>$6,200</td>
<td>7.5%</td>
<td>$465</td>
<td>$7,100</td>
<td>11%</td>
<td>$781</td>
</tr>
<tr>
<td>Abrasion and wear resistant</td>
<td>$5,000**</td>
<td>1.1%</td>
<td>$55</td>
<td>$7,600</td>
<td>5.5%</td>
<td>$418</td>
<td>$8,100</td>
<td>8%</td>
<td>$648</td>
</tr>
<tr>
<td>Self-cleaning (Bionic)</td>
<td>$145</td>
<td>100%</td>
<td>$145</td>
<td>$550</td>
<td>100%</td>
<td>$550</td>
<td>$720</td>
<td>100%</td>
<td>$720</td>
</tr>
<tr>
<td>Self-cleaning (Photocatalytic)</td>
<td>$1,200***</td>
<td>100%</td>
<td>$1.2</td>
<td>$2,200</td>
<td>100%</td>
<td>$2,200</td>
<td>$2,650</td>
<td>100%</td>
<td>$2,650</td>
</tr>
<tr>
<td>UV-resistant</td>
<td>$365</td>
<td>3.5%</td>
<td>$12.7</td>
<td>$535</td>
<td>9%</td>
<td>$48</td>
<td>$685</td>
<td>14%</td>
<td>$95</td>
</tr>
<tr>
<td>Anti-icing</td>
<td>$200</td>
<td>14%</td>
<td>$28</td>
<td>$320</td>
<td>35%</td>
<td>$112</td>
<td>$417</td>
<td>40%</td>
<td>$166</td>
</tr>
<tr>
<td>Thermal barrier/flame retardant</td>
<td>$4,000</td>
<td>1%</td>
<td>$40</td>
<td>$7,600</td>
<td>3.5%</td>
<td>$266</td>
<td>$8,400</td>
<td>5%</td>
<td>$420</td>
</tr>
<tr>
<td>Anti-fouling/easy to clean</td>
<td>$2,500</td>
<td>4%</td>
<td>$100</td>
<td>$4,4000</td>
<td>13%</td>
<td>$572</td>
<td>$5,050</td>
<td>17%</td>
<td>$858</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$25,490</strong></td>
<td>-</td>
<td><strong>$2,060</strong></td>
<td><strong>$42,300</strong></td>
<td>-</td>
<td><strong>$6,840</strong></td>
<td><strong>$7,100</strong></td>
<td>-</td>
<td><strong>$9,735</strong></td>
</tr>
</tbody>
</table>

* Some reports put this market as high as $8 billion.
** Estimates for this market vary from $4.5 billion to $13 billion
*** The Japanese market is estimated to be over $1 billion alone in 2012, with Asia and Europe comprising the rest of the market.
In this report, nanocoating refers to the process of covering a substrate with a layer on the nanometre scale. Nanocoating forms a nanocomposite that comprises a combination of two or more different substances of nanometer size, thereby producing a material that generally has enhanced or specific targeted properties due to the combined properties and/or structuring effects of the components. The report covers the main nanostructured sol-gel coatings suppliers and application developers. The market is also forecasted from 2012 through to 2024. End user markets and applications are also outlined. The research methodology initially encompassed a comprehensive and exhaustive search of the literature on nanostructured coatings. Secondary sources included journals and related books, trade literature, marketing literature, technology roadmaps, other product/promotional literature, annual reports, analyst reports, conference proceedings and other publications. An extensive patent analysis was conducted to gauge technological innovation and to determine research activity as it applies to new product development.

A series of interviews were conducted via email and phone with nanotechnology and nanomaterials company representatives, academics, technology suppliers, technical experts, trade association officials, and consulting companies. In addition, service providers and end users were contacted to evaluate current and future demands.

The market was then quantified for relevant application impact and the main prerequisites for commercial success were identified including performance of the technology, supplier distribution, legislation, pricing of competing products, sale of complementary products, industry environment and demographics of the customer.

Market revenues were forecast based on current revenues generated by companies marketing nanocoated products, market penetrations in key end user markets of these products and future estimated growth in these markets.
Introduction

Nanostructured coatings offer great potential for various applications due to their superior characteristics that are not typically found in conventional coatings. They are now routinely applied to a wide variety of substrate materials (plastics, glass, metals, ceramics and textiles). Nanoscale characterisation is drawing increasing interest from manufacturers and regulators with the former concerned about achieving the desired performance at appropriate cost and the latter concerned about toxicological impact.

Interest in nanostructured materials for coatings is due to their remarkable mechanical, electrical, magnetic and optical properties and the possibilities of synthesizing materials with unique physical–chemical properties. Highly sophisticated surface related properties, such as optical, magnetic, electronic, catalytic, mechanical, tribological, chemical as well as magnetic, electronic and optical can be obtained by advanced nanostructured coatings, making them attractive for many modern industrial applications.

Definition

Nanomaterials are manufactured with at least one dimension less than 100 nm. Nanocoatings are two-dimensional materials that can be produced by physical (e.g. plasma, PVD), chemical (e.g. CVD, sol-gel) and particulate (e.g. TiO2) technologies. Nanocoatings can be categorized as nanocrystalline, multilayer coatings with individual layer thickness of nanometres, and nanocomposites. In nanocoating systems the uppermost layer is a clear coating (ranging between 5–50 μm in thickness), which, for example, not only protects the underlying layers or substrate from chemical and UV degradation, but also provides protection from mechanical damage that can result in surface blemishes/scratches. Design of nanostructured coatings requires consideration of numerous factors, e.g. the interface volume, crystallite size, single layer thickness, surface and interfacial, energy, texture, epitaxial stress and strain, etc., all of which depend significantly on materials selection, deposition methods, processing parameters and what is especially important, service condition of coated parts. The size and size distribution of nanoparticles in a coating formulation has a large influence on its functional characteristics.

Properties

Due to the properties inherent at the nanoscale, nanostructured coatings are typically multifunctional, exhibiting one or combinations of the following properties: scratch and abrasion resistance, anti-static, oleophobic, easy-to-clean, anti-reflective, anti-microbial activity, sensor and catalytic activity. They are mainly used for the prevention of soiling (incrustation/clogging; protein adhesion/cell adhesion; biofilm formation); aging/degradation; and friction/wear.
Advantages of nanocoatings include:
- Better surface appearance
- Good chemical resistance
- Decrease in permeability to corrosive environment and hence better corrosion properties
- Optical clarity
- Increase in modulus and thermal stability
- Easy to clean surface
- Anti-skid, anti-fogging, anti-fouling and anti-graffiti properties
- Better thermal and electrical conductivity
- Better retention of gloss and other mechanical properties like scratch resistance.
- Anti-reflective in nature
- Chromate and lead free
- Good adherence on different type of materials.

Nanoparticles
The exploitation of the novel properties afforded by nanoparticles in coatings and paints is a relatively recent development. Nanoparticles allow for novel products such as:
- Easy-to-clean coatings
- Effect coatings
- Antibacterial coatings
- Scratch-resistant coatings
- Photocatalytic coatings
- Paints with UV protection
- Wall coatings as screens against high-frequency electromagnetic radiation
- Switchable coatings
- Electro-conductive coatings
- Self-healing coatings
- Nano-primers for anti-corrosive coatings and paints
- Heat-insulating coatings.

Nanoparticles used in the coatings industry include:
- Titanium dioxide
- Silicon dioxide
- Iron oxide
- Zinc oxide
- Silver.

Titanium dioxide has photocatalytic properties. For this reason, titanium dioxide in nanoscale form is found in wall paints for removing organic pollutants from ambient air. Nanostructured silicon dioxide mainly serves as a rheological additive; it is also used in self-cleaning wall paints. UV protection in transparent coatings is the most important application for iron oxide and nanoscale zinc oxide. Silver in nano-form is a constituent of wall paints for hospitals and food processing operations, in order to prevent attack by bacteria and other microorganisms.

Particle size, surface area and electronic properties are three key properties that nanoparticles desirable for a variety of industrial applications. The large specific surface areas of nanoparticles allow them to have enhanced reactivity, superior absorption, higher solubility, lower melting point and enhanced electronic properties, such as quantum effects found on particles with particle size < 10 nm (important for electronic and optoelectronic applications). Because of the salient features of nanoparticles, advanced products and coatings can be produced by embedding nanocomposites into polymer matrices. Nanoparticles are invisible to the human eye; when embedded in a polymer matrix. They do not affect visible light transmission, making them ideal materials for advanced clear coats. When nanoparticles are dispersed in polymer to form advanced transparent nanocomposites, they offer improvements in coating strength, thermal and scratch resistance, solar absorption and reflectance (window coatings) and improve performance of photochromic coatings and automotive clear coatings. Polymer nanocomposite coatings embody properties with incredible practical applications for mechanical, optical and electronic products.

No sacrifice in light transmission in optical applications In general, improving the mechanical properties of a polymer coat (such as scratch resistance) involves the optimization of the polymer lacquer components and reinforcement of the structure of the coat using microscopic fillers. When using nanopowders (size < 100 nm) as fillers to reinforce polymers, their higher interfacial surface area makes the nanofiller behave differently than common fillers; with the nanocomposite requiring very low loading of nanomaterial to yield significant improvement in mechanical and other desired properties. These properties are enhanced without sacrificing visible light transmission. This is critical for optical applications. Where glass coatings are concerned, spectrally selective coatings made of nanoparticles is a hot topic. Nanoparticles offer greater spectral control than other materials by offering market-leading transparency and clarity. For spectrally selective solar control films, high transparency in the visible light spectrum with absorption and reflection of infrared light are key criteria being considered.
Commercial window films can gain competitive advantage by embedding nanoparticles into plastic films later applied to glass surfaces. Nano films offer heat absorption and reflective properties while maintaining fairly high levels of transparency.

**Production methods**

With the advent of vacuum-based physical vapor deposition technologies, methods such as sputtering and pulse laser deposition have become the primary tools in nanomaterial R&D (although they were originally discovered and produced by solution chemical methods). However, there is a new drive to bring transparent ceramic oxide processing back to chemical solution deposition.

Production methods include:

- **Electrospray and electrospinning:** Reactants are passed through a fine nozzle, which is subject to a high voltage, causing the reactants to form charged droplets or fibers that are collected on a grounded collector. Such processes can be used to coat large surfaces.

- **Gas phase synthesis (chemical and physical vapor deposition, CVD and PVD, plasma and laser ablation):** The material is vaporized by intense heat (e.g. laser) and then deposited on a substrate (usually under vacuum). This is generally expensive, difficult to scale-up and not suitable for temperature-sensitive materials (e.g. polymers, biomolecules).

- **Self-assembly:** Reactants combine in a predefined manner to form a layer on the desired substrate.

- **Sol-gel processes:** Reactants are mixed under defined temperatures and pressures to produce colloids of nanoparticles. Major issues include strictly defining particle size distribution (or porosity), preventing particle agglomeration, and the amount of waste material produced.

Solution-based approaches to nanoparticle-polymer composite deposition are more cost effective than ultra-high vacuum physical processes, allowing a thick layer of nanomaterial to be deposited in a single step. General coating approaches involve dip coating, doctor blade coating, metering rod coating, slot-casting, spray-coating, screen printing and inject printing. All these approaches use nanoparticle-polymer dispersion to cast a nanocomposite polymer onto suitable substrates.

A key challenge to this approach is the inherently poor dispersability of specific nanomaterial. Although, there are numerous commercially available nano powders in the market, aggregate contained in those products makes their processing very challenging as they can directly affect performance as well as transparency. The ability to achieve polymer nano-dispersion amenable to current liquid-based coating processes will usher in an era of nanocoating supremacy over traditional industrial coating products with smarter, stronger, more durable, cost-effective coating materials.

Most of the current nanotechnology coating solutions for repelling stains and preventing scratches on a variety of surfaces are first generation nanotechnology solutions. There are deposited so they are electro-statically or at best ionically bonded to the surfaces they are deposited on. This means that the repelling ability of many first-generation nanocoated fabrics degrades rapidly with washing or use and very few can pass normal abrasion testing. The new, second-generation nanocoatings are covalently bonded.

**Sol-gel nanocoatings**

Among these processes, the sol-gel process is viewed as one of the most attractive for the synthesis of metal oxide nanocrystals, ordered organic-inorganic hybrid materials and inorganic heterostructures. These routes, involving the reaction of metal oxide precursors in organic solvents (e.g. benzyl alcohol) at moderate temperature and pressure, offer advantages such as high crystallinity of the as synthesized oxides, high purity, high reproducibility and the ability to control the crys-
tal growth without the need of using additional ligands. Through this process, homogeneous inorganic oxide materials with desirable properties of hardness, optical transparency, chemical durability, tailored porosity, and thermal resistance, can be produced at room temperatures, as opposed to the much higher melting temperatures required in the production of conventional inorganic glasses. Moreover, non-aqueous sol-gel is particularly suitable for the syntheses of multi-metal oxides and doped materials. The main nanomaterial utilized is silicon dioxide.

Process
The sol-gel process (see figures below) involves the evolution of inorganic networks through the formation of a colloidal suspension (sol) and gelation of the sol to form a network in a continuous liquid phase (gel). There are two basic chemical reactions involved:

\[
\text{Hydrolysis and Condensation:}\quad \begin{align*}
\text{M-OR + H}_2\text{O} & \rightleftharpoons \text{M-OH + R-OH} \\
\text{M-OH + M-OH} & \rightleftharpoons \text{M-O-M + H}_2\text{O}
\end{align*}
\]

In hydrolysis reaction, alkoxyl groups react with water and turn into hydroxyl groups given out alcohol. In condensation reaction, hydroxyl groups react and condense to form metal-oxygen bond given out water.

Advantages
• simple and economic technique, as the fabrication does not need expansive machinery or apparatuses.
• Great variety of available precursors -> a broad spectrum of high-purity materials
• Soluble precursors ensure mixing on molecular level -> very homogeneous products.
• Tailored material composition and microstructure Incorporation of useful functionalities
• Cured at low temperature or by UV

Figure 1: The coating system is applied to the surface. The solvent evaporates.

Figure 2: A first organization takes place where the silicon-containing bonding component (blue dots in figure 2) bonds covalently with the surface and cross-links with neighbouring molecules to form a strong three-dimensional...

Figure 3: During the curing, the compounds organise themselves in a nanoscale monolayer. The fluorine-containing repellant component (red dots in figure 3) on top makes the glass hydrophobic and oleophobic.
• Offers a high flexibility as one can produce materials with a wide range of stoichiometry and additional dopants.
• Allows the fabrication of high quality coatings.
• Starting materials are easily to obtain, not expensive and available in a high purity.

Properties
Properties that can be achieved with sol-gel nanocoatings include:
• Hydrophobic surfaces (contact angle with water of more than 120 degrees)
• Anti-fingerprinting.
• High temperature resistance.
• Oleophobic surfaces.
• Anti-microbial surfaces.
• Easy-to-clean surfaces.
• Protective transparent coatings.
• Corrosion resistance.
• Low friction.
• Chemical resistance.
• Anti-static surfaces.
• Conducting/semi-conducting surfaces.
• Extreme mechanical wear-resistant properties.
• UV protection.
• Anti-graffiti.

End user markets and applications
Typical end user markets for sol-gel nanocoatings include:
• construction (pipes, facades, bridges, window insulators, reinforcement fibers, anti-reflection coatings, non-slip industrial floor coatings).
• automotive (paint surface treatments, metal parts, metal structures, anti-reflection coatings, mirrors and lamps, plastic hoods).
• marine.
• environmentally friendly high performance corrosion protection coating with no hazardous materials used.
• electronics (components, screens and displays, plastic and metal parts).
• sanitary.
• oil and gas (pipes).
• energy (wind power structures and blades, high temperature superconductors, glass surfaces on solar panels).
• consumer electronics (optical coatings, dielectric and electronic coatings, displays and plastic and metal parts).
• food manufacturing.
• protective and decorative coatings.
• porous films.
• thermal insulation.
• abrasives.
• membranes for separation and filtration.
Anti-fingerprint nanocoatings

Table 2: Market summary anti-fingerprint nanocoatings

<table>
<thead>
<tr>
<th>Main markets</th>
<th>Consumer electronics, touch panels, automotive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total market 2012</td>
<td>$85 million</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>12%</td>
</tr>
<tr>
<td>CAGR to 2020</td>
<td>12.1%</td>
</tr>
<tr>
<td>Total market 2020</td>
<td>$213 million</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>65%</td>
</tr>
<tr>
<td>Nanocoatings market 2020</td>
<td>$138 million</td>
</tr>
<tr>
<td>Nanocoatings market 2024</td>
<td>$210 million</td>
</tr>
</tbody>
</table>

Transparent anti-fingerprint coatings find application on stainless steel surfaces, plastics and glass. They are particularly suitable for designer surfaces in car interiors, households and buildings and on glass touch panels. Structured stainless steel surfaces are used in the household such as housings, facings, decorative mouldings, grips, handles or faucets, general office items and especially decorative utilities and are especially sensitive to fingerprints. The cleaning requirements of stainless steel products are extensive. Typical anti-fingerprint coatings require multiple wipes to remove smudges. Anti-fingerprint nanocoatings reduce fingerprint to a minimum and can be simply wiped away with a dry cloth. They facilitate cleaning glass doors, prevent limestone deposits in shower cabins and also offer long-term protection against glass corrosion. The largest market for anti-fingerprint coatings is touch-screen devices. Displaybank forecasts that the total touch-screen panel market will grow to $9.65 billion and 1.35 billion units, and 800 million smartphones are expected to be touch-enabled in 2014.

Market drivers
There is a high demand for clean surfaces presenting a perfect, hygienic optical appearance insensitive to fingerprints. With the rise of touch screen technology, the demand for anti-fingerprint coatings on the screens of electronic devices has grown considerably. Companies are focusing on high-performance surfaces for plastics and metals - a fast-growing market with strong margins and an annual volume of around EUR 800 million across Europe in 2010, and touch panels. There has been a sharp increase in the demand for touch panels used in a wide range of consumer products such as car navigation systems, smart phones and tablet PCS and the market has been expanding year by year. Such devices are routinely subjected to touch and thus commonly stained with undesirable fingerprint, skin oil, sweat and cosmetics when used. As a result there is an increasing need anti-fingerprint coatings that provide material surfaces with self-cleaning, or easy-to-clean features that improve aesthetic appearance and save maintenance cost. Anti-fingerprinting of stainless steel surfaces found in interior and exterior architecture, passenger elevators, public ticket machines and cover panels of white goods is also desirable. Cleaning and maintenance costs can be significant, especially in publically accessed buildings.

Innovative anti-fingerprint coatings are being developed in the automotive market due to the increase in the use of touch-based automotive human machine interfaces (HMI’s) and displays. This need is two-fold as fingerprints not only cloud the user’s view of the display weakening the efficacy of the information being delivered, but also hinder the clarity of the display making distraction free viewing of the display less likely.

Nanocoatings
Thin film nanocoatings enhance the performance and quality of glass substrates giving more functionality and aesthetic value. In order to make the touching surfaces of electronic touchscreens and displays have an anti-fingerprint function, they must have characteristics of hydrophobic and oleophobic. Beyond the aesthetics, fingerprint smudges can interfere with actual viewing under conditions such as bright sunlight. This problem is more significant when multi-layer optical coatings are applied to touch screens, usually to enhance high-ambient-light readability. Then, the presence of fingerprints can cause unattractive bluish smudges that can make the device almost unreadable. For military or medical applications, fingerprints that affect readability in high ambient light are a serious concern.

According to Toray Industries, if effective anti-fingerprint coatings technology can be commercialized, a market will be created on the scale of an annual coating.
area of 6,000,000 m². The company has demonstrated an anti-fingerprint, self-repairing film for touchscreens. It was made by applying an anti-fingerprint technology to a self-repairing film that is currently sold by Toray. Other companies developing sol-gel nanocoatings for anti-fingerprint applications include Clariant, Nano-X, InterLotus GmbH, Matrio Group SA, Nanocare AG and Acreo.
Table 3: Anti-fingerprint nanocoatings—Principles, Properties, Effect, Applications and Companies

| Principle | • Protection of metal surfaces against fingerprints with a fine nanocomposite coating, which maintains the metal optic. It involves establishment of surface with low surface free energy followed by establishing extremely flat surface using nanoparticles. This kind of surface significantly reduces fingerprints and other contaminants. As adhesion of fingerprints is reduced, oxidation will not take place and hence increases durability. Also, time to clean the surface will reduce significantly.  
• By smart modification substantial improvement of cleaning ability |
| Properties | • Water-based respectively low-solvent-containing coating fluid for stainless steel, cooper, brass and other metals  
• Simple application e.g. by spray dip coating  
• Curing either at room temperature or thermal curing between 60°C and 150°C  
• Very good adhesion  
• Transparent or slight mat, i.e. the metallic surface character is saved  
• High abrasion resistance  
• High chemical stability against acids and alkali (10 % sulfuric acid, 10% soda lye)  
• Additional antibacterial (biozide) properties or graffiti protection is possible. |
| Effect | • Prevention of unsightly smears. Fingerprints are optically less noticed and don’t leave any traces of oxidation (tarnishing of the metal). The effect is based upon the reduction of the optical contrast caused by a fingerprint. The user is able to enjoy an appropriately clear image even after longer and intensive periods of use.  
• Less cleaning effort: Fingerprints can be removed easily and without residue, e.g. with a paper cloth |
| Applications | • Optics  
  – Anti-reflective films  
  – Optical filters  
  – Ophthalmic lenses  
  – Mirrors  
  – Camera lenses  
  • Kitchens, Cafes, Restaurants  
  – Kitchen surfaces  
  – Treated Glass  
  – Earthenware  
  – Appliances  
  – Ducting  
  • Electronic Display Screens  
  – Liquid crystal displays  
  – CRT displays  
  – Plasma displays  
  • Textiles  
  • Floor Sealants  
  – Projection TVs  
  – Handheld electronic devices  
  • Automotive  
  – Windows/mirrors  
  – Interior surfaces  
  • HVAC Systems |
### Table 3: Anti-fingerprint nanocoatings

<table>
<thead>
<tr>
<th>Companies</th>
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</thead>
<tbody>
<tr>
<td>Avaluxe</td>
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<tr>
<td>Bioni CS GmbH</td>
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<tr>
<td>CTC Nanotechnology</td>
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<tr>
<td>Dow Corning</td>
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<tr>
<td>FEW</td>
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<tr>
<td>Leibniz Institute for New Materials</td>
</tr>
<tr>
<td>Matrio Group SA</td>
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<tr>
<td>N-Tech GmbH</td>
</tr>
<tr>
<td>Nanocare AG</td>
</tr>
<tr>
<td>Nanogate</td>
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<tr>
<td>Nanomat Technology Ltd.</td>
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<tr>
<td>Nanopool</td>
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<tr>
<td>Nano-X GmbH</td>
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<tr>
<td>Ntec GmbH</td>
</tr>
<tr>
<td>Nilima Nanotechnologies</td>
</tr>
<tr>
<td>Plasmatreat</td>
</tr>
<tr>
<td>SPN International</td>
</tr>
<tr>
<td>The Inox in Color</td>
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</tbody>
</table>
Anti-microbial nanocoatings

The spread of diseases is a huge global problem in modern society. Microorganisms such as bacteria, fungi and viruses represent potential threats for our modern hygienic lifestyle. Infection is a major medical complication associated with healthcare environments.

**Market drivers**

Infection control is of great importance and requires a high level of hygiene. Hospitals, pharmaceutical production units, food factories etc. need to be rigorously disinfected in order to destroy pathogenic microbes. Applications for antimicrobial coatings include medical products, packaging materials, or filters used in air-conditioning systems. Microbial contamination of water also poses a major threat to public health too. With the emergence of microorganisms resistant to multiple antimicrobial agents there is also an increased demand for improved disinfection methods. The classical biocides function in coatings is to either inhibit the growth of bacteria (biostatic) or by kill them (biocidal). New legislations and the aforementioned possibility of bacterial mutation have forced coating manufacturers to seek new alternatives. Today, more emphasis is placed on the development of bio-repulsive (without killing) antibacterial coatings. A wide variety of organic or inorganic biocides are available commercially and these demonstrate a wide variety of biocidal and biostatic mechanisms.

### Table 4: Market summary for anti-microbial nanocoatings

<table>
<thead>
<tr>
<th>Main markets</th>
<th>Medical, household, textiles, sanitary/hygiene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total market 2012</td>
<td>$6.5 billion</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>5.5%</td>
</tr>
<tr>
<td>CAGR to 2020</td>
<td>3.7%</td>
</tr>
<tr>
<td>Total market 2020</td>
<td>$8.7 billion</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>13.5%</td>
</tr>
<tr>
<td>Nanocoatings market 2020</td>
<td>$1.17 billion</td>
</tr>
<tr>
<td>Nanocoatings market 2024</td>
<td>$1.64 billion</td>
</tr>
</tbody>
</table>

**Nanoparticles**

Nanoparticles are a utilized as antimicrobial additives mainly due to their size which is similar to the size of the cells and particles and can pass through the membrane easily. The main mechanism of toxicity of nanoparticles is thought to be via oxidative stress that damages lipids, carbohydrates, proteins, and DNA. Antimicrobial coatings can be made in different ways.

Highly active microbicide agents that can be covalently bonded to a substrate typically utilize the sol-gel application technique to adhere to ceramic surfaces, and carry a positive charge, which creates an electromagnetic attraction between the microorganisms with electrical charge and themselves. This coating has been undoubted proved that it causes no zone of inhibition because:

- The microbicide is bonded to the substrate.
- No sign of migration to the environment.
- Continuous action is not depleted.

When applied on ceramic products (e.g. tiles and sanitary ware) this coating quickly and strongly binds to the substrate, and then shows perfect killing mechanism against bacteria and viruses (over 99.99% kill rate).

Currently, the most commonly used solutions in nanocoatings are based on silver and titanium dioxide (TiO2), and there are a number of reports on the antimicrobial properties of carbon nanotubes. Nanoparticulate zinc oxide is also utilized. Leachable antimicrobial chemicals such as silver seek to control deadly chemical releasing bacteria. Silver is used for antimicrobial coating materials because of the low toxicity of silver on human cells, long biocide action, high thermal ability and low volatility. Silver has a broad spectrum of biocide activity against 650 bacteria, mushrooms and viruses. TiO2-based antimicrobial coatings are based on photocatalysis and its ability to dissolve organic “dirt.” Also under development are controlled release/reactive coatings in which the biocides are released only when needed, for example, when the surface coating is anchored to microbial flora. The coating actively reacts to the chemical or physical presence of the flora.

**Applications**

Application areas are new material technical solutions that reduce or prevent the adhesion of bacteria and other organic flora in healthcare, pharmaceutical and food.
industry equipment. Antimicrobial coatings can also be used on flow surfaces to prevent biofouling and reduce biofouling induced corrosion. In addition, indoor and humid areas, microbial growth can be limited by surfaces that are easier to clean.

Antimicrobial surface modification without a toxic environmental effect has been used, for example, in the silver coatings of refrigeration equipment. Coatings of this type do not kill the flora, but prevent or very strongly slow their growth on the surface. There has also been widespread development in applications demanding a high hygienic level such as the food and healthcare sectors. The textiles and paint sectors are also key markets. The market of antibacterial textiles has gained increasing importance in the last few years.
### Table 5: Anti-microbial nanocoatings - Principles, Properties, Effect, Applications and Companies

<table>
<thead>
<tr>
<th>Principle</th>
<th>• ZnO, TiO2 and SiO2 and silver are anti-bacterial at the nanoscale</th>
</tr>
</thead>
</table>
| Properties | • Silver ions have a high affinity for negatively charged side groups on bacterial molecules, which bind to the bacterial DNA. This hinders bacterial replication and simultaneously de-activates the metabolic enzymes of the cell. The result is that reproduction of the microorganism is stopped or the microorganism is killed.  
• Particles are dispersed at the surface and also throughout the coating. Additionally, a higher concentration of anti-microbial particles can be created at the surface.  
• Anti-microbial properties on the surface coating are permanent and remain effective even if the coating is cleaned  
• Low friction coating properties unaffected by the anti-microbial nanoparticles  
• Tenacious bonding to surfaces: do not require an intermediate layer and can uniformly treat all exposed surfaces, without altering the device's original mechanical or physical properties.  
• Nanoparticles are stabilized with additives and integrated homogeneously into the polymer matrix. Antimicrobial activity does not decrease with time because the solid nanoparticles are not volatile, like many commonly used biocide additives. |
| Effect | • Germs, bacteria or fungal spores brought into contact with surfaces coated with nanoparticles, are very quickly eliminated. As the particles interfere with various stages of cell metabolism, it can destroy a wide range of germs and make it difficult for microbes to develop resistance.  
• Improvement in the level of hygiene in medical and nursing facilities of all kinds, and also protection against the formation of mould and mildew in bathrooms, toilets, wash areas and kitchens and food processing facilities.  
• Long lasting antimicrobial effect, constant release of the active substance, effectiveness against bacteria and other micro-organisms, no chemical impurities, produced according to the requirements, easy processing, no changes to the characteristics of the equipped material, and no later discoloration of the equipped material. |
| Applications | • Suitable for all stainless steel, glass, and ceramic surfaces, coatings are ideal for clean rooms, bathrooms and toilets, lifts, kitchens, equipment, as well as surfaces that are repeatedly touched by people, such as keyboards, door handles, and light switches.  
• Medical hygiene, for medical devices and surface hygiene. Antibacterial and antimicrobial nanotechnology-based wall coating for hospitals, which can destroy antibiotic resistant super bug  
• Medical facilities and sensitive building applications such as schools, bathrooms, food industry facilities, hotels and retirement homes.  
• Dental implants, synthetic bones, catheters, artificial heart valves, food packages, and toys.  
• Food packaging  
• Antibacterial products with nano ZnO, TiO2 and SiO2 Nano-ZnO impregnated onto cotton textiles |
| Companies | • Acrymed, Inc.  
• Arceo  
• Bio-Gate AG  
• Bioni  
• Duraban LLC |
Table 5: Anti-microbial nanocoatings

<table>
<thead>
<tr>
<th>Companies</th>
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</thead>
<tbody>
<tr>
<td>Eco Products Group, LLC</td>
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<tr>
<td>HeiQ Materials AG</td>
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<tr>
<td>LaamScience Inc.</td>
</tr>
<tr>
<td>Millidyne Oy</td>
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<tr>
<td>NanoHorizons Inc.</td>
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<tr>
<td>Nano Hygiene Coatings Ltd</td>
</tr>
<tr>
<td>Nanokote</td>
</tr>
<tr>
<td>Nanoparticle Biochem, Inc.</td>
</tr>
<tr>
<td>Nilima Nanotechnologies</td>
</tr>
<tr>
<td>PChem Associates, Inc.</td>
</tr>
<tr>
<td>Sarastro GmbH</td>
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<tr>
<td>Surfactis</td>
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</tbody>
</table>
Anti-corrosion nanocoatings

Table 6: Market summary anti-corrosion nanocoatings

<table>
<thead>
<tr>
<th></th>
<th>Main markets</th>
<th>Total market 2012</th>
<th>Nanocoatings %</th>
<th>CAGR to 2020</th>
<th>Total market 2020</th>
<th>Nanocoatings %</th>
<th>Nanocoatings market 2020</th>
<th>Nanocoatings market 2024</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil &amp; gas, marine, military</td>
<td>$3 billion</td>
<td>1.5%</td>
<td>9.5%</td>
<td>$6.2 billion</td>
<td>7.5%</td>
<td>$465 million</td>
<td>$781 million</td>
<td></td>
</tr>
</tbody>
</table>

Corrosion is a significant problem for owners of industrial equipment, installations, and plants. As it is a slow process it can change, assuming many forms and arising very rapidly since it is triggered by environmental factors, such as oxygen and water, which cannot be eliminated. It is possible, however, to prevent corrosion, and nanocoatings are important as they can shift the focus of the problem from the protection against corrosion to its prevention.

Market drivers
Main market drivers are as follows:
• constantly increasing requirements on the performance of anti-corrosion coatings
• rising cost awareness
• increasing environmental attention related to the reduction of solvent content
• growing application of surface tolerant protective coatings systems or coatings providing universal adhesion
• replacement of toxic inhibitors such as hexavalent chromium

The presence of corrosive chemicals and harsh operating and environmental conditions can result in structural failure or loss of containment, which can be costly in terms of repairs, lost or contaminated products, environmental damage, and potential risk to personnel. Corrosion factor is very costly and has a major impact on the economies of industrial nations companies. The annual direct cost of metallic corrosion in U.S. economy is estimated $300 billion and € 200 billion in Europe. While there is an increasing need for more effective and less costly products, EU and government regulations are also driving demand for lower content of chemicals in coatings. Therefore need for new solutions is urgent.

Nanoparticles
Protective coatings incorporating nanoparticles have been developed as industrial protective coatings, corrosion protection coatings, thermal resistant, fire retardant coatings, water based anti-corrosion coatings and fire retardant polymers. Nanocoatings can significantly increase the cost/benefit ratio, providing cost effective solutions and improved performances. Nanoparticles such as nano silica, clay, ZnO, Fe2O3 and TiO2 are typically used in organic coatings for improving corrosion resistance. These nanomaterials have a very high surface area. When this surface is functionalized, it can deliver high loadings of organic corrosion inhibitors. Thus, tailored nanoparticles are the perfect carrier for delivery of the needed level of active corrosion inhibitors. Nanomaterials engineering also extend the possibility of engineering ‘smart’ coatings that can release corrosion inhibitors on demand when the coating is breached, stressed or an electrical or mechanical control signal is applied to the coating.

Applications
In the past few years, chromium (VI) compounds have been widely used for corrosion protection in numerous industrial applications. However, chromium (VI) is very oxidizing and classified as carcinogenic. As a result, in 2007 the use of chromium (VI) was banned in the European Union for the automotive sector.
Alternatively corrosion protection systems on base of organic-inorganic hybridmaterials with integrated oxidic nanoparticles (TiO2, ZrO2, CeO2, SiO2, etc.) have been developed, which completely avoid the use of chromium (VI) or heavy metals. These materials are thermally or photo chemically curable and can be applied via common industrial wet chemical methods.
such as spaying, dipping etc. These coatings are suitable not only for steel but also for light- or non-ferrous-metals (e.g. aluminum, magnesium, copper) and their alloys (e.g. brass). Further advantages of these coating systems are their transparency, which preserves the visual appearance of the substrate surface and good adhesion- and barrier-properties realized with a coating thickness of only a few micrometers. The minor material usage due to the low layer thickness also contributes to saving resources and to increasing the energy efficiency by weight reduction. Adapted to specific requirements the corrosion protection coatings can also be combined with other functionalities such as abrasion resistance.

Sol-gel hybrid coatings of organic and inorganic materials can combine the mechanical toughness and flexibility of organic components with the thermal stability and hardness of inorganic components. Sol-gel nanocoatings can be designed to be used on any steel substrate and could thus be applied to anti-corrosion components from a wide range of markets. These markets include mining (ore processing, surface and underground mining, and drilling), utilities (seals, accessories, and bearings), defense, agriculture (tillage and planting), construction (drill bits, grinder hammer tips, and other hardware), shipping, energy (wind power at sea) and transportation (brakes, valve trains, bearings, and gears).
Table 7: Anti-corrosion nanocoatings—Principles, Properties, Effect, Applications and Companies

| Principle | Nanoparticle materials have a very high surface area. When this surface is functionalized, it can deliver high loadings of organic corrosion inhibitors. Thus, tailored nanoparticles are the perfect carrier for delivery of the needed level of active corrosion inhibitors.  
- Nanostructured materials engineering extends the possibility of engineering ‘smart’ coatings that can release corrosion inhibitors on demand when the coating is breached, stressed or an electrical or mechanical control signal is applied to the coating. Inherently conducting polymer (ICP) films containing inhibiting anions as the dopant anions can release them when the film is coupled to a breach in the coating. Research has developed chromate-free corrosion inhibiting additives in which organic corrosion inhibitors are anchored to nanoparticles with high surface areas that can be released on-demand.  
- Incorporation of nanoparticles in the hybrid sol–gel systems increases the corrosion protection properties due to lower porosity and lower cracking potential. Incorporation of inorganic nanoparticles can be a way to insert corrosion inhibitors, preparing inhibitor nanoreservoirs for self-repairing pre-treatments with controlled release properties.  
- Nanostructures form protective oxidation scales with superior adhesion to the substrate. The high density of grain boundaries provides fast diffusion paths, promoting selective oxidation of protective oxide scales. The fine-grained coatings and/or the fine-grained oxide scales show a fast creep rate at high temperatures, which can release the stresses accumulated in the scales, therefore reducing the scale spallation tendency. The oxides formed on nanocrystalline coatings are micro pegged onto the grain boundaries to form a complex interface that results in better scale adhesion to the metal substrate. Nanocrystalline alloy coatings, oxide-dispersive alloy coatings and metal-oxide composite coatings show superior high-temperature corrosion resistance |
| Properties | Nanoparticles have:  
- High surface areas (e.g. good carriers)  
- Novel surface chemistries (triggered release)  
- Multiple property enhancements (e.g. corrosion resistance and chemical resistance to Skydraul) |
| Effect | Protect organics from reacting with resin due cure  
- Prevents leach-out  
- Triggered release possible due to novel surface chemistries  
- Nano-sized silica has proved to be an alternative to phosphate–chromate pretreatment that is hazardous due to toxic hexavalent chromium  
- Nano cobalt–phosphorus is compatible with most existing electroplating equipment and positioned as an effective replacement for the hexavalent chromium  
- Nanocomposite coatings based on hydroxyapatite nanoparticles can provide better corrosion protection of titanium that can be utilized for fabrication of advanced biomedical implants |
Table 7: Anti-corrosion nanocoatings-Principles, Properties, Effect, Applications and Companies

<table>
<thead>
<tr>
<th>Applications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Corrosion resistance is essential for metals used in a wide range of applications. Sectors that require the use of anticorrosive coatings include: Oil and Gas, Shipping and Shipyard sector, Energy, Infrastructures, Rolling Stock, Lifting equipment, Port machinery and the Lighting sector&lt;br&gt;• Current naval ships utilize a protective coating system that consists of separate primer and topcoat films, both individually applied. This practice contributes significantly to the ship’s construction schedule and cost. The affordability of the coating process could be improved if a one-coat, direct-to-metal coating could be used instead.</td>
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<table>
<thead>
<tr>
<th>Companies</th>
<th></th>
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<tbody>
<tr>
<td>• AnCatt</td>
<td></td>
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<tr>
<td>• Millidyne Oy</td>
<td></td>
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<tr>
<td>• NanoHorizons Inc.</td>
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<tr>
<td>• Nano Hygiene Coatings Ltd</td>
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<tr>
<td>• PChem Associates, Inc.</td>
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<td>• Sarastro GmbH</td>
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<td>• Surfactis</td>
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<td>• Xtalic</td>
<td></td>
</tr>
</tbody>
</table>
Abrasion and wear-resistant nanocoatings

Table 8: Market summary for abrasion and wear-resistant nanocoatings

<table>
<thead>
<tr>
<th>Main markets</th>
<th>Automotive, aerospace and aviation, tools, manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total market 2012</td>
<td>$5 billion</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>1.1%</td>
</tr>
<tr>
<td>CAGR to 2020</td>
<td>5.37%</td>
</tr>
<tr>
<td>Total market 2020</td>
<td>$7.6 billion</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>5.5</td>
</tr>
<tr>
<td>Nanocoatings market 2020</td>
<td>$418 million</td>
</tr>
<tr>
<td>Nanocoatings market 2024</td>
<td>$648 million</td>
</tr>
</tbody>
</table>

By engineering composite materials at the nanoscale it is possible to obtain super hard materials that rival diamond in performance. In machining and wear resistant applications, hard coatings are essential for enhancing the wear resistance and toughness properties of cutting tools. Conventional coatings do not meet the needs of current machining and manufacturing requirements as well as nanostructured coatings.

Nanoparticles
Nanoparticle containing organic–inorganic hybrid sol–gel films have been developed to improve the corrosion resistance property of steel. Surface hardness and the wear resistance of materials can be significantly improved through a nanoparticulate coating making the base material harder and improving the wear resistance of the surface. Nanoparticles improve wear resistance and toughness properties and offer comprehensive corrosion inhibition as well as meeting stringent regulatory and safety requirements. Research is very active and significant progress has been achieved. There are already many commercial applications in mechanical structures and in the machining of materials. The emphasis is on metal treatment, but also promising results have been shown for non-metallic materials. Nanoscale structuring using nano size grains and nanolayers helps in preventing/pinning dislocations, thereby dramatically enhancing wear-resistance properties. Nanocoatings also significantly improve other properties such as toughness and thermal shock resistance of the intended surface for a variety of conventional materials such as ceramics, composites and metal alloys. Nanocoatings display a lower wear rate than their counterparts of commercial coarse-grained powders. This improvement in wear resistance is attributed to the high hardness and toughness of the nanomaterials, and the change of fracture and material-removal due to ultrafine particle size. Nanoscale multilayer coatings, which consist of alternating layers of materials, further improve the performance of single-layer nanostructured coatings. When properly tailored, nano-multilayer coatings produce super hardness and super modulus effects.

Markets
Target markets are friction management, machine and engine technology are especially large targets of developmental activity. The metal finishing market is estimated to be $32 billion. Application targets are heavily worn items such as floors, stairs, handrails, safety goggles, visors and dental fillers. There is also great commercial potential in engines and devices. The potential market for such coatings and coated articles is very wide range from large scale steel, Ni and Ti alloys sheet products to cutting and processing tools; wear resistant parts for automotive, aircraft/space and chemical industries; biocompatible and wear resistant surgical implants down to miniature parts for electronics and microelectronics, including MEMS.
### Table 9: Abrasion and wear-resistant nanocoatings—Principles, Properties, Effect, Applications and Companies

<table>
<thead>
<tr>
<th>Principle</th>
<th>Abrasion</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Inorganic based nanoparticles provide improved scratch and abrasion resistance, by increasing alumina or silica content. High concentration is responsible for the improved scratch and wear resistance of the coating.</td>
<td></td>
</tr>
<tr>
<td>• By engineering composite materials at the nanometer scale it is possible to obtain super hard materials that rival diamond in performance. In machining and wear resistant applications hard coating are essential for enhancing the wear resistance and toughness properties of cutting tools. Conventional coatings do not meet the needs of current machining and manufacturing requirements as well as nanocoatings</td>
<td></td>
</tr>
<tr>
<td>• Nanoscale structuring using nano size grains and nanolayers helps in preventing/pinning dislocations, thereby dramatically enhancing wear-resistance properties. Nanocoatings also significantly improve other properties such as toughness and thermal shock resistance of the intended surface for a variety of conventional materials such as ceramics, composites and metal alloys</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Properties</th>
<th>Abrasion</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Scratch resistance of coating can be improved by using micron sized inorganic fillers, but they cause matt or semi-matt appearance to coating by scattering visible light. However, by using nanoparticles, scattering of light can be reduced significantly. Nano powders of particle size around 40 to 60 nm are effective fillers. Nanoparticles such as ZrO2, AIOOH, SiO2 have been embedded in UV-curable lacquers, resulting in improved abrasion resistance</td>
<td></td>
</tr>
<tr>
<td>• Protective layers based on polymeric or particulate sols applied onto a surface as a sol by simple mechanical coating techniques such as dip and spin coating. The resulting protective layers are purely inorganic, transparent and curable or sinterable even at a low temperature and have a high microhardness in addition to a very good corrosion protection effect. Storage modulus and temperature resistance are increased</td>
<td></td>
</tr>
<tr>
<td>• Highly reactive as they cure in seconds, easy to apply as no special equipment is needed, are environmentally friendly because they contain no solvents, and because of the small particle size, are transparent.</td>
<td></td>
</tr>
</tbody>
</table>

| Wear |  |
| • Outstanding wear, abrasion and erosion resistance |  |
| • Unique flexibility, toughness and impact-resistance |  |

<table>
<thead>
<tr>
<th>Effect</th>
<th>Abrasion</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ceramic network gives hardness to the coatings and organic components make coatings more flexible and tough</td>
<td></td>
</tr>
<tr>
<td>• The materials are resistant to a large number of chemicals.</td>
<td></td>
</tr>
<tr>
<td>• Nanoparticles have been shown to improve the mechanical properties even at low loadings and due to their small particle size; they do not affect the transparency of clear coats. Scratch resistance also improved further due to homogeneous distribution of nanoparticles in polymers. Even a small amount can retain the appearance of surface without any negative impact on coating and its gloss</td>
<td></td>
</tr>
</tbody>
</table>

| Wear |  |
| • Nanocrystalline metals or coatings display a lower wear rate than their counterparts of commercial coarse-grained powders. This improvement in wear resistance is attributed |  |
to the high hardness and toughness of the nanostructured materials, and the change of fracture and material-removal due to ultrafine particle size.

- Nanoscale multilayer coatings, which consist of alternating layers of materials, further improve the performance of single-layer nanocoatings. When properly tailored, nano-multilayer coatings produce superhardness and supermodulus effects.

<table>
<thead>
<tr>
<th>Applications</th>
<th>Abrasion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Vehicle and protective environments. Scratch-resistant varnishes for automobile paint</td>
</tr>
<tr>
<td></td>
<td>• Light metals (Aluminium and Magnesium) and various kinds of steel, such as technical parts for cars and aircrafts as well as engine parts and production areas for food technology.</td>
</tr>
<tr>
<td></td>
<td>• Mar and scratch resistant coatings for furniture and parquet, scratch resistant high gloss lacquers on wood and barrier coatings on plastics.</td>
</tr>
<tr>
<td></td>
<td>• Protective layers for semiconductor chips</td>
</tr>
<tr>
<td></td>
<td>• Transparent plastics such as acrylic glass (PMMA), SAN and polycarbonate, e.g. for plastic walls or displays of mobile phones.</td>
</tr>
<tr>
<td></td>
<td>• Anti-corrosion coatings for pipelines</td>
</tr>
</tbody>
</table>

| Wear | Steel coatings: Wear on steel components leads to both direct and indirect costs and energy losses, including losses due to plant inefficiencies and down-time for repairs. The cost of wear to the U.S. economy was estimated to be $20 billion annually in 1978, equivalent to $65 billion dollars annually today |
|      | Nanocoatings can be designed to be used on any steel substrate and could thus be applied to components from a wide range of markets. These markets include mining (ore processing, surface and underground mining, and drilling), utilities (seals, accessories, and bearings), defense, agriculture (tillage and planting), construction (drill bits, grinder hammer tips, and other hardware), and transportation (brakes, valve trains, bearings, and gears). |
|      | • Aerospace parts |

| Companies | • BYK-Chemie |
|           | • Mitsubishi Carbide |
|           | • Advanced Thin Film, Inc. |
|           | • Cleancorp Nanocoatings |
|           | • CMR Coatings |
|           | • DAW Caparol |
|           | • Industrial Nanotech, Inc. |
|           | • Industrial Science and Technology Network (ISTN, Inc.) |
|           | • Inframat Corp. |
|           | • Integran Technologies |
|           | • Modumetal, Inc. |
|           | • Nanofilm |
|           | • Nanogate Coating Systems GmbH |
|           | • Nanosol AG |
|           | • The NanoSteel Co. |
|           | • Nanovere Technologies, Inc. |
|           | • NANO-X GmbH |
|           | • NTC Nanotech Coatings GmbH |
|           | • Perpetual Technologie |
|           | • Resodyn Corporation |
|           | • TDA Research |
Anti-fouling/easy to clean nanocoatings

Table 10: Market summary for anti-fouling and easy to clean nanocoatings

<table>
<thead>
<tr>
<th>Main markets</th>
<th>Construction, marine, household, sanitary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total market 2012</td>
<td>$2.5 billion</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>4%</td>
</tr>
<tr>
<td>CAGR to 2020</td>
<td>7.3%</td>
</tr>
<tr>
<td>Total market 2020</td>
<td>$4.4 billion</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>13%</td>
</tr>
<tr>
<td>Nanocoatings market 2020</td>
<td>$572 million</td>
</tr>
<tr>
<td>Nanocoatings market 2024</td>
<td>$859 million</td>
</tr>
</tbody>
</table>

Anti-fouling and easy to clean nanocoatings have gained impressive market traction, especially in the building materials, marine and household (mainly bathroom) sectors. These coatings allow for improvement in the appearance of machinery and equipment, hygiene and corrosion resistance in different environments. Applications are in:

- Machinery and equipment operating in dirty process conditions.
- Energy technology equipment; wind generators, solar cells and solar collectors.
- Sensors
- Packaging
- Home appliances.

Application targets are generally all surfaces for which contaminants harm the aesthetic, hygienic or technical operation. The goal is both a better level of cleanliness as well as a reduction of cleaning costs.

Nanoparticles

Coatings incorporating nanoparticles and nano layers have been developed more durable, easy-to-clean paints and anti-graffiti coating for buildings and structures. Nanoparticulate coatings can make the applied surface both hydrophobic and oleophobic at the same time, which have been used on anti-graffiti surfaces.

Anti-graffiti coatings have been developed in the last few years that include the use of polysiloxane modified polyurethanes whose weathering resistance is increased by adding silica nanoparticles.

Markets

A number of large multinationals, including Evonik, Dupont, Schott, 3M and Corning produce anti-fouling and easy-to-clean coatings for a variety of markets. Other companies in this and self-cleaning markets include Ferro, United Protective Technologies, Masco, PPG, AGC and Raytheon.

Commercial examples of easy-clean coatings include construction materials such as painted metals for increased durability (predicted lifetime of 5-7 years), plastic materials (e.g. polycarbonate, PMMA) with increased transparency and dirt resistance (easy-to-clean surface hinders the dirt pick-up by the substrate, resulting in cleaner surfaces that are easier to clean) and surfaces in kitchens and bathrooms.

The marine sector a main market for anti-fouling nanocoatings. Marine fouling is estimated to cost the shipping industry over 200 billion dollars per year. Anti-fouling nanocoatings are also being applied in the food processing industry. Heat exchangers are widely used in industries such as brewing, dairy and food processing. A problem for these heat exchangers is fouling due to the adhesion of both organic and inorganic materials on the steel walls. This results in reduced thermal transfer efficiency and increased energy costs. Fouling in heat exchangers and associated pipes in the dairy sector reduce performance and increase costs, as well as causing potential contamination problems. By applying anti-fouling nanocoatings it is possible to reduce downtime and cut cleaning costs.

According to G-Shield, the costs of removing and repairing graffiti damage are estimated at $12 - $25 billion annually. Graffiti is a major, increasing danger to architectural heritage materials. Graffiti can affect to all class of surfaces materials and in the majority of the cases, the cleaning is very expensive and quite often, the penetration into the pores contained in the sub-
strate material induces an irreparable effect onto the painted surface. Anti-graffiti paint has been developed by functionalizing nanoparticles and polymers to form a coating repellent to water and oil at the same time. As a result, the coated surface is non-stick and very easy to clean, and able to withstand repeated graffiti attacks. Nanostructured coatings represent the latest application area for anti-graffiti coatings by making the surface highly hydrophobic independently on its nature and protecting it against water, minimizes the adhesion of the graffiti paint and facilitates the removing process with water, soft detergents or hand cleaning by employing a cloth.

| Principle | • Minimization of free surface energy by chemical nanotechnology  
|          | • Self organizing anti-adhesion groups |
| Properties | • Suited for metal, glass, ceramic, stone and plastic surfaces  
|           | • Simple application e.g. by spraying and room temperature or thermal curing  
|           | • Transparent, good adhesion on the substrate without difficult pretreatment  
|           | • Low free surface energy: < 24 mN/m² contact angle about 60° against hexadecane  
|           | • Anti-stick- and easy-to-clean-properties, additionally with corrosion protection (for metals)  
|           | • Durable, inert surface protection with good mechanical and chemical stability, for plastic materials: scratch and abrasion resistance comparable with mineral glass possible  
|           | • Additionally anti-bacterial (bioizide) properties or protection against moss-, fungus and alga growth possible |
| Effect | • Durable hydro and oleophobicity, meaning water and organic liquids pearl off easily  
|        | • Anti-stick properties: leading to less staining and easy-cleaning-effect  
|        | • Anti-graffiti properties mean that stubborn stains such as graffiti, which in the past called for intensive cleaning efforts can be washed away simply with a high pressure hose  
|        | • Nanocoatings inhibit the adhesion of microbes and marine fouling organisms. Establishment of nanostructure results in appreciable reduction in interaction between germs and surface. Nano-coating helps in reduction of germs, virus, algae by oligodynamic effect of metal component. |
| Advantages | • Water and soil repellent; can be graffiti repellent  
|           | • Easy to clean (but cleaning of dust still needed)  
|           | • Invisible  
|           | • Several types commercially available  
|           | • Fairly durable |
| Disadvantages | • Easily mechanically damaged  
|              | • Sometimes vulnerable to sunlight  
|              | • Not always easy to repair  
|              | • Not all types applicable on existing surfaces  
|              | • Care must be taken to apply the coating correctly  
|              | • Needs (regular and even) water source  
|              | • Oil and oily dirt as well as surfactants stick to the surface very well.  
|              | • If droplets contain dirt and remain on the glass, a punctiform soiling will result.  
|              | • Sometimes dust attraction because of electrostatic charge.  
|              | • Weak or no bonding between coating material and glass: short durability.  
|              | • Sanitary equipment: tiles, bath tubs, shower bath, wash basin, armature made of stainless steel and chromium, shower cabinets, toilet seat, bath room furniture |
Table 11: Anti-fouling and easy to clean nanocoatings-Principles, Properties, Applications and Companies

<table>
<thead>
<tr>
<th>Disadvantages</th>
<th>Applications</th>
<th>Companies</th>
</tr>
</thead>
</table>
| • Building protection and the construction industry: Anti-graffiti, facades, windows, doors, gates, distributor box  
• Kitchen and domestic articles: kitchen utensils, baking oven, pots and frying pans  
• Industrial beverage and food production: kneader, stirrer, containers. | • Garden, leisure and sport utensils: garden-furniture, lawn-mower, boats, outdoor-lamps  
• Automobiles: head lights, windows, felloe, varnish as well as vehicle industry in general: construction machines, tractors, military and camping vehicles  
• Marine: Wetted surfaces of naval vessels coated with nanomaterial approximately five years ago still show virtually no signs of biofouling. In addition, this nanocomposite material has superior bond strength, toughness, wear resistance, corrosion resistance and ductility compared to conventional coatings. Also, the material is very environmentally friendly, as it does not contain copper, lead or other heavy metals that are hazardous to the marine environment. | • Aculon  
• Akzo Nobel  
• Bühler AG  
• Chamelic Ltd  
• Clariant Produkte (Deutschland) GmbH  
• Cotec GmbH  
• De Cie GmbH  
• Diamon-Fusion International, Inc.  
• Evonik Degussa  
• GXC Coatings  
• Hempel  
• Inframat  
• LANCAS  
• Millidyne Oy  
• NanoCare AG  
• Nanocyl  
• Nanogate Coating Systems GmbH  
• Nanolabs Corp.  
• Nanophos SA  
• Nanopool GmbH  
• Nanosol AG  
• Nanovations Pty Ltd  
• NANO-X GmbH  
• Nano Hygiene Coatings Ltd  
• n-tec GmbH  
• NTC Nanotech Coatings GmbH  
• Percenta AG  
• Rittal GmbH |
Self-cleaning (Bionic) nanocoatings

Table 12: Market summary for self-cleaning (bionic) nanocoatings

<table>
<thead>
<tr>
<th>Main markets</th>
<th>Glass, hygiene, household, plastics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total market 2012</td>
<td>$145 million</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>100%</td>
</tr>
<tr>
<td>CAGR to 2020</td>
<td>18.1%</td>
</tr>
<tr>
<td>Total market 2020</td>
<td>$550 million</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>100%</td>
</tr>
<tr>
<td>Nanocoatings market 2020</td>
<td>$550 million</td>
</tr>
<tr>
<td>Nanocoatings market 2024</td>
<td>$720 million</td>
</tr>
</tbody>
</table>

Manufacturers are greatly interested in implementing technology that can keep their products looking clean and new after years of use. Ideally, these coatings will be durable and allow greatly prolonged cleaning cycles such that products would need only occasional rinsing with water or wiping with a damp cloth to remove dirt and oils. Applications include virtually any outdoor surface that requires occasional cleaning. A number of existing technologies minimize cleaning, but typically lack durability. Therefore manufacturers are seeking to exploit nanocoatings that both minimize cleaning and are durable enough to last a number of years when exposed to environmental conditions such as sand, dirt, oil, pH, wind, ice, moisture, salt, sun, pollution, bird droppings and tree sap. The market for hydrophobic coatings has expanded in recent years and is finding traction in automotive glass, sanitary equipment, consumer electronics, medical devices, footwear and textiles and aviation exteriors.

Nanoparticles

Clean or self-cleaning surfaces can be achieved by two principally different approaches. A photocatalytic coating can be applied to the surface, where the effect of the sun’s ultraviolet rays catalytically breaks down organic dirt. At the same time the surface changes into a superhydrophilic at which time the water spreads evenly over the surface and less drying traces are formed by dripping.

Another way to manufacture a self-cleaning (bionic) surface is done in accordance with the Lotus effect phenomenon in which the surface becomes a super-hydrophobic. The level of hydrophobicity is determined by the contact angle of water – contact angles greater than 90º are generally regarded as hydrophobic. A hydrophobic surface can be achieved when hydrophobic surface chemistry is combined with a suitable surface roughness. A superhydrophobic surface is able to repel water droplets completely; such surfaces exhibit water droplet advancing contact angles (CA) of 150º or higher. The most

Markets

Superhydrophobic coatings and films have a wide spectrum of applications; they are used not only for resisting water and fog condensation, but also for preventing contamination. Markets include:

- Architectural glass
- Building materials
- Auto glass
- Shower doors
- Consumer electronics
- Solar panel glass covers
- Traffic signs/signals
- Greenhouses
- Displays
- Military/Defence
- Aerospace
- Industrial, sports and military protective eyewear
- Optical components and sensors.

A number of companies have developed products seeking to replicate the lotus effect (BASF, Evonik). However there are a number of disadvantages to this technology that have reduced its widespread uptake. There are questions over durability, requirements for expensive lithography and resultant scalability to large surface areas. This also applies to hydrophobic and superhydro-
Hydrophobic coatings in general. The coatings can be easily damaged and lack durability. Common approaches to hydrophobic coating include application of nanoparticles in a formulation and use of fluorinated polymers. Aculon, Inc. utilizes a self-assembled monolayer of phosphonates (SAMP) method. SAMPs can coat metals, metal oxides, glass, ceramics, particles, semiconductors, and even some polymer surfaces by drawing on its library of structurally tailored phosphonic acids. The SAMP is covalently bound to the substrate surface. Consumer applied hydrophobic coatings for plastics currently on the market include Raincoat (MotoSolutions), Visor Proof (Nikwax), and Oakley Hydrophobic Coating (Oakley). However, none of these are superhydrophobic, resulting in only modest improvements in water contact angle. Liquipel, Aridion, and NeverWet and HzO (Samsung) have been developed for application in consumer electronics (smart phone waterproof coatings). As well as providing a direct barrier to moisture, hydrophobic coatings are also used for anti-icing, anti-corrosion, anti-fouling, and anti-microbial surfaces.
### Table 13: Self-cleaning (Bionic) nanocoatings—Principles, Properties, Applications and Companies

<table>
<thead>
<tr>
<th>Principle</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Minimization of free surface energy by chemical nanotechnology</td>
<td>• Self organizing anti-adhesion groups on nanostructured surface</td>
</tr>
<tr>
<td>Properties</td>
<td></td>
</tr>
<tr>
<td>• Suited for metal, glass, ceramic, stone and plastic surfaces</td>
<td></td>
</tr>
<tr>
<td>• Simple application e.g. by spraying and subsequent thermal treatment</td>
<td></td>
</tr>
<tr>
<td>• Translucent (metal, ceramic, glass, stone) or transparent (plastic, e.g. Polycarbonate)</td>
<td></td>
</tr>
<tr>
<td>• Good adhesion on the substrate without difficult pretreatment</td>
<td></td>
</tr>
<tr>
<td>• Low free surfaces energy: &lt;24mN/m²</td>
<td></td>
</tr>
<tr>
<td>• Contact angle &gt;120 (water), superhydrophobic</td>
<td></td>
</tr>
<tr>
<td>• Self-cleaning effect, if the nanostructured low free energy surface is exposed to rain fall</td>
<td></td>
</tr>
<tr>
<td>Effect</td>
<td></td>
</tr>
<tr>
<td>• Water nearly pearls off completely</td>
<td></td>
</tr>
<tr>
<td>• Leaned dirt is rinsed off easily by (rain-)water</td>
<td></td>
</tr>
<tr>
<td>Advantages</td>
<td></td>
</tr>
<tr>
<td>• Water and soil repellent</td>
<td></td>
</tr>
<tr>
<td>• Self cleaning (if wetted by rain or other method)</td>
<td></td>
</tr>
<tr>
<td>• Invisible</td>
<td></td>
</tr>
<tr>
<td>• Several types commercially available</td>
<td></td>
</tr>
<tr>
<td>Disadvantages</td>
<td></td>
</tr>
<tr>
<td>• Not very durable</td>
<td></td>
</tr>
<tr>
<td>• Easily mechanically damaged</td>
<td></td>
</tr>
<tr>
<td>• Not always easy to repair</td>
<td></td>
</tr>
<tr>
<td>• Not all types applicable on existing surfaces</td>
<td></td>
</tr>
<tr>
<td>• Metal surfaces hard to treat with most systems</td>
<td></td>
</tr>
<tr>
<td>• Care must be taken to apply the coating correctly</td>
<td></td>
</tr>
<tr>
<td>• Needs (regular and even) rain or other water source</td>
<td></td>
</tr>
<tr>
<td>• Detergents destroy the effect</td>
<td></td>
</tr>
<tr>
<td>• Coating is visible in most cases (translucent, not transparent).</td>
<td></td>
</tr>
<tr>
<td>• Surfactants adhere very well and can block the effect even permanently.</td>
<td></td>
</tr>
<tr>
<td>• Coating is removed by and by – porous surface remains and is much harder to clean than an uncoated surface.</td>
<td></td>
</tr>
<tr>
<td>• No “self-repair-effect”</td>
<td></td>
</tr>
<tr>
<td>• Coating cannot be repaired on site.</td>
<td></td>
</tr>
<tr>
<td>Applications</td>
<td></td>
</tr>
<tr>
<td>• Outdoor surfaces, which are exposed to the elements such as self-cleaning facades (concrete-, plastic, metal or painted surfaces), windows, doors and gates;</td>
<td></td>
</tr>
<tr>
<td>• Solar plants, wind turbines (rotor blades, housing), satellite bowls.</td>
<td></td>
</tr>
<tr>
<td>• Windows</td>
<td></td>
</tr>
<tr>
<td>• Car screen windows and mirrors</td>
<td></td>
</tr>
<tr>
<td>• Clothes</td>
<td></td>
</tr>
<tr>
<td>• Road signs</td>
<td></td>
</tr>
<tr>
<td>Companies</td>
<td></td>
</tr>
<tr>
<td>• Cleanercorp Nanocoatings</td>
<td></td>
</tr>
<tr>
<td>• CTC Nanotechnology</td>
<td></td>
</tr>
<tr>
<td>• CVD Technologies Limited</td>
<td></td>
</tr>
<tr>
<td>• Cytonix Corporation</td>
<td></td>
</tr>
<tr>
<td>• Gelwell Biotech Corp</td>
<td></td>
</tr>
<tr>
<td>• GXC Coatings</td>
<td></td>
</tr>
<tr>
<td>• Luna Innovations</td>
<td></td>
</tr>
<tr>
<td>• Microphase Coatings, Inc.</td>
<td></td>
</tr>
</tbody>
</table>
### Table 13: Self-cleaning (Bionic) nanocoatings-Principles, Properties, Applications and Companies

<table>
<thead>
<tr>
<th>Companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>• NanoCover A/S</td>
</tr>
<tr>
<td>• Nanoproofed</td>
</tr>
<tr>
<td>• Nanovere Technologies, Inc.</td>
</tr>
<tr>
<td>• NANO-X GmbH</td>
</tr>
<tr>
<td>• Nano Hygiene Coatings Ltd</td>
</tr>
<tr>
<td>• Nelman Sciences</td>
</tr>
<tr>
<td>• nGimat Co.</td>
</tr>
<tr>
<td>• Oak Ridge National Laboratory</td>
</tr>
<tr>
<td>• Percenta AG</td>
</tr>
<tr>
<td>• Resodyn Corp.</td>
</tr>
<tr>
<td>• Ross Technology</td>
</tr>
<tr>
<td>• Sandia National Laboratory</td>
</tr>
<tr>
<td>• Seashell Technologies</td>
</tr>
</tbody>
</table>
Self-cleaning (Photocatalytic)

Table 14: Market summary for self-cleaning (photocatalytic) coatings

<table>
<thead>
<tr>
<th>Main markets</th>
<th>Glass, hygiene, sanitary.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total market 2012</td>
<td>$850 million</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>100%</td>
</tr>
<tr>
<td>CAGR to 2020</td>
<td>7.87%</td>
</tr>
<tr>
<td>Total market 2020</td>
<td>$1.2 billion</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>100%</td>
</tr>
<tr>
<td>Nanocoatings market 2020</td>
<td>$2.2 billion</td>
</tr>
<tr>
<td>Nanocoatings market 2024</td>
<td>$2.65 billion</td>
</tr>
</tbody>
</table>

Self-cleaning coatings based on photocatalysts are currently suitable mainly for exterior use for inorganic surfaces and coatings, but photocatalytic materials operating at the wavelength of visible light are also widely studied. Industries impacted by self-cleaning photocatalytic coatings include:

- Architectural glass and construction (including road)
- Medical (self-disinfecting coatings)
- Food production and packaging
- Water purification
- Air purification (indoor)
- Solar coatings.

Nanocoatings

Nanocoatings boosts chemical reactions under irradiation with light. This is particularly true for the decomposition of organic substances such as fats, oils or even microbes. The catalytic efficiency is considerably enhanced by the utilization of nanoscale photocatalysts; with TiO2 the most commonly used photocatalyst. Nanostructured TiO2 possesses high specific surface area, high pore volume and pore size, high activity, and low density. These properties increase the accessible surface area and mass transfer for organic pollutant adsorption, resulting in better photocatalytic performance, since photocatalytic reactions are based on chemical reactions on surfaces. Applications make use of the self-cleaning, antifogging, anti-microbial or water cleaving properties. In indoor environments, most surfaces, e.g. ceramic tiles, windows glass or paper, are gradually covered with organic matter such as oils, dirt, and smoke residue and become fouled. Transparent TiO2 coatings can be completely unobtrusive, causing no readily discernable changes in the substrate colour or transparency, but they can decompose organic matter as it deposits.

Markets

Nano-TiO2 (coated with 10-20nm layer of TiO2) self-cleaning coatings greatly benefit building maintenance, especially for skyscrapers, as they reduce the need for costly surface cleaning. Various types of surfaces with TiO2 can be covered to make them self-cleaning under sunlight as well as room light. Thus, surfaces based on paints, ceramics, glass, cementitious materials containing active photocatalytic titania nanoparticles have widespread applications to create environmentally clean areas within their proximity. Numerous applications have been developed from utilizing the photocatalytic reaction of TiO2:

- Self-Sanitizing Surface: Photocatalyst coating is utilized as a hygienic coating to reduce bacteria and virus contamination. This coating removes the organic matter necessary for bacteria growth. The strong oxidation mechanism also eliminates any bacteria by causing lesion of cell membrane and lysing of cell content.
- Self-Cleaning Coating: Building’s exterior surface benefit from these sustainable photocatalytic coatings by eliminating any contaminants that are causing the building to become dirty such as the oil content from car exhausts and any mold or mildew stains.
- Reduce Indoor Air Pollution and Sick Building Syndrome: Photocatalyst coating and products control Sick Building Syndrome by removing Volatile Organic Compounds emitted from building material and furniture and create a purer space for comfortable living and working conditions.
- Reduction of Air Pollution: Photocatalytic oxidation reduces hydrocarbon waste produced from industrial factories burning fossil fuel or coal.
- Waste Water Treatment: Photocatalysts can replace chlorine to be more effective and a much safer alterna-
Table 15: Self-cleaning (Photocatalytic) nanocoatings—Principles, Properties, Applications and Companies

<table>
<thead>
<tr>
<th>Principle</th>
<th>Properties</th>
<th>Effect</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanoscaled anatas type titania particles in an inert binder</td>
<td>• Good adhesion on metals and glasses</td>
<td>• Anatas type photocatalytic titania nanoparticles in an photocatalytically non-degradable matrix</td>
<td>• Removes odor, greasy components</td>
</tr>
<tr>
<td>Stable interface substrate/coating</td>
<td>• High chemical resistance against solvents and acids</td>
<td>• Excitation by environmental UV-rays</td>
<td>• Kills bacteria, viruses (claim conflicts with biocides legislation)</td>
</tr>
<tr>
<td>Wet coating technologies/chemical nanotechnologies</td>
<td>• Highly transparent by nanodimensioned inorganic components</td>
<td>• Superhydrophilic surface (antifogging)</td>
<td>• Invisible</td>
</tr>
<tr>
<td></td>
<td>• Glass-like surface hardness</td>
<td>• Self-cleaning effect by degradation of organic and noxious materials</td>
<td>• Several types commercially available</td>
</tr>
<tr>
<td></td>
<td>• Application technology commercially available, e.g. spray, dip, flow or roller coating</td>
<td></td>
<td>• Organic dirt can be destroyed by ultraviolet light and will be swept away by water</td>
</tr>
</tbody>
</table>

Nano-TiO2 coatings are widely commercially available and have been used in (mainly in the Japanese and European markets) in water and air purification, self-cleaning glass, concrete products and a variety of coatings applications. Photocatalytic coatings have been applied to numerous buildings in Japan including Chuba International Airport Terminal. Photocatalyst coatings have been proven to combat Bird Flu and SARS infections in high risk areas. Hundreds of hospitals and thousands of buildings in Asia and recently in Europe were coated to protect property against deadly infections and environmental pollution damage.

The market for photocatalytic technology in Japan has experienced significant growth in the last decade and was worth over $1 billion million in sales in 2012 (Photocatalysis Industry Association of Japan). The general sales volume for clean-up technologies has increased greatly in recent years, such as photocatalytic air-purifiers, especially in Asia. Asia and Europe are the largest markets, with little traction at present in the United States.

Products currently available include Pilkington’s Activ self-cleaning glass, Ecoclean sidings from Alcoa, and Boral’s BoralPure™ SMOG-EATING Tile. These products all contain nanoscale TiO2.
<table>
<thead>
<tr>
<th>Disadvantages</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Not easy to repair</td>
<td>• High humidity areas (e.g. bath rooms)</td>
</tr>
<tr>
<td>• Non durable</td>
<td>• Architectural units</td>
</tr>
<tr>
<td>• Chemical attack by bird dropping et cetera</td>
<td>• Automotive parts</td>
</tr>
<tr>
<td>• Easily mechanically damaged</td>
<td>• Machines/covers</td>
</tr>
<tr>
<td>• Not all types applicable on existing surfaces</td>
<td>• Clinical surfaces</td>
</tr>
<tr>
<td>• Needs UV (and water) source</td>
<td>• Pharmaceutical packing</td>
</tr>
<tr>
<td>• Inorganic dirt can incorporate into the microporous structure and cannot be</td>
<td></td>
</tr>
<tr>
<td>destroyed by ultraviolet light</td>
<td></td>
</tr>
<tr>
<td>• No E2C-effect for inorganic soiling. Cleaning can be difficult.</td>
<td></td>
</tr>
<tr>
<td>• Photocatalytic coating sometimes causes changing glass colors</td>
<td></td>
</tr>
<tr>
<td>• In case of heavy rain, reduced visibility because of varying refraction –</td>
<td></td>
</tr>
<tr>
<td>uneven water film.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Bioshield Inc.</td>
</tr>
<tr>
<td>• Caparol</td>
</tr>
<tr>
<td>• Carrier Corp</td>
</tr>
<tr>
<td>• Cristal</td>
</tr>
<tr>
<td>• Daikin Ltd.</td>
</tr>
<tr>
<td>• FN Nano, Inc.</td>
</tr>
<tr>
<td>• Green Earth Nanoscience, Inc.</td>
</tr>
<tr>
<td>• Green Millennium Inc.</td>
</tr>
<tr>
<td>• Hiranuma Industries</td>
</tr>
<tr>
<td>• Hitachi Home and Life Solution</td>
</tr>
<tr>
<td>• Integrated Surface Technologies, Inc.</td>
</tr>
<tr>
<td>• Italcementi Group</td>
</tr>
<tr>
<td>• JFE Building Materials</td>
</tr>
<tr>
<td>• KRONOS</td>
</tr>
<tr>
<td>• Mitsubishi Plastics</td>
</tr>
<tr>
<td>• Nanopower Co.</td>
</tr>
<tr>
<td>• Nippon Soda</td>
</tr>
<tr>
<td>• n-tec GmbH</td>
</tr>
<tr>
<td>• Panahome</td>
</tr>
<tr>
<td>• Pilkington</td>
</tr>
<tr>
<td>• PPG</td>
</tr>
<tr>
<td>• Saint-Gobain</td>
</tr>
<tr>
<td>• Sekisuo Plastics</td>
</tr>
<tr>
<td>• Sto Group</td>
</tr>
<tr>
<td>• Sumitomo Metal Industries</td>
</tr>
<tr>
<td>• Taiyo Kogoyo</td>
</tr>
<tr>
<td>• Toshiba Lightec</td>
</tr>
<tr>
<td>• Toto Ltd.</td>
</tr>
<tr>
<td>• UBE Industries</td>
</tr>
</tbody>
</table>
UV-resistant nanocoatings

Table 16: Market summary for UV-resistant coatings

<table>
<thead>
<tr>
<th>Main markets</th>
<th>Wood, exteriors, textiles, paints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total market 2012</td>
<td>$365 million</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>3.5%</td>
</tr>
<tr>
<td>CAGR to 2020</td>
<td>4.9%</td>
</tr>
<tr>
<td>Total market 2020</td>
<td>$535 million</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>9%</td>
</tr>
<tr>
<td>Nanocoatings market 2020</td>
<td>$48 million</td>
</tr>
<tr>
<td>Nanocoatings market 2024</td>
<td>$95.9 million</td>
</tr>
</tbody>
</table>

Nanoparticles can provide improved UV resistance for solvent, waterborne and UV coatings. Transparent UV-absorbing or UV-blocking coatings currently have two main applications: as a UV-protecting lacquer for wooden surfaces, and as a UV-barrier coating deposited on the surface of polymer-based products or devices to slow down their deterioration. As the intensity of ultraviolet (UV) radiation increases every year, effective methods to block UV rays to protect human skin, plastics, timber and other polymer materials are urgently sought. UV radiation can also cause severe damage in textiles, plastics, paints and timber products in the forms of discoloration, chalking and reduced mechanical properties. Therefore, the development of effective UV-shielding materials is of great importance to our health, society and environment. The ability to increase the durability of outdoor products, that can withstand solar radiation for months or years, makes the use protective sol-gel coatings for outdoors applications (paints, dyes and plastics or artwork pieces) very attractive for commercial applications. These coatings are typically based on organic UV absorber molecules entrapped in hybrid organic-inorganic matrices that drastically reduce UV light reaching the substrate that needs to be protected. Photodegradation is decreased upon prolonged exposition to UV sources. The coatings are also fully transparent in the visible spectrum and do not affect the optical properties of the materials that need to be protected.

Nanomaterials

Nanoparticles that contain functional coatings to achieve UV-blocking properties have been developed during the last decade. Zinc oxide (ZnO), titanium dioxide (TiO₂) and cerium oxide (CeO₂), nanoparticles are used for UV light protection products for lacquers. Nanoparticles display a significant increase in effectiveness of blocking UV light compared to natural material due to their large surface area to volume ratio.

Markets

In textiles, the UV-blocking property of a fabric is enhanced when a dye, pigment, delustrant, or ultraviolet absorber finish is present that absorbs ultraviolet radiation and blocks its transmission through a fabric to the skin. Textiles serve as important materials for UV protection in many applications. Nano-TiO₂ and ZnO is being applied for UV protection in textiles. Products on the market include Belfasun from Pulcra Chemicals, which contains nanoparticulate zinc oxide and UV cotton textiles with nanosilver coatings from Geckoline Sportswear GmbH. ZnO nanoparticles have also been incorporated into the surface of cotton and wool fabrics. The addition of ZnO increases the mechanical strength of both fabrics and results in an UV absorbing fabric. The UV absorption spectrum of ZnO is broader than TiO₂. ZnO has additional functionality, including antifungal and antistatic properties that TiO₂ cannot offer. Nanoparticles have also been utilized as additives in coatings intended to reduce the discoloration of clear-coated wood exposed outdoors. Altana (www.byk.co.jp/products/pdf/shownews_nanotech13_en.pdf) produces NANOBYK® UV absorbers based on cerium oxide or zinc oxide that remain stable and provide long-lasting protection.
### Table 17: UV-resistant nanocoatings-Principles, Properties, Applications and Companies

| Principle | Decrease in light scattering as a particle diameter approaches nanosize. Photochemical degradation caused by UV rays is a common mode of failure of most of coating systems. It causes the oxidation and decomposition of polymer films along with inorganic or organic pigments. Organic UV stabilizers also undergo deterioration after certain periods. Using nanoparticles like titania or zinc oxide improve UV resistance property by not only absorbing but also reflecting those harmful rays. Also, they are not easily destroyed by UV rays and hence can increase the life span and weather resistance of paints.  
| Properties | ZnO and TiO2 nanoparticle-embedded coatings effectively protect the surfaces from UV radiation, even at lower loading levels, than do micron size particles  
| Effect | TiO2, ZnO, SiO2 and Al2O3 particles provide extended protection in semi-transparent stains and provides long-term protection from harmful UV radiation in harsh environments. UV absorbers provide long-term gloss retention and color fastness keeping damaging UV radiation away from the polymer or paint layer that they are protecting and will not impart color change  
| Applications | Electronics, textiles, varnishes, cosmetics and the paint industry. Exterior protection. In addition to appearance, the particles help improve adhesion, tannin blocking and provide improved coating durability. Polymer materials such as Kevlar that are susceptible to UV degradation may be protected by appropriate coatings. UV-blocking treatment for cotton fabrics. Includes UV protective swimsuits and sunsuits, sun protective rash shirts (rash vests), swim shirts and swim shorts, UV protection surf shirts and board shorts, sun hats and UV protective wear for babies, including romper style UV suits, sunsuits and legionnaire caps.  
| Companies | Altana  
| | Behr Paints  
| | Bühler AG  
| | Nanophase  
| | Nanovere Technologies, Inc.  
| | XL-Lutz |
The icing of surfaces is a major problem which impairs the function of those surfaces and incurs significant costs. For example, the ice storm of 2008 caused serious damage to power systems in Southern China, with more than 100 billion yuan ($16 billion) in direct economic losses. Ice and wet-snow adhesion and excessive accumulation on exposed structures and equipment is well known as a source of numerous types of failures and malfunctions in cold-climate regions. Industries affected include machine building, aviation, power transmission, maritime, trains, automotive, refrigeration, construction and wind turbines. The effects of icing include increased weight, impaired function of equipment, longer maintenance time and downtimes and human safety issues. According to the Environmental Protection Agency, 25 million gallons of deicing agents are applied to aircraft at U.S. commercial airports each year. De-icing cost typically $5,000 per aircraft, per annum. The aviation industry is also using energy-intensive pneumatic and electric anti-icing systems on aircraft to prevent ice formation on wings and other surfaces. Also in numerous other machine construction and structural technology applications, surface freezing can cause malfunctions, such as in antennas and wind turbine wings. Sol-gel nanocoatings are under development for several applications.

### Nanomaterials

Ice-phobic surfaces that have been developed generally utilize lotus leaf-inspired superhydrophobic surfaces to reduce ice or snow accumulation. However, these surfaces fail in high humidity conditions due to water condensation and frost formation and even lead to increased ice adhesion due to a large surface area. Under a frost-free environment (e.g., low humidity conditions), superhydrophobic surfaces show promising behavior in preventing ice formation, at temperatures as low as -25 to -30°C. However, recent studies have shown that these surfaces may induce ice nucleation at an even faster rate than smooth surfaces of the equivalent materials at high humidity conditions.

### Markets

GE Global Research is developing anti-icing nanocoatings. In addition to dramatically reducing ice adhesion, these surfaces now have been shown to significantly delay the onset of ice formation in simulated atmospheric icing conditions. The company are targeting applications in the aviation and wind power industry. Oil and gas companies are also seeking to exploit ice-phobic coatings for exploration in cold regions. Statoil ASA and the Nanomechanics Lab at the Norwegian University of Science and Technology are developing anti-icing coatings for potential application in the Arctic region where 20% of the world’s resources. Due to the low temperature, exploration can be compromised due to the exposed structures and equipment being affected by ice accretion and adhesion, resulting in damage, degraded reliability and occasional loss of lifetime. IceWind is a 4million euro project funded by the Norwegian Research Council that is investigating the use of carbon nanotubes in a coating or film absorb MW radiation and generate heat for anti-icing of wind turbine blades. More than 5% of annual production loss due to icing in cold climates.
Table 19: Anti-icing nanocoatings—Principles, Properties, Applications and Companies

<table>
<thead>
<tr>
<th>Principle</th>
<th>Properties</th>
<th>Effect</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Applications</th>
<th>Companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Minimization of free surface energy by chemical nanotechnology</td>
<td>• Simple application e.g. by spraying and subsequent thermal treatment</td>
<td>• Block ice formation</td>
<td>• Reduced ice adhesion</td>
<td>• Durability</td>
<td>• Transportation (aircrafts, cars and trains)</td>
<td>• Battelle</td>
</tr>
<tr>
<td>• Self organizing anti-adhesion groups on nanostructured surface</td>
<td>• Translucent</td>
<td>• As with anti-fogging application, the coating keeps water or ice from</td>
<td>• Invisible</td>
<td>• Easily mechanically damaged</td>
<td>• Cooling units</td>
<td>• Cg2nanocoatings</td>
</tr>
<tr>
<td></td>
<td>• Good adhesion on the substrate without difficult pretreatment</td>
<td>being able to stick to the nanostructured surface, and it rolls off</td>
<td>• Scalable to large surfaces</td>
<td>• Not always easy to repair</td>
<td>• Wind energy plants</td>
<td>• GE Global Research</td>
</tr>
<tr>
<td></td>
<td>• Low free surfaces energy</td>
<td></td>
<td></td>
<td>• Not all types applicable on existing surfaces</td>
<td>• Bridges</td>
<td>• NanoSonic</td>
</tr>
<tr>
<td></td>
<td>• Static water contact angle (CA)&gt;150°, superhydrophobic</td>
<td></td>
<td></td>
<td>• Fail in high humidity conditions due to water condensation and frost formation</td>
<td>• Antennas and transmission lines</td>
<td>• Nanovere</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Can lead to increased ice adhesion due to large surface area</td>
<td>• Rotor blades</td>
<td>• NeverWet</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Statoil ASA</td>
</tr>
</tbody>
</table>
Thermal barrier and flame retardant nanocoatings

Table 20: Market summary for thermal barrier & flame retardant nanocoatings

<table>
<thead>
<tr>
<th>Main markets</th>
<th>Diesel and gas engines, aerospace and land based turbine engines, and aerospace structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total market 2012</td>
<td>$4 billion</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>1%</td>
</tr>
<tr>
<td>CAGR to 2020</td>
<td>8.35%</td>
</tr>
<tr>
<td>Total market 2020</td>
<td>$7.6 billion</td>
</tr>
<tr>
<td>Nanocoatings %</td>
<td>3.5%</td>
</tr>
<tr>
<td>Nanocoatings market 2020</td>
<td>$266 million</td>
</tr>
<tr>
<td>Nanocoatings market 2024</td>
<td>$420 million</td>
</tr>
</tbody>
</table>

In 2012, the market for thermal barrier coatings was estimated to be over $3.75 billion (Modumetal). Thermal spray coatings on gas turbine engines is a major market where there is a need for higher power and efficiency. Gas-turbine engines are currently a $42 billion industry, rising to $55 billion by 2013 (NOE). More than 1.7 million metric tons of flame retardants are used each year, with the global market for flame-retardant chemicals estimated at over $4 billion (Paintsquare). The coatings element of this market is considerably smaller. Managing the flow of thermal energy through materials is important in a wide range of industries. Thermal energy transfer can be reduced or controlled by the use of both insulation and heat reflecting materials. However both of these options are limiting in areas such as aerospace where the insulation adds weight and the reflective surfaces accrues maintenance costs. Layered nanocoatings can interfere with heat flow.

Nanomaterials

Nanocoatings incorporating nanoscale zirconia oxide show better thermal resistance and reduced thermal conductivity compared to coarse grained coatings. Thermal barrier coatings containing nanoparticles exhibit improved high temperature performance over a comparable material containing fewer of such features. A significant reduction in grain size in the case of nanomaterials induces an increase in resistance to thermal fatigue by an average of 170°C, as compared to conventional materials. Thermal barrier coatings containing nanoparticles provide improved thermal cycle life, reduced tendency for sintering in columnar grained structures, and reduced thermal conductivity. These properties make them suitable for use as both a thermal barrier coating for turbine blades and vanes and a thermoelectric generator to power high temperature electronics, high temperature wireless transmitters, and high temperature sensors. Unique to these applications is that the thermal barrier coatings can act as a temperature sensor and/or a source of power for other sensors or high temperature electronics and wireless transmitters.

Nanoparticles can improve the fire retarding performance of polymeric materials. Among the different nanoparticles used in flame retardancy, layered silicates have attracted most attention. Fire-protective glass is achieved by using a clear intumescent layer sandwiched between glass panels (an interlayer) formed of fumed silica (SiO2) nanoparticles which turns into a rigid and opaque fire shield when heated. Polyhedral Oligomeric Silsesquioxanes (POSS) and carbon nanotubes (CNT) have also been incorporated in various polymers, showing strong fire-retardant effects.

Graphene also shows great potential for thermal barrier and control applications. It has high thermal conductivity (Thermal conductivity ~3000 W/m-K in plane—and highly anisotropic; ~ 2 W/m-K out of plane) for application in heat and energy storage and thermal management. Thermal conductivity in graphene nanoplatelets and carbon nanotubes is the same.
Markets
Nanoscale thermal barrier coating systems are under development for aircraft surfaces (metal and fiberglass) capable of exposure to moderate short-duration heating; high temperature hard environments in military vehicles; and in military gas turbine engines to increase component life and engine performance. Military equipment and personnel must withstand some of the most demanding environments on earth. Nanostructured coating technology enables, for example, military aircraft and turbine powered vehicles and equipment to operate uninterrupted for longer by withstanding these extreme conditions.

Table 21: Thermal barrier and flame retardant coatings—Principles, Properties, Effects, Applications and Companies

| Principle | Nanostructure provides superior toughness and strain tolerance to withstand the high thermal strains in gas turbine engines.  
Most of the flame retardant coatings such as ammonium polyphosphate and melamine lose their effective fire resistance because of their reduced mechanical properties and reduced char formation in fire and hence get easily detached from the substrate. Mechanical and chemical properties of flame retardant coating can be improved by incorporating nanoconcentrates like nano sized magnesium aluminum--layered double hydroxides (LDH) to different flame retardant coating system. Also, specific amount of nano LDH improve the fire resistance and char formation properties of flame retardant coating. Nano--LDH absorbs the heat and send out water and carbon dioxide when burns and hence lowers the temperature of substrate along with enhancement in char formation. |
| Properties | Protection against high temperature oxidation and hot corrosion attack  
Increased hardness of coating  
Increased wear resistance of coating  
Superior thermal shock resistance  
Better coefficient of thermal expansion match between bond coat and top coat  
Reduced stress in top coat due to slower growing thermally grown oxide  
Potential barrier against oxygen diffusion  
Increased lifetime of thermal barrier coatings |
| Effect | Nanostructured, nanocomposite bond coat layer below the top coat in the thermal barrier coatings prevents interface cracking  
Porous coatings insulate hot section metallic components (turbine blades, turbine vanes, combustors) from the hot gas stream in a modern aircraft gas turbine engines and in industrial gas turbine engines used for power generation  
Enables a temperature reduction of as much as 160 °C at the metal surface, thereby improving the durability of the metal component and reducing engine fuel consumption. |
### Table 21: Thermal barrier and flame retardant coatings—Principles, Properties, Effects, Applications and Companies

<table>
<thead>
<tr>
<th>Applications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Naval (diesel) engines, in military and commercial aircraft, and inland-based gas turbine engine components</td>
<td></td>
</tr>
<tr>
<td>• Coatings for turbine blades and vanes and a thermoelectric generator to power high temperature electronics, high temperature wireless transmitters, and high temperature sensors</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Companies</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Advanced Nano Coatings</td>
<td></td>
</tr>
<tr>
<td>• Beijing Zhishengweihua Chemical Co., Ltd.</td>
<td></td>
</tr>
<tr>
<td>• Boeing</td>
<td></td>
</tr>
<tr>
<td>• Industrial Nanotech Inc.</td>
<td></td>
</tr>
<tr>
<td>• Inframat</td>
<td></td>
</tr>
<tr>
<td>• Mitsubish Carbide</td>
<td></td>
</tr>
<tr>
<td>• Mettech</td>
<td></td>
</tr>
<tr>
<td>• NCoat, Inc.</td>
<td></td>
</tr>
</tbody>
</table>
Nanocoatings are opening up new market opportunities in the global coatings arena. Despite the market being affected by the global economic recession, product innovation and the need to meet stringent environmental regulations is driving demand across a wider range of markets.

01 ion-mask™: The ion-mask™ treatment of footwear and textile products delivers reduced water uptake with no loss of breathability. The company’s splash-proof liquid repellent nanocoatings have been applied to Motorola and TCL Communication smartphones and tablets. They are a leading materials provider in this growing market.

02 Clarity Defender® PLUS: A self-assembling thin film that coats automotive glass and mirrors with an invisible, water-repellant nano-barrier. Independent tests prove these repellents can increase visibility 34% on a rainy night, which can add a full second to response time.

03 TripleO coating: The tripleO coating is made of nano-scale acrylic polymer beads. The company’s coatings have been utilized by Easyjet and British Airways on their aircraft exteriors.

04 X-Clean: The X-Clean Brand allows for prevention of surface defects for easy-to-clean surfaces with nano-effect in the areas of protection against soiling for glass, ceramics and metal, protection against graffiti and demoulding aids.

05 Herbol-Symbiotec: A facade coating which incorporates the advantages of both organic and inorganic coatings in a single product, exhibits much higher dirt pick-up resistance and colour retention than traditional materials due to the nanotech-based formulation.

06 Oxylink™: Buhler Partec produces Oxylink™ an additive for waterborne coatings. The use of Oxylink™ leads to a sustainable improvement of waterborne coating systems. Nanorepel™ is a dirt repellent coating that can be applied glass, ceramics, metal, wood, textile, leather, concrete, stone and other mineral substrates. Buhler is an established player in these markets and has been for a number of years.


08 FEPORID® 388: DFE Chemie GmbH produces a nanotechnology based pickling inhibitor used as an additive to acid to protect steel surfaces against acid attack. This prevents the all too typical over-pickling and thus results in a higher surface quality of the steel.

09 LIFEKER®: Nanophos SA The company co-develop with Keraben LIFEKER®, a line of self-cleaning and self-sterilizing ceramic tiles.

10 WaterBlock: A super-hydrophobic nanocoating that has been applied to a line of back-lit magnetic compasses by NavELite, and the TAG Heuer RACER Sub-Nano—a limited edition, Android-based smartphone.
Energy

With worldwide expenditure on renewable energy breaking through the $trillion barrier in the next few years, nanomaterials are under commercial development as a means of reducing costs and making these energy sources competitive. Nanomaterials are enabling major breakthroughs in wind and solar energy, fuel cells, thermoelectrics, batteries and supercapacitors, which are now beginning to translate into tangible products. Nanocoatings are allowing for new paradigms in low-cost and environmentally friendly energy conversion and storage systems.

MARKET POTENTIAL
4★

Applications and Estimated Time to Market
- Self-cleaning solar panel coatings (Now)
- Conductive additives in batteries (1 year)
- Protective coatings on wind turbines (1-2 years)
- Nano TiO₂ thin films on solar panels (On market)

Battery

Batteries are one of the limiting factors in current mobile electronic devices. Graphene is a leading candidate for developing ultra-thin flexible batteries. It has a good electrical conductivity and high surface area. Electrical conductivity is caused by its unique electronic properties, which include massless Dirac fermion, ambipolar electric field effect and extremely high carrier mobility. Applications are predicted to be onstream by 2013 in grid energy storage and electric vehicles.

MARKET POTENTIAL
3★

Solar

Self-cleaning coatings are finding application on solar panels for protection against dust and water. Clean solar panels conserve energy more efficiently and reduce the amount of cleaning required. Pilkington has recently produced a self-cleaning coating for solar panels, Pilkington Activ Suncool, and Chamelic is developing anti-dust nanocoatings in this sub-market. NanoTiO₂ is also incorporated into thin films on solar panels to enhance the light harvesting capabilities.

MARKET POTENTIAL
4★

Oil & Gas

The oil and gas industry has adopted nanostructured coatings for anti-corrosion applications. A major problem in the Oil Country Tubular Goods market (OCTG) is the degradation of downhole pipes and tubes, surface piping, pressure vessels, storage tanks and other equipment due to corrosion, abrasion and other factors. Nanostructured coatings for corrosive and elevated temperature environments are being used in a variety of pipeline applications.

MARKET POTENTIAL
5★
Increasingly, oil and gas production operators are seeking alternatives to traditional coatings to reduce corrosion, extend asset life and improve their bottom line. Nanomaterials offer the potential to improve the way companies drill and complete their wells through increasing strength, durability (e.g. surface coating to avoid erosion or scale attachment) and potentially provide completion design options not possible with existing technologies. Nanomaterials may lead to fully optimized production through the employment of nanoparticle inhibitors, nano sealants and fluorescent taggants for real time reservoir monitoring.

**Properties**
Desirable functional properties for the oil and gas industry afforded by nanomaterials in coatings include:
- thermal conductivity (CNT, graphene)
- wear-resistance (silicon carbide, alumina)
- corrosion-resistance (fullerenes, CNT).

**Applications**
These properties are of great interest for refurbishing and lengthening the working life of equipment and pipelines. Incorporated into coatings, they protect structures like drilling platforms, bridges and metal construction from corrosion; they safeguard shut-off valves and pumping and compressor fixtures; they protect equipment for drilling, oil and gas extraction, and processing and refining from wear and tear. Drilling equipment in the oil and gas industry tends to wear down very quickly.

**Anti-corrosion**
Estimates for the cost of corrosion degradation run to about €200 billion a year in Europe and over US$270 billion a year in the U.S. The annual cost of corrosion consists of both direct costs and indirect costs. The direct costs are related to the costs of design, manufacturing, and construction in order to provide corrosion protection, and the indirect costs are concerned with corrosion-related inspection, maintenance and repairs. The oil and gas industry has adopted nanostructured coatings for anti-corrosion applications. A major problem in the Oil Country Tubular Goods market (OCTG) is the degradation of down hole pipes and tubes, surface piping, pressure vessels, storage tanks and other equipment due to corrosion, abrasion and other factors. Long-lasting coatings are needed to protect under sea pipes from seawater. Coatings currently used on rigs and other platforms to prevent rust and corrosion can cause safety issues and environmental issues.

**Commercial activities**
Nanocoatings have already been applied as anti-wear coatings for drilling parts, thermal coatings to lower deformation and anti-corrosion for pipelines and other long-term structures. Integran (www.integran.com)
produces Nanovate for nanocoatings with increased strength, hardness and thermal resistance. Companies eager for pipeline coating solutions include many Asian and Middle East national oil and gas companies and several multinational oil and gas companies such as Shell and BP. The Russian government is also investing heavily in this area in the company Technological Systems for Protective Coatings. California Nanotechnologies Corporation’s (www.calnanocorp.com) nano-enhanced coatings have been approved for down hole drilling by one of the largest service companies in the oil and gas industry. Cleancorp Nanocoatings (www.cleancorp.de) produces corrosion protection nanocoatings for metals in oil pipelines. Nanotech Universal (www.nanotechnuniversal.com) is also producing anti-corrosion nanocoatings for the oil industry. In an initial test, 75,000 feet of treated pipe was installed between the months of May and July 2008 in shallow, low-pressure, low-temperature wells up to 1,500 feet in depth with issues ranging from hydrogen sulfide and hydrochloric acid corrosion to paraffin contamination that, over time, reduced the internal diameter of pipes and slowed flow rate. NEI Corporation has introduced a nanotechnology-enabled, two-layer coating that significantly improves the corrosion resistance of zinc-plated and hot-dip galvanized (HDG) steel. The NEI coating is a drop-in replacement for trivalent chromium. The coating process consists of first applying NANOMYTE® PT-100, a self-healing conversion coating, followed by NANOMYTE® TC-5001. The new technology is part of NEI’s efforts to develop corrosion resistant coating systems, including pretreatments, primers and topcoats that protect steel, aluminum and magnesium from corrosion. DuraSeal (http://durasealcoatings.com) coatings are being applied to oil and equipment as permanent seals against corrosion from sulfur, heat, water, salt, CO2 infiltration etc. The coating tolerate 800 degrees Fahrenheit, there’s minimal film build, no pressure pressure-rating change and the finished product requires no special care. The Advance Energy Consortium (www.beg.utexas.edu/aec/), comprising companies such as BP, Baker Hughes, ConocoPhilips, Halliburton, Schlumberger and Shell was established in 2008 to look at new technologies for exploitation in the oil and gas industry. Their mission is to drive pre-competitive research in micro and nanotechnologies for upstream oil and gas industry applications. Tesla Nanocoatings (www.teslanano.com/oilgas.html) has created CNT-based corrosion control coating for metals. Teslan® can be applied to a variety of substrates including steel and aluminum. These surfaces should, if needed, be prepared to remove existing corrosion products, oil, grease and other contaminates, following similar procedures used with traditional paints and coatings.

**SOLAR**

Solar technology has yet to achieve efficiency goals (typically 20% range although Si solar cells are moving closer to the single–band gap efficiency limit of ~30%) to enable it’s widespread adoption as a viable alternative energy source. The energy generated from solar photovoltaics (PV) amounts to less than 1% of the total worldwide energy usage at present. As well as technological deficiencies, there are also costs associated with the maintenance of solar panels. The energy conversion rate reduces significantly when dust, grime, pollen, and other particulates accumulate on the transparent protective casings of the solar panels.

**Properties**

Desirable functional properties for the solar power industry afforded by nanomaterials in coatings include:

- self-cleaning/superhydophobic (silica, titanium dioxide)
- excellent energy conversion-high optical absorption, and maintain superior thermal and photostability (carbon nanotubes, fullerenes, graphene titanium dioxide).

**Self-cleaning coatings**

Solar panels are exposed to dirt and pollution leading to a reduction in energy generation. Therefore regular cleaning cycles are required. Self-cleaning nanocoatings have been produced for solar panels that allow them stay cleaner and clearer for much longer between maintenance cycles. C-Voltaics (www.c-voltaics.com) is currently producing these coatings. UK-based nanocoatings company Nanoshell Ltd (www.nanoshell.co.uk) produces nanoShell Solar PV, a self-cleaning hydrophobic coating for solar panel glass. EcoSolargy (www.ecosolargy.com) produces a range of solar panels that incorporate self-cleaning, anti-fading, anti-fogging and anti-bacterial nanocoatings. NanoCare (www.perfectsolar.de) Top Ceram® VP 12 for application in easy-clean solar panel coatings. Magnolia Solar produces anti-reflection coatings for photovoltaic devices (www.magnoliasolar.com).
**Application: Dye-sensitized solar cells (DSC)**

Nano-porous TiO2 thin films have been widely used as the working electrodes in dye-sensitized solar cells (DSCs) due to their appropriate energy levels, dye adsorption ability, low cost, and easy preparation. In September 2013 it was announced that DSCs based on perovskite could provide a 15 percent efficiency. Companies active in this area include 3G Solar (www.3gsolar.com), Dyesol (www.dyesol.com), G24 Innovations (www.g24i.com), Exeger (http://exeger.com), Oxford Photovoltaics (www.oxfordpv.com), Solaronix (www.solaronix.com), SolarPrint (www.solarprint.ie) and a number of multinationals such as Samsung SDI, Sharp, Sony, BASF, Everlight Chemical, Merck and Umicore.

**Organic based photovoltaics thin films**

Another approach to photovoltaics devices fabrication is developing technologies with moderate efficiency goals (<20%) but with significantly reduced fabrication costs (< $20/m^2). Organic molecular/polymeric semiconductors meet these needs and can be fabricated from solution-processible materials using low-temperature, non-vacuum techniques such as inkjet or screen printing. These cells can be processed from solution, hence the possibility of a simple roll-to-roll printing process, leading to inexpensive, large scale production. Organic solar cells and polymer solar cells are built from thin films (typically 100 nm) of organic semiconductors and carbon nanomaterials. OPV efficiencies have been are continuously improving, a 7.3% (http://pubs.rsc.org/en/Content/ArticleLanding/2013/EE/c3ee40860d#IdivAbstract) efficiency was recently achieved. Mitsubishi Chemical claims to have achieved 9.2 % through proprietary technology and announced a goal of 15% by 2015.

**WIND ENERGY**

Larger and more powerful wind generators require materials with increased protection from the elements. Wind turbines can suffer from ice and freezing with large sheets of ice building up on the blades and support structure in extreme conditions. This can lead to large slabs of ice falling off these turbines risking injury to people below. In addition, the ice can freeze between the blades and motor unit preventing the turbine from moving, thus reducing its effective working life and efficiency. Nanomaterials are utilized on wind turbines as nanocomposites in rotor blades, corrosion and wear protective coatings for bearings and gearboxes and conductive materials for improving lightning protection. Nanotube composites also find application in protection against lightning strikes, which are responsible for more than 10% of the failures of wind generators. Nanocoatings are also impacting the wind energy market, with hydrophobic coatings applied to blades to prevent ice formation. This technology is being developed by General Electric (www.ge.com/audio_video/ge/innovation/the_water_bounce_sequel_repelling_ice_with_nano_coatings.html).

**Properties**

Desirable functional properties for the wind power industry afforded by nanomaterials in coatings include:
- self-cleaning/superhyrdophobic for anti-icing (silica, titanium dioxide)
- improved surface smoothness and thus reduction in surface friction (silica)
- resistant to weathering, UV, fungus and algae thus retaining power output from blades. Coating resists fungus formation thus wind blades maintain optimum power output for longer periods
- ecologically beneficial, biologically safe and enhances environmental efficiency
- improved robustness (CNTs, graphene).

**Commercial activities**

Companies developing nanocoatings for wind energy applications include Vestas (www.vestas.com), Nanoshell (www.nanoshell.co.uk). Anti-corrosion coatings are finding application in offshore wind turbines to fight corrosion caused by the conditions at sea. A number of large offshore renewable energy companies are seeking to develop these coatings. Ocean wind and marine energy, a renewable and inexhaustible resource for electricity production, has vast untapped potential, as about 70 per cent of the world is covered by oceans. The European Wind Energy Association expects the market for offshore wind turbines to increase from an annual growth rate of 1.5 GigaWatt (GW) in 2011 to 6.9 GW in 2020. This would mean an increase in annual investments from S$5.8 billion in 2011 to S$15.5 billion in 2020.
### Table 22: Nanocoatings in the energy industry—suppliers, intermediate developers, target market revenues

<table>
<thead>
<tr>
<th>Main suppliers</th>
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<tbody>
<tr>
<td>• Angstron Materials LLC</td>
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<tr>
<td>• Bluestone Global Tech</td>
<td></td>
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<tr>
<td>• Cabot Corporation</td>
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<tr>
<td>• Durham Graphene Science</td>
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<td>• GRAnPH Nanotec</td>
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<td>• Graphene Laboratories</td>
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<td>• Graphenea</td>
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<tr>
<td>• XG Sciences, Inc.</td>
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<td>• Xolve</td>
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<tr>
<td><strong>Intermediate developers</strong></td>
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<tr>
<td>• BASF</td>
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<tr>
<td>• Grafin Ltd</td>
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<td>• Bayer</td>
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<td>• Dow Chemical</td>
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<td>• DuraSeal Coatings Company</td>
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<tr>
<td>• Graphene Batteries</td>
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<tr>
<td>• Graphene Energy Inc.</td>
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<tr>
<td>• California Lithium Battery</td>
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<td>• Solan</td>
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<td>• C-Voltaics 82</td>
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<td>• Magnolia Solar, Inc.</td>
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<tr>
<td>• Brisbane Materials Technology</td>
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<tr>
<td>• Tesla Nanocoatings</td>
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<tr>
<td>• Mesocoat</td>
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<tr>
<td><strong>Product developers</strong></td>
<td></td>
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<tr>
<td>• Ionex Energy Storage Systems</td>
<td></td>
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<tr>
<td>• mPhase</td>
<td></td>
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<tr>
<td>• SiNode Systems</td>
<td></td>
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<tr>
<td>• LG Chem Power, Inc.</td>
<td></td>
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<table>
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<tr>
<th>Target markets size according to industry estimates</th>
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<tbody>
<tr>
<td>• Global steel pipe coating market 2009: EUR 5 billion, 2013: EUR 6.5 billion</td>
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<tr>
<td>(Applied Market Information Ltd.)</td>
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<tr>
<td>• Global solar energy market will grow from $39.6 billion in 2011 to $75.2</td>
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<td>billion in 2016 (Markets and Markets)</td>
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<tr>
<td>• Global supercapacitors market 2010: $470 million, 2015: $1.2 billion (BCC</td>
<td></td>
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<tr>
<td>Research)</td>
<td></td>
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<tr>
<td>• Global market for batteries, supercapacitors and fuel cells targeting</td>
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<tr>
<td>transportation and smart grid applications will more than double from $21.4</td>
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<tr>
<td>billion in 2010 to $44.4 billion in 2015. (Lux Research)</td>
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<tr>
<td>• Electrodes for displays and solar cells a $2 billion market growing at 20%/</td>
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<td>yr. (Canatu)</td>
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<tr>
<td>• Supercapacitors market 2012: $2 billion (Frost and Sullivan)</td>
<td></td>
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<tr>
<td>• Addressable market for high performance coatings for oil sands applications:</td>
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<tr>
<td>$25 million/year (Hyperion Technology Inc)</td>
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<tr>
<td>• 2010 US solar module market alone represented $1.6 billion.</td>
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<tr>
<td>• Solar glass market 2012: $2 billion (ORNL)</td>
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</tbody>
</table>
The market for metal cladding with corrosion-resistant alloys is more than $3.8 billion, which includes the $2 billion clad pipe market. This market is expected to double in size as the global oil and gas capital expenditure is expected to increase from $1,036 billion in 2012 to $1,201 billion in 2013, registering a growth of 15.9 percent (Abakan).
Nanostructured coatings are already being applied in the aerospace industry for improving the life span, reliability and durability of components; erosion, sliding and wear resistance; improving surface quality; de-icing; and corrosion resistance against pitting, peeling, oxidation and heat. Coatings are currently being commercialised to detect corrosion and mechanical damage to aircraft skin; react to chemical and physical damage, improve adhesion, and increase the life span of metal parts. Lightweight, high-strength, heat stable nanomaterials are also under development for aircraft engines.

MARKET POTENTIAL ★★★★★

Anti-Icing

Graphene coatings are under development for numerous aerospace coatings applications. Promising areas include de-icing coatings. The EU-funded SANAD project is combining graphene with carbon nanotubes to make a coating for planes that can be connected to the electrical system and heated up to stop the build-up of ice. SAAB has also filed a patent for the development of de-icing coatings. The graphene additive could strengthen the acrylics and shield against EMI interference.

MARKET POTENTIAL ★★★★★

The use of nanomaterials greatly improves the thermal barrier properties in the manufacture of aircraft turbine engines. Nanocoatings allow for high thermal conductivity, high melting points and excellent adhesion to the underlying metallic substrates. The high thermal insulation properties of the coatings produced by this technique will also allow aircraft engines to be operated at higher temperatures, improving the engine's burn efficiency for lower fuel consumption.

MARKET POTENTIAL ★★★★★

Aerospace

Nanostructured metals can provide superhard coatings that are resistant to corrosion, for applications in aerospace components such as landing gear. Nanoparticles significantly reduce wear while maintaining low friction in tests. Super hard nanocomposite coatings can be widely applied on various kinds of cutting and forming tools, particularly for applications in high speed machining, high temperature wear components, moulds and dies.

MARKET POTENTIAL ★★★★★

Thermal Barrier

MARKET POTENTIAL ★★★★★
Traditional aerospace finishing processes often involve the use of strong acids or bases and toxic materials such as hexavalent chromium, but the industry is working to replace conventional finishing materials and processes with environmentally friendly alternatives that still meet stringent performance requirements. To meet these dual objectives, aerospace companies are developing sol-gel coatings that can be applied to a range of substrates (aluminum, titanium, nickel, steel) using a variety of methods (dip, immersion, spin, brushing, spraying).

A number of aerospace companies and agencies are beginning to use, or investigate the use of, nanostructured coatings to add special characteristics to aircraft frames and interior and engine parts and component surfaces, which can include properties such as: self-cleaning; improved hardness; wear and corrosion resistance; improvement in fuel efficiency; and improved thermal performance and flame retardancy. There is an increasing use of composite components in aircraft design such as radomes, propellers and aircraft structural components. Nanomaterials such as CNTs and graphene are seen as an alternative to the more traditional carbon black/graphite or metal particle additives; their high conductivity and high aspect ratio result in the formation of percolated conductive networks within coatings at very low loadings. Nanocoatings can also allow for new aerodynamic concepts designed to reduce the air resistance and thus the fuel consumption of aircraft.

Properties
Desirable functional properties for the aerospace and aviation industry afforded by nanomaterials in coatings include:
- Reduced weight and increased strength (carbon nanomaterials)
- High temperature control/resistance (SiC Nanoparticles in SiC-particle-reinforced alumina, Yttria stabilized nanozirconia)
- Electrostatic discharge, EMI shielding and low friction (CNT, graphene, nanoaluminium, copper, iron, silver nanoparticles)
- Corrosion/Wear Resistance (silica nanoparticles, aluminium, Nanocrystalline Carbide, Diamond like Carbide and metal dichalcogenide, TiN nanocrystallites embedded in amorphous Si$_3$N$_4$)
- Easy Reparability & reusability
- Less Maintenance & increased durability.

Coatings are generally used in the aerospace industry for protecting the structures and surfaces of the aircraft from harsh environments. Stringent regulatory and technological requirements such as resistance to extreme temperatures, extreme climates, corrosion, abrasion and wear of engine parts have lead to an increased demand for more reliable high performance coatings.

Thermal barrier
Thermal spray nanocoatings applied in aerospace structures insulate hot section metallic components.
Nanocoatings have been designed for thermal barrier coatings enabling the fuselage of spacecraft to endure exposure to 4,200 degrees F for a period during orbital re-entry. Applied Thin Films, Inc. (www.atfinet.com) is developing a patented ceramic amorphous aluminum phosphate material (CERABLAK®) with excellent dielectric properties and thermal stability. It is suitable for various military and commercial aerospace applications, including next-generation radomes for hypersonic missiles such as the SM-6.

Nanocoatings are also safer than the existing coatings, as they emit lesser volatile organic compounds (VOC) and employ thermal spray and diamond-like technologies, which are non-hazardous when compared to electroplating chrome technologies and organic paints. Inframat Corporation (www.inframat.com) produce nanocoatings to insulate hot section metallic components (turbine blades, turbine vanes, combustors) from the hot gas stream in all modern aircraft gas turbine engines.

Sensors
Multi-functional sensor coatings can achieve the dual requirements of higher turbine efficiency and lower gaseous emissions, and the monitoring of temperature, erosion and phase changes, are projected to reduce maintenance costs and improve safety standards. Carbon coated nanoparticles show potential in pressure/temperature sensing.

De-icing
According to the Environmental Protection Agency, 25 million gallons of deicing agents are applied to aircraft at U.S. commercial airports each year. The aviation industry is also using energy-intensive pneumatic and electric anti-icing systems on aircraft to prevent ice formation on wings and other surfaces. GE are one of a number of companies developing anti-icing nanocoatings that reduce ice adhesion and have also been shown to delay the onset of ice formation. Easyjet has applied a nanocoating from tripleO (www.tripleops.com) for fuel savings and carbon footprint reduction. The coating reduces drag by up to 39%. SAAB (www.saab.com) has filed a patent to use graphene for de-icing airplanes. The graphene layer would be embedded in a heating jacket covering the aircraft.

CG2 NanoCoatings, Inc. (www.cg2nanocoatings.com) has developed a process to utilize nanoscale properties by first functionalizing nanoparticles and then incorporating them into a base material (polymers, metals, ceramics or composites) for anti-icing coatings. Nanovere (www.nanovere.com) also produces nanocoatings to significantly reduce ice adhesion, de-icing maintenance costs, and reduce the coefficient of wind and water drag resistance, thereby decreasing the cost of jet fuel.

Conductive and anti-static
For aircraft applications there is an increasing need for conductive and anti-static coatings, for instance to protect safety-relevant structural elements made of fibre composites against lightning strikes. An aircraft can statistically expect a lightning strike to occur every 1,000-10,000 flight hours, or at least one per year. In terms of safety for aircrafts, lightning induced damages have emerged as an important issues. Currently, most of the external surfaces of composite fuselages are covered with wire mesh, expanded foil of aluminum to prevent and/or reduce damages from lightning strikes; however, it tends to increase the weight of fuselage by adding a thin metal layer in the fuselage and wings, and also it may induce galvanic corrosion that may become a concern after long service flights. Nanomaterials are used as nanocomposite coatings for carbon-fiber (CFRP) layers to enhance electrical conductivity of carbon-fiber reinforced plastics, without increasing the weight of structures. The use of CFRP materials on commercial aircraft has increased with the Boeing 787 “Dreamliner” and Airbus A350 XWB, incorporating over 50% composite materials by weight. Graphene and carbon nanotubes offers superior current carrying and heat dissipating qualities as is being developed for this application. Powdermet (www.powdermetinc.com) has partnered with the U.S. Navy to provide a solution to contamination issues in spherical plain airframe bearings using advanced coatings that have already been commercialized through Abakan subsidiary MesoCoat. These nanocomposite cermet materials have applications across the transportation, energy, military, construction and other sectors for reducing friction and extending the life of, or eliminating the need for lubricants, in highly stressed systems.

Magnetic Shield (www.magnetic-shield.com) produces electromagnetic shield coatings. Vorbeck and BASF are collaboratively developing dispersions of highly conductive graphene for graphene/epoxy composites for use as EMI shielding materials.
Wear-resistant/Anti-corrosion

The most studied and most promising systems include (Ti,Si)N, (Ti,Al,Si)N and (Cr,Al,Si)N systems. These coatings are characterised as highly stable nanocomposites consisting of cubic nanocrystalline hard grains (TiN, TiAlN, or CrAlN) embedded in an amorphous matrix of silicon nitride, i.e. nc-TiN/a-Si3N4, nc-TiAlN/a-Si3N4, or nc-CrAlN/a-Si3N4. Nanocomposite coatings are developed to eliminate mechanisms such as multiplication and pile-up of dislocations in crystalline materials and growth of microcracks in amorphous materials, which may lead to fracture. Such nanocomposite coatings subsequently give ultra-hardness characteristics to coated surfaces on tools and components. Super hard nanocomposite coatings possess several advantages over those currently available such as TiN, TiAlN, and TiCN, etc:

- Super hardness (=40 GPa) ensures high abrasion wear resistance, and consequently improve the lifetime and performance of cutting & forming tools
- High temperature thermal stability and oxidation resistance (>800°C) makes it possible for the coated tools to work under high temperature and/or high speed conditions
- Excellent toughness and adhesion strength onto the substrate ensures high load-bearing capacity of the coating system.

During aircraft operation, gas turbine engines are continuously exposed to erosive media that damage engine components. Nanostructured coatings applied to compressor airfoil surfaces can significantly reduce material loss, leading to improved engine performance and fuel efficiency. MDS Coating Technologies Corporation (www.mdsprad.ca) have produced an erosion-resistant nanocoating material and application process, which significantly reduces erosion of compressor airfoils.

EnvAerospace (www.envaerospace.com) uses NPS-PVD (Physical Vapour Deposition) to produce a wide range of wear-resistant, anti-corrosive, thin ultra-hard films applicable to aerospace applications. Integran’s (www.integran.com) Nanovate nanometal surface coating for carbon fiber reinforced plastic (CFRP) aerospace tools, is designed to protect them from damage.

NCoat, Inc. (www.ncoat.com) manufactures high performance nano-formulated and microned coatings with improved bond strength, heat management, corrosion resistance, abrasion protection, friction reduction, and appearance enhancement for the automotive, aerospace, defense, diesel engine, recreational vehicles, and energy services industries.

Luna Innovations (www.lunainnovations.com) are developing superhydrophobic coatings to offer improved corrosion resistance on aluminum and the ability to scale to large substrates (such as spray coating for aircraft). Luna's coatings could reduce maintenance, decrease life cycle costs, and increase readiness by limiting equipment down-time. NTC Nano Tech Coatings (www.ntcgmbh.com) produces scratch resistant, corrosion resistant and easy to clean coatings. NTC mainly focuses on coatings for light metals (Aluminium and Magnesium) and various kinds of steel, such as technical parts for cars and aircrafts as well as engine parts and production areas for food technology.

Tesla NanoCoatings (www.teslanano.com) produces corrosion control coatings with fullerene carbon nanotube cathodic protection of metal to the aerospace/military, petrochemical, transportation, marine, and industrial markets. AnCatt, Inc. (www.ancatt.com) produces a conductive polymer nano dispersion to replace heavy-metal pigments such as chromate, lead and zinc. In a 13,000-hour salt-fog test, the coating platform produced no rusting or blistering.
Table 23: Nanocoatings in the aerospace industry-suppliers, intermediate developers, target market revenues

| Intermediate developers | • AnCatt, Inc.  
|                         | • BASF  
|                         | • Bayer  
|                         | • Dupont  
|                         | • EnvAerospace  
|                         | • Innovnano  
|                         | • Lotus Leaf Coatings  
|                         | • Luna Innovations  
|                         | • MDS Coating Technologies Corporation  
|                         | • Nanotec-USA  
|                         | • Nanovere  
|                         | • Tesla NanoCoatings  
|                         | • tripleO Performance Solution |
| Product developers      | • Airbus  
|                         | • BAE Systems  
|                         | • GE Global Research  
|                         | • Rolls-Royce  
|                         | • Boeing Co. |
| Target markets size     | • Aircraft coatings market 2008 USA: $140 million (Chemark Consulting)  
| according to industry   | • Aircraft de-icing: $5000 per aircraft (ORNL)  
| estimates              | • Global flame retardant market 2018: $5.8 billion (Ceresana Research)  
|                         | • Global flame retardant market 2008: $4.1 billion (BCC Research)  
|                         | • Global flame retardant market 2014: $6.1 billion (BCC Research)  
|                         | • Thermal spray coatings market 2010: $1.35 billion (Materials World)  
|                         | • Global thermal barrier coatings market 2011: $3.75 billion (Modumetal)  
|                         | • Global demand for EMI/RFI shielding options is estimated at about $4.5 billion in 2011 and is expected to increase to $5.2 billion by 2016 (Bharat)  
|                         | • Maintenance, repair and overhaul of aircraft engines estimated to be $29.2 billion in 2018 (Department of Energy) Market sizes for 2017 have been calculated on the basis of global market size in 2010 and annual growth rates to 2017 of 12%.  
|                         | • De-icing Solutions: the addressable market for de-icing solutions exceeds $500 million in 2012 (BioAmber)  
|                         | • The market for thermal barrier coatings is over $3.75 billion in 2012 (Modumetal) |
Automotive

Nanomaterials incorporated into hybrid coatings have been widely adopted in the automotive industry. Nanocoating allows for new coloration effects and greater hardness and durability. Coatings containing nanoscale carbides, nitrides, metals or ceramics play a key role in the performance of internal mechanical components of a vehicle, such as the engine. Other applications include anti-scratch and self-healing, self-cleaning, thermal barrier, conductive and anti-fingerprint coatings. There is also a high demand in the automotive industry for anti-fingerprint coatings, especially with the increasing incorporation of touch panel displays.

MARKET POTENTIAL

ESP coatings

Nanomaterials such as graphene have been incorporated into automotive components including fuel systems and those that require electrostatic spray painting (ESP). Electrically conductive graphene additive polymers show sufficient electrical conductivity to be painted directly by ESP. The approach offers advantages to automotive manufacturers and the public. By allowing direct ESP of polymers 18 percent of volatile organic compounds are eliminated from the process and costs can be reduced.

MARKET POTENTIAL ★★★★★☆

Anti-Scratch

Scratch-proof coatings have been developed for application in automotive bodies and window glazings. Bayer and Nissan (Scratch Guard Coat) have produced self-healing coatings and nanoparticles additives are improving the improve the scratch/mar resistance of clearcoats. Alumina and silica nanoparticles increase the surface hardness and resistance to indentation.

MARKET POTENTIAL ★★★★★☆

Anti-fogging

UV-curable, highly crosslinked polymer coating systems containing both hydrophobic and hydrophilic nanodomains are utilized in anti-fogging coatings. Surfaces coated are capable of spreading water and thus preventing fog formation on a variety of optical substrates such as automotive plastic and glass, including the headlamp covers of automobiles.

MARKET POTENTIAL ★★★★★☆

APPLICATIONS AND ESTIMATED TIME TO MARKET

- Thermal barrier nanocoatings (On market)
- Hydrophilic nanocoatings (On market)
- Wear/scratch resistant nanocoatings (On market)
- ESD, EMI and RFI nanocoatings (On market)
- Anti-fingerprint coatings (On market)
Properties
Surface protection is a key area in the automotive market both for protection from UV, wear, heat; promotion of adhesion; and reduction of engine friction. The overall world automotive paints and coatings market was estimated to be $7.75 billion in 2010 and nanomaterials will play a key role in future growth. Many automotive parts have a protective coating applied to improve the appearance or provide additional durability to the substrate which can be enhanced by the incorporation of nanomaterials. Desirable functional properties for the automotive coatings industry afforded by nanomaterials include:

- Scratch resistance (alumina and silica nanoparticles)
- Anti-fingerprint
- Self-cleaning (Nano-Tio2, nanosilica)
- Chemical resistance
- UV resistance (zinc oxide, cerium oxide, titanium oxide, iron oxide nanoparticles)
- Abrasion resistance (silica and aluminium oxide nanoparticles).

By reducing wear and friction, nanostructured coatings increase the lifetime of the working material at the same time that they reduce the dissipation of energy as heat, thus increasing the efficiency of the vehicle. Nanocomposite coatings offer improved solvent, fuel and gas barriers, and have heightened flame resistance, stiffness, and other mechanical properties. These coatings can increase tool productivity (longer tool life, higher cycle frequencies, less work piece finishing), reduce manufacturing costs, improve the quality of products (due to smoother surfaces, better dimensional stability, higher degrees of metal deformation and fewer manufacturing steps) and reduce lubricant consumption.

Current applications in the automotive industry are for oxide scale protection and easy to clean coatings for automotive glass. Volkswagen, BMW, Toyota and Subaru all utilise nanomaterials in these areas. Mercedes-Benz have introduced ceramic scratch-resistant nanocoatings to automobiles. These nanoparticle clearcoats display significantly greater scratch resistance and enhanced paint gloss compared to vehicles with conventional paintwork.

Scratch-resistance
Consumers desire a permanent, scratch-free finish on all parts of automobiles, and scratch performance is the highest rated customer concern for automotive paint systems and displays. Nanocoatings provide protection against scratches caused by mechanical car-washes, for example ensure visibly enhanced gloss over an extended period of time. Aluminum oxide nanocomposite scratch resistance coatings have been applied as automotive finishes. When the additives are blended into resins and coatings at very low 1.5 to 6 percent concentrations, scratch resistance increases dramatically. BASF (www.basf.com)has created a topcoat for automobile paint that combines two types of materials in a nanostructured hybrid. Between 90 and 95% of the coating is organic material, making the finish flexible,
elastic and weather resistant, the company says, while the remaining 5 to 10% consists of nanoscale clusters of inorganic silicate that are particularly hard and scratch-resistant. The organic and inorganic components are covalently bound.

Nanovere Technologies (www.nanocoatings.com) has developed coatings for BMW to improve scratch resistance and gloss. PPG's (www.ppg.com) CeramiClear is another product in this area and Bayer also develop nanoparticle coatings for scratch, mar, and etch resistance.

Altana's NANOBYK® (www.byk.com/en/additives/additives-by-name/nanobyk.php) additives are utilized in scratch-resistant coating applications in automotive refinish. Nanophase (www.nanophase.com) produces NanoArc® Aluminum Oxide for surface coatings and films to provide long-term scratch resistance without significantly impacting optical clarity, gloss, color, or physical properties.

Hydrophobic and oleophobic
Hydrophobic and oleophobic glass allowing greatly improved visibility in the rain, and reduces the adherence of dirt and contaminants to a treated surface. Nanovere Technologies has developed a Wipe-On clear nanocoating, Vecdor Nano-Clear®, to restore original color, gloss and surface hardness back into oxidized textured plastics, highly oxidized fiberglass and highly oxidized paint surfaces while reducing surface maintenance by 60%

Diamon-Fusion International (www.dfisolutions.com) flagship product Diamon-Fusion® provides multi-functional characteristics that include: water and oil repellency (hydrophobic and oleophobic), impact and scratch resistance, protection against graffiti, dirt and stains, finger print protection, UV stability, additional electrical insulation, protection against calcium and sodium deposits and increased brilliance and lubricity for application in the automotive industry.

ISTN, Inc.'s (www.istninc.com) UV FOGuard™ is hydrophobic and hydrophilic coating for preventing fog formation on automotive windows.


Conductive
Carbo e-Therm (www.inno-x.ch) is a high-efficiency, electrically heated coating that consists of an aqueous dispersion on an acrylate base with carbon nanomateri-
Table 24: Nanocoatings in the automotive industry-suppliers, intermediate developers, target market revenues

| Main materials suppliers | Altana  
| Angstron Materials LLC  
| Nanophase  
| XG Sciences, Inc. |
| Intermediate developers | BASF  
| Carlyle Group LP  
| Cleancorp Nanocoatings  
| DuraSeal  
| Diamon-Fusion International, Inc.  
| Ecology Coatings, Inc.  
| Lightmotif BV  
| Kansai Paint  
| Nanofilm Ltd.  
| Nanotec-USA  
| Nanovere  
| NCoat, Inc.  
| nGimat Co.  
| Nippon Paint  
| PPG  
| Sulzer |
| Application developers | BMW  
| Land Rover  
| Jaguar  
| Accuride Truck Wheels  
| Toyota Motor Corp. |
| Target markets size according to industry estimates | Automotive OEM and refinish coatings markets. €6.6 billion (BASF)  
| Automotive glass market 2012: $2 billion (ORNL)  
| Global world automotive paints and coatings market is estimated to be $7.75 billion in 2010. |
Textiles

Textiles modified with nanomaterials display huge advantages as conventional methods used to impart different properties to fabrics often do not lead to permanent effects, and will lose their functions after laundering or wearing. Nanomaterials allow for increased durability for fabrics, as nanoparticles have a huge surface area-to-volume ratio and high surface energy. This allows for better affinity for fabrics and an increase in durability, without affecting the breathability or hand feel. There are a number of consumer textile products on the market incorporating nanomaterials.

MARKET POTENTIAL
★★★★☆

Electronic

Incorporation of conductive nanocoatings in textiles could lead to improvement in electronic devices and enable the development of next-generation functional fabrics (electronic textiles). Graphene is a leading candidate and recent research has focused on conductive, flexible, and durable reduced coated with graphene oxide. Vorbeck Materials is utilizing graphene conductive inks to produce electronic textile products. Carbon nanotubes are another widely investigated candidate.

MARKET POTENTIAL
★★★★☆

Waterproof

Water-repellent textile fabrics are often used in many different applications, such as rain clothes, anti-adhesive bandages, and stain-repellent tablecloths. Water repellent nanocoatings have also been recently applied to Motorola and Nokia handsets. Most of these coatings are currently based on the Lotus Effect concept to provide ultrahydrophobic textiles.

MARKET POTENTIAL
★★★★☆

Anti-microbial

The market for antimicrobial textiles has grown greatly in the last few years, driven by the increased need of consumers for fresh, clean and hygienic clothing. Nanosilver is used widely in anti-microbial textiles finishes, including medical textiles. Products on the market include nanosilver coated socks that kill the bacteria associated with foot odour. Ant-microbial products with nano ZnO, TiO2 and SiO2 Nano-ZnO have also been impregnated onto cotton textiles.

MARKET POTENTIAL
★★★★★☆
The market for antimicrobial textiles has grown greatly in the last few years, driven by the increased need of consumers for fresh, clean and hygienic clothing. The application of nanomaterials to textiles involves the modification of existing textile materials using electrostatic self-assembly and atomic layer deposition techniques (sol-gel, CVD etc.) to create novel and customizable surfaces on conventional textile substrates with an emphasis on natural fibers. When using nanomaterials in the manufacturing and finishing process, these materials are either integrated into the fiber volume or applied as a coating onto the textile. Nanoscale zinc oxide, silicon dioxide, aluminum (hydr)oxides, titanium dioxide, silver, and nanoclays and carbon nanotubes (CNT) have all been incorporated in base polymeric coatings to enhance the performance of coated textiles to achieve the following properties on fabrics:

Properties
Nanoparticles have a large surface area-to-volume ratio and high surface energy, thus presenting better affinity for fabrics and leading to an increase in durability of the function. In addition, a coating of nanoparticles on fabrics will not affect their breathability or hand feel. Desirable functional properties for the textiles industry afforded by nanomaterials include:
• electroconductive/antistatic (nanomaterials utilized include CNT, Copper, Polypyrrol, graphene and Polyani-line )
• UV protection (Titanium dioxide (rutile), Zinc oxide)
• anti-microbialism (Silver, Chitosan, Silicon dioxide, Titanium dioxide, Zinc oxide)
• gas barrier
• durability (Aluminum oxide, CNT, Polybutyl acrylate, Silicon dioxide, Zinc oxide)
• abrasion resistance (CNT)
• drug/fragrance delivery (Nanostructured hollow bodies (e.g. cyclodextrine-based), Montmorillonite (nanoscale clay), Silicon dioxide)
• flame retardant (CNT, Boroxosiloxane, Montmorillonite nanoclay, Antimony ash )
• self-cleaning (CNT, Fluoroacrylate, Silicon dioxide, anatase titanium dioxide)
• moisture absorbent (titanium dioxide)
• heat conducting or insulating properties (CNT, Vanadium dioxide)
• EM shielding (Indium tin oxide)
• improved dyeability (nanoporous hydrocarbon-nitrogen coating, Silicon dioxide).

These areas have been commercialized to different degrees of effectiveness and practicality.

Applications
Current applications for fibers and textiles incorporating nanomaterials include:
• stain resistant clothing
• anti-odor sportswear
• anti-microbial medical textiles
• conducting cloth
• water repellent fabrics and textiles.

Nanomaterials are also being developed for protective clothing for firefighters, emergency responders, and military personnel that selectively blocks hazardous gases and minuscule contaminants but allows air and moisture to flow through. Main markets are interior trim and upholstery, sports and leisure, automotive interiors, protective clothing, and medical textiles. In household products, antibacterial textiles are incorporated into kitchen clothes, sponges or towels. In the medical sector, products include antibacterial wound dressings, patient dresses, bed lines or reusable surgical gloves and masks.
**Water and oil repellent**

Water and oil repellence is extremely desirable in textiles, and the so-called lotus effect, a biomimetic approach for fabrication of ultra hydrophobic fibers with repellency and self-cleaning ability, is one that has received a great deal of coverage over the past decade, without a huge degree of commercial success. Nanomaterials employed in textiles for superhydrophobicity include silicon oxide, nanoclays and nanofibers. BASF produces a lotus-effect aerosol spray that combines nanoparticles with hydrophobic polymers such as polypropylene, polyethylene and waxes. Mincor TX TT is a composite material consisting of nanoparticles embedded in a carrier matrix. This finish may provide a solution for the fabrics like polyester awning, sunshades, flags and sails that are generally required to remain continuously in outdoor environment; therefore these can not be cleaned in washing machine.

**Anti-bacterial**

The growth of micro-organisms has negative effects on textiles, such as the generation of odour and stains, which is a particularly important problem in biomedical and technical textiles. Nowadays, commercially-available antibacterial textiles usually use broad-spectrum biocides such as silver, quaternary ammonium compounds and triclosan as active agents. For imparting anti-bacterial properties, nano-sized silver, titanium dioxide and zinc oxide are routinely used as they have a sterilising effect. Nano-silver is applied in applications such as anti-bacterial sportswear and medical dressings. Nanosilver is widely incorporated in textiles and fabrics such as outerwear, sportswear, underwear, socks, and bedding materials such as comforters, sheets and mattress covers. Products on the market include nanosilver coated socks that kill the bacteria associated with foot odour. Textile applications are one of the main areas that are most open to regulatory scrutiny. Several studies have shown that widespread use of silver nanoparticles in consumer products, especially textiles, likely results in the distribution of nanoparticles in lakes and streams via leaching into wastewater during washing. A 2008 study showed that socks lose nearly all of their silver content within a few washings. In January 2012, The Natural Resources Defense Council filed a lawsuit in the US federal court against the U.S. Environmental Protection Agency (EPA) in a bid to limit public exposure to antimicrobial nanosilver used in clothing and other textiles such as blankets, pillow cases and interior textiles.

**UV protection**

The UV-blocking property of a fabric is enhanced when a dye, pigment, delustrant, or ultraviolet absorber finish is present that absorbs ultraviolet radiation and blocks its transmission through a fabric to the skin. Organic compounds that absorb in the UV range or inorganic metal oxides such as TiO2 are being applied for UV protection in textiles. Products on the market include Belfasun from Pulcra Chemicals (www.pulcra-chemicals.com), which contains nanoparticulate zinc oxide. Titanium dioxide (rutile) is also used for UV-resistance.

**Flame retardant**

Alexium International (http://alexiuminternational.com) has a commercial agreement with Duro Textiles, LLC (www.duroindustries.com) to apply Alexium’s novel, environmentally friendly, bromine and halogen free, flame retardant (FR) treatment for commercial and military customers in North America. Duro and Alexium are targeting a North American current market opportunity in excess of 4 million linear yards of nylon. Alexium has also been awarded a $200,000 contract with the US Air Force Research Laboratory to demonstrate Cleanshell® CB treatments for chemical and biological protection applications. An estimated 200,000 chemical and biological protection suits are purchased annually by the US military. Alexium’s Cleanshell® CB repellency treatment is targeted specifically to the treatment of the outershell fabric of CB protection ensembles. Alexium’s Cleanshell® CB treatment has been optimized to provide excellent water and oil repellency, but has also shown dramatically increased repellency of Chemical Warfare Agent simulants.

**Companies**

At present there are over 100 companies developing nanotechnology enabled textile products. Brand owners who utilise the coatings in products include New Balance, Gap, Old Navy, Target, Smith and Nephew, Hugo Boss, Paul Stuart, Rene Lezard, Lee, Nike, Champion, Levi and Simmons. Vestagen Technical Textiles (www.vestagen.com) produces Vestex nanocoatings that can help prevent the formation of potentially dangerous microorganisms on hospital and healthcare textiles, such as scrubs, uniforms, laboratory coats, privacy curtains and gowns. Clariant (www.clariant.com) and Schoeller Technologies AG (www.schoeller-tech.com) develop textile materials.
finished with Nanosphere repel liquids, dirt and stains. Toray (www.toray.com) produces ‘Nano-Plem’ technology that imparts water repellent characteristics and color resilience to nylon and polyester fabrics, and Terylene/wool blends. Nano-Tex (www.nano-tex.com) is a leading producer of nanocoated textile finishes for increasing durability, water and oil repellency, and stain resistance. Their chemical formulation and application technology is easily adopted by existing textile mills and embeds textiles with “nanowhiskers” that make the fabric dense, increasing the surface tension so drops of liquid can’t soak through. P2i’s (www.p2i.com) plasma technology enables the surfaces of textiles be enhanced with a super oleophobic and hydrophobic treatment while leaving the other properties of the product unchanged.

CMR Coatings (www.cmr-coatings.de) produces scratch resistant and abrasion resistant coatings for protective environments. They functionalise translucent water lacquers with nanoparticles incorporated into epoxies and plastic films (e.g. vehicle films, furniture films, various protective foils) as well as technical textiles. Eeonyx Corporation (www.eeonyx.com) produces conductive fabrics, sold under the EeonTex™ name, for anti-static applications, such as in electronic industry clean rooms and engineered conductive fabrics with radar absorbing properties for military uses involving stealth requirements.

iFyber, LLC (www.ifyber.com) develops, licenses and sells nanoparticle coating technology used to functionalise natural and synthetic textiles for high-end technical applications. Inspiraz Technology Pte Ltd (www.inspiraz.com.sg) produces NanoCotz™ Eco-Refresh, a Titanium Dioxide & Titanium Phosphate catalytic coating that decomposes organic sources or odor and bacteria for walls & ceilings of building/home interior, upholstery, curtains/blinds, air conditioning filters etc.

NanoSys GmbH (www.nanosys.ch) produces NanoPerli, a nanoscale chemical coating for various substrates and functions, for corrosion resistance, water repellency of raw, varnished, waxed, oiled and painted wood or wood materials, the hydrophobic treatment of sandstone, bricks, concrete and glass, which improve the adhesion of coatings on all types of plastics.

Nanoyo Group Pte Ltd (www.nanoyo.co) has developed ‘NanoShield TiO2 Coating Liquid’ that utilizes the photocatalytic effect of nano-titania to incorporate antibacterial, anti-microbial, UV protection, odour removal, self-cleaning and anti-static properties to any type of substrate or fabric.

HeiQ (www.heiq.com) produces HeiQ AGS-20 antimicrobial nanocomposite silver integrated into medical devices (wound dressings, implants). Nanyan Textiles (www.nanoyantextile.com) produces nanosilver coated fabrics with the Sensor Research Unit at the Faculty of Science, Chulalongkorn University.
Table 25: Nanocoatings in the textiles industry—suppliers, intermediate developers, target market revenues

<table>
<thead>
<tr>
<th>Intermediate developers</th>
<th>Application developers</th>
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</thead>
<tbody>
<tr>
<td>• BASF AG</td>
<td>• Devan Chemicals</td>
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<td>• BigSky Technologies LLC</td>
<td>• Microban International</td>
</tr>
<tr>
<td>• Nano-Tex, Inc.</td>
<td>• Saint Gobain</td>
</tr>
<tr>
<td>• P2i, Ltd.</td>
<td>• Takata Corporation</td>
</tr>
<tr>
<td>• PureTi, Inc.</td>
<td></td>
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<tr>
<td>• Alexium</td>
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<tr>
<td>• BASF</td>
<td></td>
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<tr>
<td>• CMR Coatings</td>
<td></td>
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<tr>
<td>• Eeonyx Corporation</td>
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<tr>
<td>• iFyber, LLC</td>
<td></td>
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<tr>
<td>• Inspiraz Technology Pte Ltd</td>
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<td>• Greenshield</td>
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<tr>
<td>• HeiQ Materials AG</td>
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<tr>
<td>• Mitsubishi Rayon Co., Ltd.</td>
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<td>• NanoHorizons, Inc.</td>
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<td>• Nanoproofed</td>
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<td>• Nanosonic</td>
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<td>• NanoSys GmbH</td>
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<td>• Nano-tex</td>
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<td>• Nanoyo Group Pte Ltd</td>
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<tr>
<td>• Nissan Chemical America Corporation</td>
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<tr>
<td>• P2i Ltd</td>
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<td>• Schoeller</td>
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<tr>
<td>• Ross Technology Corporation</td>
<td></td>
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<tr>
<td>• TitanPE Technologies Inc</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Target markets size according to industry estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Global textiles market 2011: $400 billion</td>
</tr>
<tr>
<td>• Global market for smart fabric and interactive textile technologies is expected to reach $1.8 billion by 2015.</td>
</tr>
<tr>
<td>• US coated fabrics market 2018: $3.68 billion (Transparency)</td>
</tr>
<tr>
<td>• Global Demand for Coated Fabrics is estimated to be 13-14B USD (SRF).</td>
</tr>
<tr>
<td>US, China &amp; Europe account for close to 2/3 of the global demand. Demand expected to grow by 2-3%</td>
</tr>
</tbody>
</table>
The medical market will be a high growth area for nanoscale coatings over the next 5-10 years, and this is reflected in the high number of companies exploiting technology in this area, especially in the anti-microbial domain. Nanocoating products have been commercialized in life sciences & healthcare as anti-bacterial surfaces for medical catheters, have been added to paints and lacquers used to coat operating tables, door knobs and door handles in hospitals and also as ultra-hard porous coatings for surgical and orthopedic implants such as screws, plates or joint implants.

**MARKET POTENTIAL**

- **Advantages of nanocoatings in the biomedical sector include long lasting anti-microbial effect, constant release of the active substance, effectiveness against bacteria and other micro-organisms, no chemical impurities, easy processing, no changes to the characteristics of the equipped material, and no later discoloration of the equipped material. The main driver is the prevention of the spread of deadly infections in medical facilities. Drug-resistant bacteria are a growing problem in hospitals worldwide.**

**MARKET POTENTIAL**

- **The properties sought for medical implants such as mechanical stability, thermal/electrical conductivity, diffusion, water absorption, biostability and biocompatibility are all greatly enhanced at the nanoscale. Nanostructured materials can stimulate self-healing cell responses or can increase the biocompatibility of implants. Nanomaterials are also being utilized the coating of vascular stents. Nanoporous alumina and hydroxyapatite coatings increase biocompatibility and thus efficient stenting.**

**MARKET POTENTIAL**

- **Medical textiles is the fastest growing niche textiles market. Anti-bacterial medical textiles incorporating nano-ZnO and silver are already on the market. Next generation products will utilize nanomaterials coated fibers that control the delivery of medicine to administer time released antibacterial and antiallergenic compounds.**

**MARKET POTENTIAL**
In medical facilities it is necessary to equip materials and surfaces with a high level of hygiene, using anti-microbial agents to protect them against bacteria and other micro organisms, to prevent infections caused by bacteria and contribute significantly to reducing health costs. Drug-resistant bacteria, the so-called “superbugs,” are a growing problem in hospitals worldwide and poor hygiene among staff is often blamed for the spread of such infections. The Centers for Disease Control and Prevention (CDC) estimates that roughly 1.7 million hospital-associated infections, from all types of bacteria combined, cause or contribute to 99,000 deaths each year. Other estimates indicate that 10%, or 2 million, patients a year become infected, with the annual cost ranging from $4.5 billion to $11 billion. There has been a growing use of anti-bacterial and superhydrophilic coating in medical devices in recent years to combat these problems. The increased need by an ageing population for spinal, orthopaedic and dental medical devices will also boost demand for medical device coatings.

Nanocoating products are already finding application in life sciences & healthcare in enabling anti-bacterial surfaces for medical catheters, added to paints and lacquers used to coat operating tables, door knobs and door handles in hospitals and as ultra-hard porous coatings for surgical and orthopedic implants like screws, plates or joint implants.

**Properties**

Nanomaterials have key implications for the development of future biomaterials via the surface modification of medical devices to enhance their biological interface. They are currently used in the following applications:

- Carbon nanotubes in bone cements (Graphene is also being developed for the same application);
- Nano hydroxyapatite paste for bone void and dental filling;
- Nano-crystalline diamond-coated dental implants
- Polycrystalline nanoceramics in dental restorative materials;
- Nanosilver or other nanomaterials (e.g. Nano hydroxyapatite), as coatings on implants and catheters;
- Nanosilver used as an anti-inflammatory, anti-viral, anti-biofilm, anti-fungal and antibacterial agent in wound dressings and medical textiles.

Anti-infective nanoscale coating materials improve the efficacy of indwelling and implantable medical devices, while reducing the risk of deadly medical device-related infections. Self-cleaning coatings have application for improved biocompatible surfaces able to prevent cells from adhering to implanted medical devices. Many medical device coatings attempt to reduce bacterial infection by releasing active biocides. These biocides may not protect against new bacterial strains, and may actually promote the evolution of resistant strains. Moreover, the biocides can prove toxic to surrounding tissues.
Anti-fouling
Biofouling of implantable medical devices remains a serious problem, for example in the form of thrombus formation on cardiovascular devices and bacterial biofilm formation on catheters and other medical devices. Biofouling is often responsible hospital-acquired and device-based infections that are a major cause of mortality in the U.S. and other parts of the world. Easy to clean nanocomposite sol gel coatings are currently used to coat medical devices and equipment. Anti-fouling nanocoatings prevent bacterial attachment and colonization on a device surface. They are biocompatible and act against all bacterial strains, including those that resist other biocides.

Anti-microbial
There are a number of companies producing anti-microbial nanocoatings for medical devices and surfaces in hospitals. Benefits of nanomaterials include long lasting anti-microbial effect, constant release of the active substance, effectiveness against bacteria and other microorganisms, no chemical impurities, easy processing, no changes to the characteristics of the equipped material, and no later discoloration of the equipped material. Biogate Ag (www.bio-gate.de) equips materials and surfaces in all areas where a high level of hygiene is needed with its antimicrobial agents, consisting out of elemental silver, to protect them against bacteria and other microorganisms. ItN Nanovation (www.itn-nanovation.de) also manufactures products in this market that are added to paints and lacquers used to coat operating tables, door knobs and door handles in hospitals and surfaces in sanitary facilities. AeonClad Coatings (www.aeonclad.com) nanocoatings increase biocompatibility by treating the surfaces of medical devices, stents, and catheters with ultra thin, ultra smooth coatings that better prevent protein and bacterial attachment. These nanocoatings allow for prevention of biofilm, lubrication and cell adhesion for medical implants. Under development are:
• biocompatible nanostructured implant surfaces and TiO2 coated stents;
• artificial retinas and cochlear that are more body friendly, and mimic more closely nature’s light/sound receptor and transmission systems.
Also utilized are bone-like synthetic nanopowders and hydroxyapatite coatings. Nanoscale coatings of hydroxyapatite are used for superior biocompatible coatings for implants. According to Nanointerface Technology, Inc. (www.nanointerfacetech.com), the hip, knee and dental implants have a worldwide market size of $15 billion dollar with growth rate of 15-25%. Companies developing nanocoatings for medical implants include Inframat (www.inframat.com) and Debiotech SA (www.debiotech.com).
Orthopaedic surgeons have made great improvements in the operating procedures of hip and knee implants. But there has been no increase in the lifespan of hip or knee implants because the quality of coatings on the implants has not improved over the decades. As well as their high stability, chemical versatility and biocompatibility silica nanoparticles are employed in artificial implants due to the osteogenic property of the resultant composites. Nanocrystalline metal-ceramic coatings have been applied to orthopedic and dental implants for increased biocompatibility, and can provide a huge increase in binding to bone proteins compared to conventional coatings. Nanoporous alumina is also under development for use on titania alloys. Nanovis Incorporated (www.nanovisinc.com) is developing nanopatterned implant surfaces for the degenerative spine implant market. Acrymed, Inc. (www.acrymed.com) develops anti-infective nanosilver coatings for implants. Namos GmbH (www.namos.de) also produces nanostructured functional surface coatings for implants.
Nanosilver
Nanosilver has been incorporated in numerous medical applications including diagnostics, wound care, drug delivery, medical devices and coatings. Nanosilver coated polymers have been incorporated into plastic catheters, for their antibacterial and disinfecting effect. The antimicrobial effect of nano silver has been successfully used in medical textiles for a number of years in hospital clothing and anti-microbial dressings, diabetic socks, scaffolds, sterilization materials in hospitals, and contraceptive devices. Nanocrystalline silver wound dressing inhibit the growth of bacteria allowing wounds to heal more quickly.

Nanosilver particles are coated onto fibres via:
- mixing in a polymer (master batch) before being spinning it into fibres. This is applied, e.g., in polyester and cellulose acetate fibres, resulting in firm integration into the fibre, leading to a long lasting antibacterial effect.
- applied on the fibre surface as a finish. In this method, adhesion strength, and thus the effective duration can vary greatly. Weakly bound nanoparticles can suffer from poor adhesion after just a few washes.

Nanosilver is also used as an antibacterial additive for poly (methyl methacrylate) (PMMA), used in bone implants. Nanosilver is also used in dentistry for making artificial teeth and in eye care for coating contact lenses. DocuGuard uses silver-based paper to protect hospital case notes and medical files against the proliferation of bacteria.

The antimicrobial effect of silver is based on the release of silver ions (Ag+). Bacteria are killed by Ag+-ions. The EU biocide directive applicable from September 2013 onwards requires that nanosilver (when it is used as a biocide) be approved for textiles and declared on the products. Kimberley Clark (www.iflo.com) is a large company that produces nanosilver coatings for catheters. Most of the coatings based on silver are widely regarded as being costly and there are concerns over leaching of sliver ions into the environment and of silver nanoparticles through the skin.
Table 26: Nanocoatings in the biomedical and life science industry—suppliers, intermediate developers, target market revenues

<table>
<thead>
<tr>
<th>Application developers</th>
<th>Product developers</th>
<th>Target markets size according to industry estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kimberley Clark</td>
<td>Johnson &amp;Johnson</td>
<td>CUNY Anti-bacterials target markets:</td>
</tr>
<tr>
<td>Duraban LLC</td>
<td>Ge Healthcare</td>
<td>• Global active sportswear market 2011: $52 billion</td>
</tr>
<tr>
<td>ItN Nanovation</td>
<td>Siemens Healthcare</td>
<td>• Global athletic footwear market 2011: $86 billion</td>
</tr>
<tr>
<td>Nanointerface Technology, Inc.</td>
<td>Medtronic</td>
<td>• Global disinfectant and antimicrobial chemical market 2011: $1.2 billion</td>
</tr>
<tr>
<td>Nanovis Incorporated</td>
<td>Baxter International</td>
<td>• Global disposable paper products market 2011: $2.3 billion</td>
</tr>
<tr>
<td>Acrymed, Inc.</td>
<td>Philips Healthcare</td>
<td>• Global wipes products market 2011: $1.9 billion</td>
</tr>
<tr>
<td></td>
<td>Abbott Laboratories</td>
<td>• Global diapers market 2011: $7.5 billion</td>
</tr>
<tr>
<td></td>
<td>Becton Dickinson &amp;Co</td>
<td>• Global cosmetics products market 2011: $4.4 billion</td>
</tr>
<tr>
<td></td>
<td>3M Health Care</td>
<td>• Global deodorant products market 2011: $2.3 billion</td>
</tr>
<tr>
<td></td>
<td>Toshiba Medical Systems</td>
<td>• Global skin care products market 2011: $7.1 billion</td>
</tr>
<tr>
<td></td>
<td>Smith &amp; Nephew</td>
<td>• Global packaging market 2011: $144.5 billion</td>
</tr>
<tr>
<td></td>
<td>Danaher</td>
<td>• Global frozen food packaging market 2011: $5.8 billion</td>
</tr>
<tr>
<td></td>
<td>Terumo Corporation</td>
<td>• Global filters market 2011: $9.8 billion</td>
</tr>
<tr>
<td></td>
<td>Roche</td>
<td>• US paint &amp; coating market 2011: $19.7 billion</td>
</tr>
<tr>
<td></td>
<td>Paul Hartmann AG</td>
<td>• US disposable medical supplies market: $47.1 billion</td>
</tr>
<tr>
<td></td>
<td>Zimmer</td>
<td>• US sterile medical packaging demand: $4.8 billion</td>
</tr>
<tr>
<td></td>
<td>Varian Medical Systems</td>
<td>• Global baby products market 2011: $6.9 billion</td>
</tr>
<tr>
<td></td>
<td>Perkin Elmer, Inc.</td>
<td>• Global coated fabric market 2011: $300 billion</td>
</tr>
</tbody>
</table>

- Global active sportswear market 2011: $52 billion
- Global athletic footwear market 2011: $86 billion
- Global disinfectant and antimicrobial chemical market 2011: $1.2 billion
- Global disposable paper products market 2011: $2.3 billion
- Global wipes products market 2011: $1.9 billion
- Global diapers market 2011: $7.5 billion
- Global cosmetics products market 2011: $4.4 billion
- Global deodorant products market 2011: $2.3 billion
- Global skin care products market 2011: $7.1 billion
- Global packaging market 2011: $144.5 billion
- Global frozen food packaging market 2011: $5.8 billion
- Global filters market 2011: $9.8 billion
- US paint & coating market 2011: $19.7 billion
- US disposable medical supplies market: $47.1 billion
- US sterile medical packaging demand: $4.8 billion
- Global baby products market 2011: $6.9 billion
- Global coated fabric market 2011: $300 billion
<table>
<thead>
<tr>
<th>Target markets size according to industry estimates</th>
<th></th>
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<tbody>
<tr>
<td>• Potential surface antimicrobial market 2020: $25 billion (Frank and Sullivan)</td>
<td></td>
</tr>
<tr>
<td>• Biofilm Antibacterial 2011: $2 billion (Frank and Sullivan)</td>
<td></td>
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<tr>
<td>• Anti-mold: $500 million (Frank and Sullivan)</td>
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</tr>
<tr>
<td>• World Anti-Microbial Surfaces Market 2011: $6 billion (NMZ)</td>
<td></td>
</tr>
<tr>
<td>• Global drug delivery market 2011: $33 billion (Cientifica)</td>
<td></td>
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<tr>
<td>• Oral drug delivery market 2010: $49 billion. 2017: $97 billion (FDA)</td>
<td></td>
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<tr>
<td>• Drug delivery market 2011: $137.9 billion. 2016: $175.6 billion (BCC Research)</td>
<td></td>
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<tr>
<td>• Medical diagnostics market 2012: $380 billion (HRI)</td>
<td></td>
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<tr>
<td>• Global lab-on-a-chip market 2009: $817.6 million (Frost and Sullivan)</td>
<td></td>
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<tr>
<td>• Biocompatible polymer scaffold market: $10 billion (InVivo Therapeutics)</td>
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<tr>
<td>• The global market in 2010 for medical textiles was about €12 billion from about 238 tons of production (Cosmetic Science Technology)</td>
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</table>
Nanocoatings have been applied in military and commercial steel ship hulls and steel, aluminum or fiberglass boat hulls, making them non-susceptible to permanent adhesion of marine fouling organisms such as barnacles, sea-grasses etc. When organisms such as bacteria, barnacles and algae stick to the surfaces of ships it is a costly nuisance. These biofouling organisms mean that ships burn 40% more fuel at an annual cost of more than €5 million for businesses, as well as an incalculable cost to the environment.

**MARKET POTENTIAL** ★★★★★☆

**APPLICATIONS AND ESTIMATED TIME TO MARKET**
- Anti-corrosion CNT coatings (On market)
- Anti-biofouling coatings (On market)

### Marine

Nanocoatings are under development for marine applications that are mechanically and chemically resistant against sand, salts, enzymes, and bio-compounds produced by marine life. Nanocoatings can restore original color, extreme gloss, surface hardness and UV resistance back into oxidized clear coatings on marine vessels. Nanostructured cemented carbide coatings are used on US Navy ships for their increased durability.

**MARKET POTENTIAL** ★★★★☆

Carbon nanotubes have been incorporated into marine coatings for anti-corrosion. These coatings allow for improved integrity of barrier films due to lower pigment loading and CNT reinforcement. They also display improved improved durability and modulus under stress and impact and abrasion resistance.

**MARKET POTENTIAL** ★★★★★

Fouling organisms have traditionally been controlled through the application of antifouling paints that release biocides. Regulations now require that antifouling paints must not cause significant adverse effects on the environment. Nanomaterials allow for environmentally benign coatings. Biofouling can be minimized by reducing bio-adhesion via nanomaterials. Non-stick nanocoatings prevent adhesion of marine life to ships hulls.

**MARKET POTENTIAL** ★★★★☆
Biofouling is a major problem in the marine industry. Biofouling negatively impacts maritime activities, creating biological films on different structures. Due to biofouling, regular maintenance and the use of biocides is needed, which interrupts maritime operations and contaminates water.

The ban on organic tin compounds for use as antifouling agents to prevent organic growth has necessitated relative frequent cleaning of the coating surface on the ship’s hull to ensure cost-effective transport. Due to the self-sacrificing (self-ablative) mode of operation, or “shedding” itself into the water, typical marine hull antifouling coatings are notorious for releasing environmental and health-compromising “anti-foulant” toxins/poisons into the water during routine underwater hull cleaning.

The increase in frictional drag caused by the development of fouling on hulls of ships can reduce speed in excess of 10% (Townsin, 2003). A vessel with a fouled hull burns 40% more fuel which has an impact on fuel costs and additional greenhouse gas production (estimated to be 20 million tonnes per annum). There is a continual drive to develop improved anti-fouling coatings technologies that will have less environmental impact by allowing a reduction in fuel consumption and the release of biocides.

Marine coatings are in service to protect structures such as ships and platforms or sensors. By settling on ship hulls, mussels, barnacles and algae can substantially increase ship weight up to several tons within a short time thus leading to a higher resistance during transport, higher fuel consumption - even on long hauls.

Typically, marine coatings are tributyltin self-polishing copolymer paints containing toxic molecules called biocides. They have been the most successful in combating biofouling on ships, but their widespread use has caused severe pollution in the marine ecosystem. Nanocoatings are an entirely non-toxic alternative, which reduces the adhesion strength of marine organisms, facilitating their hydrodynamic removal at high speeds.

**Properties**

Nanocoatings reduce the flow resistance between the ship's hull and the water, thereby enabling a significant reduction in fuel consumption and carbon dioxide (CO2) emissions. The market will continue to grow, driven by environmental concerns and reducing maintenance costs. Desirable functional properties for the marine industry afforded by nanomaterial water based, anti-foul coatings include:

- super hydrophobicity (less fuel consumption)
- increase durability
- water repellent
- UV-resistant
- fungus / algae / bacteria resistant
- thermally insulating
- elastomeric
- anti-sticking and -corrosive (up to 1000 – 4000 hours of
Another major advantage is the reduction of maintenance costs. The ban on organic tin compounds for use as antifouling agents to prevent organic growth has necessitated relative frequent cleaning of the coating surface on the ship’s hull to ensure cost-effective transport. The smoothness and greater hardness of nanoscale coatings provide better durability and extends the cleaning cycle. Since biofouling represents a substantial maintenance expense for hydro-kinetic systems, anti-fouling nanocoatings could potentially provide an important value-added solution for these systems. Areas in marine coatings that nanocoatings will impact include:

- Cargo holds: Abrasion resistance
- Cargo tanks: Chemical resistance
- Underwater hull: Fouling control
- Decks: Hard wearing, impact and chemical resistance
- Ballast tanks: Corrosion resistance.

Companies

Advanced Marine Coatings (www.amcoat.no) is a Norwegian paint company producing and marketing next generation marine coating with CNTs using a new unique patented technology. BIOMIT™ is Nanocyl’s (www.nanocyl.com) trade name for a range of eco-friendly, fouling release paints designed for all major marine coating applications, such as ship hulls, oil rigs, and underwater intake valves.

Hempel’s (www.hempel.com) anti-fouling products, Globic 9000 and Globic 6000 are designed around patented nano-capsule binder technology. The nano-capsule acrylate copolymers are the main binder which in combination with a powerful bioactive mixture makes it suitable for protection on vessels operating in aggressive fouling waters.

Wetted surfaces coated with the Inframat Corporation’s (www.inframat.com) product on naval vessels that were coated with this material approximately five years ago still show virtually no signs of biofouling. NanoCover A/S (www.nanocover.dk) products include marine seals and marine glass. Nanogate Technologies GmbH has developed a non-toxic surface coating, Nano® FPU to ensure a biofouling-free ship’s hull.

Nanovere Technologies, Inc. (www.nanovere.com) specializes in the development of clear coatings ultra-scratch resistant and self-cleaning paint that can be applied to marine paint. Tesla NanoCoatings (www.teslanano.com) supplies corrosion control coatings incorporating carbon nanotubes for marine markets. Diamon-Fusion International, Inc. (www.diamonfusion.com) develops nanocoatings with water and oil repellency (hydrophobic and oleophobic) for marine glass. PURETi (www.pureti.com) produces a water based solution that air dries to form an invisible, well adhered, ultra thin, long lasting coating that actively protects all surfaces to which it is applied from the buildup of any organic matter - including bio-film, bacteria, molds or fungi. PURETi products can be applied to virtually any surface, including buildings, signs, solar panels, sidewalks, outdoor furniture, holding tanks, boats, and planes. Reactive Surfaces (www.reactivestech.com) develop exterior marine coatings functionalized with bio-based additives for submersed hull surfaces and stationary structures.
| **Intermediate developers** | • Advanced Marine Coatings AS  
• Bayer  
• BASF  
• Hempel  
• Nanovere  
• Nanocyl  
• Nanops  
• Tesla NanoCoatings |
| **Application developers** | • Bennington Marine  
• Mercury Marine  
• US Navy |
| **Target markets size according to industry estimates** | • USN field studies: fuel consumption increases by ~40% due to severe fouling.  
• Global biofouling market 2012: $650 million 2016: $1 billion (Global water intelligence)  
• In terms of value, the marine coatings market was worth approximately $4 billion in 2007, or roughly four percent of the total global coatings market, on a volume of 840 million liters and will be worth $4.7 billion in 2012 on a volume of 904 million liters (IPPIC)  
• Global marine coatings market 2012: $4.7 billion (Battelle) |
Nanomaterials are particularly suited to protecting the surface of various construction materials such as glass, concrete, sand limestone or marble from environmental influences like water staining, moss, algae as well as soot and oil stains; and can also function as corrosion inhibitors for reinforced steel. Nano additive paints and surface coatings are commercially available that create a low energy facing thus rendering a building surface highly hydro- and oleophobic, thereby helping to prolong maintenance cycles and reduce cleaning.

MARKET POTENTIAL

Photocatalytic

Nano-Tio2 photocatalytic coatings are the most wide-spread application ascribed to nanotechnology in the construction industry. There are already a great number of buildings worldwide which have been treated with it. Such coatings greatly benefit building maintenance, especially for skyscrapers, as they reduce the need for costly surface cleaning. Photocatalyst coatings are also used to improve indoor air quality by reducing the amount of volatile organic compound and other toxic chemicals people are exposed to.

MARKET POTENTIAL ★★★★★☆

Thermal

Commercial window films can gain competitive advantage by embedding nanoparticles into plastic films later applied to glass surfaces. Nano films offer heat absorption and reflective properties while maintaining fairly high levels of transparency. Nanocoatings can be used to reduce heat conduction as well as provide resistance to moisture, corrosion, mold growth and ultraviolet (UV) rays.

MARKET POTENTIAL ★★★★★☆

Anti-graffiti

Concrete structures also make profit from nano-enhanced coatings that prevent graffiti and other unwanted stains to adhere on to it. Anti-stick properties of nanocoatings leads to less staining and easy-cleaning-effect on exterior and interior surfaces. Anti-graffiti properties mean that stubborn stains such as graffiti, which in the past called for intensive cleaning efforts can be washed away simply with a high pressure hose.

MARKET POTENTIAL ★★★★★☆
The integration of engineered nanoparticles in façade coatings may lead to improved or new functionalities during their life cycle. Nanomaterials may improve environmental sustainability by saving materials, substituting hazardous substances and improving the durability of the coating. However, extended applications of nanomaterials raise concerns about potential risks for human health and the environment.

Properties
Nanostructured materials are allowing companies to develop the next generation of protective coatings for buildings. Nanoparticles found in construction are carbon-fluoride (CF-), polymers, titanium dioxide (TiO2), zinc oxide (ZnO), silica (or silica fume; SiO2), silver (Ag), and aluminum oxide (Al2O3).

Costs are prohibiting widespread adoption but TiO2 nanoparticles have been widely applied in self-cleaning coatings and carbon nanotubes are being used in concrete to improve strength. Modification or impregnation of resins with nanomaterials could improve hardness, wear and decay resistance in wood products. Dirt repellent protective paints and photocatalytic coatings are the most prominent applications in the construction and exterior protection industry. Dirt collection (accumulation) in building exteriors poses considerable problems for building maintenance. Cleaning such building surfaces is generally done by using detergents accompanied with scrubbing, wiping and high-pressure water jets. These processes have several shortcomings such as use of chemical detergents, high consumption of energy and labour cost. These naturally lead to high maintenance cost; therefore, an effective self-cleaning coating is desirable.

In recent years, self-cleaning coatings using photocatalytic Titanium Dioxide (TiO2) has gained considerable industry attention. With assistance of little UV light from fluorescence source or sunlight, TiO2 offers two unique properties: (a) strong oxidation power, and (b) super-hydrophilicity. Strong oxidation power can be used to kill bacteria attached on the wall, or oxide/remove foul smell from stains in toilets (e.g., TiO2-coated tile and TiO2-coated glass are commercially available). Super-hydrophilic properties allow dirt and stains to be easily washed away with water or by rainfall when such coating is applied to exterior surfaces.

Nanoscale titantium dioxide (TiO2) absorbs UV light and is used as a protective layer against UV degradation. Some forms of TiO2 are photo-catalytic and catalyze the degradation of organic pollutants like algae, PAHs, formaldehyde and NOx under the influence of UV light. Applications are found for practically every surface type that has to be UV-protected, made self cleaning or should assist in the reduction of air pollution. Zinc oxide (ZnO) shows similar photo-active characteristics to TiO2 and can be used for similar applications. Silver (Ag) acts as a bactericide and can be added to all sorts of materials. In construction it is mostly found in coatings.
Aluminum oxide (Al2O3) is used in coatings to interact with the binder material and to add high scratch resistance to this coating. Carbon-fluoride polymers (CF-polymers) are Teflon-like nanoparticles that are applied onto a surface to make this surface water and oil repellent. Applications are typically found on glass.

Glass
Nanostructured coatings are particularly suited to protecting the surface of construction materials such as glass from environmental influences such as water staining, moss, algae as well as soot and oil stains. Nanoparticles exhibit properties of water/dirt repellency, UV protection, antibacterial, anti-corrosion for application on glass. Strong oxidation power can be used to kill bacteria attached on glass and super-hydrophilic properties allow dirt and stains to be easily washed away with water or by rainfall when the coating is applied to exterior surfaces. There are a number of nanocoated glass products available, with Asia and Germany in particular proving to be strong markets. Pilkington Activ Glass (www.pilkingtonselfcleaningglass.co.uk) uses nano-scaled titania (TiO2) that shows photo-activation with UV light in order to prevent or reduce the soiling of surfaces. Presently, titanium dioxide can only be activated by the UVA present in sunlight. But work is ongoing activating titanium dioxide with indoor light by modifying TiO2 nanoparticles with other elements such as iron and nitrogen so they can absorb light at longer wavelengths. Lab trials show that glass coated with the nanoparticles can be activated by visible light from a lamp to kill Escherchiae coli. Applied Thin Films, Inc. (www.atfilminc.com) produces THMC, a proprietary multilayer coating stack specifically designed for applications where high visible transmission is desirable and infrared thermal radiation is rejected thus producing energy efficient windows. CTC Nanotechnology GmbH (www.ctc-nano.de) produces NANOIDENT® Supraperl Forte, a nanobiomic ultra-thin high-capacity coating for glass surfaces. Application is mainly for glass surfaces on high rises.

Wood protection
There are a number of nano-enabled products for the protection and cooling of parquet flooring systems and furniture (interior) and that focus on water (and to a lesser extent oil) repulsion, scratch resistance and UV protection. These transparent protective coating help to cool deck surface temperatures as well as protect the wood from moisture, UV and weathering, while also being resistant to mold and algae growth. High scratch resistant wood lacquers containing nano-SiO2 are Bin-dzil CC30 (Baril Coatings), Nanobyk 3650 (BYK Additives and Instruments) and Pall-X Nano (Pallmann). Nanobyk 3600 (BYK Additives and Instruments) is an example of a high scratch resistant coating based on the addition of nano sized Al2O3 particles. Nanovations’ (www.nanovations.com.au) Lignol wood coatings are water-based, VOC-free, clear impregnating wood coatings containing nanoscale UV absorbers. Nanovations 3001, designed for use on masonry and concrete surfaces, provides superior water repellency, reduces efflorescence, and provides significantly improved abrasion resistance. Industrial Nanotech, Inc. (www.industrial-nanotech.com) produces Nansulate Deck, for protection and cooling of wooden decks and railings. This clear protective coating helps to cool deck surface temperatures as well as protects the wood from moisture, UV and weathering, while also being resistant to mold and algae growth.

Paint
Rheology, settling, surface energy, corrosion resistance and mechanical properties of paint can be improved via the addition of nanoparticles. Adding nanoparticles gives paint scratchproof, easy cleaning, air purifying, UV resistant, water repellence, flame retardancy and antibacterial features. GNS Science (www.gns.cri.nz) and Resene Paints (www.resene.com) have teamed up to develop a hi-tech roof paint containing nano-particles that will be more effective than existing coating products at reflecting summer heat and keeping buildings cooler in summer. Examples of self-cleaning, photocatalytic coatings are Arctic Snow Professional Interior Paint by Arctic paint LTD (TiO2), Cloucryl by Alfred Clouth Lack-fabrik GmbH&Co KG23 (ZnO) and Amphisilan by Caparol.

Concrete
Concrete structures are subject to dynamic environments, such as dynamic loads, ultra violet from direct
Figure 2: Mechanism of photocatalytic NOx oxidation on active concrete road.

Figure 3: Jubilee Church in Rome, the outside coated with nanophotocatlytic TiO2 coatings. Photocatalytic titanium dioxide is energized by UV and accelerates the decomposition of organic particulates and airborne pollutants such as nitrous oxide (NOx).

In this condition, most resin coatings deteriorate in a short period of time in the form of cracking, blistering, disbanding, or chalking. Photocatalytic oxidizers can be installed onto the product after the manufacturing process. PCOs that cannot be installed into products during the manufacturing process may be installed using different techniques, such as spraying and dipping methods. With these processes, the lifespan of the PCO will be temporary, usually lasting between five to ten years.

Nanocoatings have been applied to cement products to reduce corrosion and ingress of harmful chemicals. Nanokote (www.nanokote.com.au) has produced NK-TC 01, a coating material that exhibits very high abrasion resistance, high chemical resistance and easy to clean surface properties. The coating material is applied to concrete and cement based substrates to give an opaque satin-gloss or matt finish. German company Nano-Care AG (www.nanocare-ag.com) is manufacturing easy-clean nano-coatings, based on silicon dioxide (SiO2) for cement products. They are used as an invisible, water- and contamination-resistant, UV-stable coating of porous substrate surfaces, regardless of whether the surface is a natural stone such as sandstone, concrete, terracotta, clay brick or stone panelling. Hi-Proguard (http://mui-int.com/Hi-Proguard-for-Con-crete.php) is another nano-based product for concrete protection. Cleancorp Nanocoatings (www.cleancorp.de) produces nanoscale anti-graffiti coatings for stone-work.
### Table 28: Nanocoatings in the exterior construction industry-suppliers, intermediate developers, target market revenues

<table>
<thead>
<tr>
<th>Intermediate developers</th>
<th>Product developers</th>
<th>Target markets size according to industry estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanovere Technologies</td>
<td>Nippon Paint</td>
<td>U.S. construction chemical industry is valued at $7.7 billion (Freedonia).</td>
</tr>
<tr>
<td>Bayer</td>
<td>Alcoa</td>
<td>The global construction materials market grew by 6.2% in 2010 to reach a value of $655,822.9 million (Data Monitor).</td>
</tr>
<tr>
<td>Reef Iran Chemical Industry Complex</td>
<td>Sveza</td>
<td>In 2015, the global construction materials market is forecast to have a value of $889,017.9 million, an increase of 35.6% since 2010.</td>
</tr>
<tr>
<td>Industrial Nanotech, Inc.</td>
<td>TATA Steel</td>
<td>The global green construction materials market is expected to exceed $405 billion by 2015 (GIA).</td>
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<tr>
<td>Nanogate</td>
<td>PPG</td>
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<td>Bioni CS</td>
<td>Duravit</td>
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<td>Cleancorp Nanocoatings</td>
<td>Roca</td>
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<td>CTC Nanotechnology GmbH, Clou</td>
<td>Erlus</td>
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<td>DAW Caparol</td>
<td>Villeroy and Boch</td>
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<td>De Cie GmbH</td>
<td>Saint Gobain</td>
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<td>Duraban LLC</td>
<td>Pilkington</td>
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<td>Green Earth Nanoscience, Inc.</td>
<td>BASF</td>
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<td>Green Millennium, Inc.</td>
<td>Clariant</td>
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<td>GXC Coatings</td>
<td>Panahome</td>
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<td>Haruna (S) Pte Ltd</td>
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<td>i-Can Nano, ISTN, Inc.</td>
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<td>NanoCare AG</td>
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<td>Nanovations Pty Ltd</td>
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<td>NANO-X GmbH</td>
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<td>nGimat Co.</td>
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<td>n-tec GmbH</td>
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<td>PURETi, Inc.</td>
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<td>Cristal</td>
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<td>Green Earth Nanoscience, Inc.</td>
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<tr>
<td>Green Millennium, Inc.</td>
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</tbody>
</table>
Table 28: Nanocoatings in the exterior construction industry-suppliers, intermediate developers, target market revenues

| Target markets size according to industry estimates | • The global construction materials market had total revenues of $664.4 billion in 2011, representing a compound annual growth rate (CAGR) of 3.6% between 2007 and 2011 (Marketline).
| | • Global photocatalysts market 2009: $800 million (BCC)
| | • Global photocatalytic coatings market 2010: $62 million (AIST)
| | • The cost of damage caused by emissions in 2009, just from the industrial facilities reporting into the E-PRTR (European Pollutant Release and Transfer Register), is estimated as being at least EUR 102–169 billion. Fifty percent of the total damage cost occurs as a result of emissions from just 191 (or 2%) of the approximately 10,000 facilities that reported at least some data for releases to air in 2009. Three quarters of the total damage costs are caused by the emissions of 622 facilities, which comprise 6% of the total number.
| | • Sales of photo-catalytic products in Japan was 650 million USD in 2008 (Nanoglobe)
| | • Global photocatalyst market 2009 was $1 billion. Japanese market $700 million (Sumitomo Chemical). |
Nanoparticles have been added to construction ceramics, which include floor and wall tiles, countertop ceramics and sanitary ware products. They have found a place on the market with self-cleaning, anti-bacterialism hygienic and scratch resistant features. They add new functional properties to a number of surfaces inside the home, for example, preventing limescale in the bathroom, keeping windows and sanitary surfaces clean as well as providing algae and moss resistance on outdoor furniture.

**MARKET POTENTIAL**

Easy clean coatings have been applied to sanitary surfaces in bathrooms, toilets, kitchens or window panes, where frequent contact with water, oil and dirt can quickly soil surfaces. The coatings contain functionalized nanoparticles such as nano silver that impart a bacteria-free surface which is anti-fouling & anti-algae.

**MARKET POTENTIAL**

Silver nanoparticles have been commercialized that destroy mold and mildew, fungi spores, and bacteria on contact. The nanoparticles are stabilized with additives and integrated homogeneously into the polymer matrix. Antimicrobial activity does not decrease with time because the solid nanoparticles are not volatile, like many commonly used biocide additives.

**MARKET POTENTIAL**

Nanoparticle TiO2 self-cleaning coating technology is applicable for use on painted surfaces. Photocatalyst coatings are also used to improve indoor air quality by reducing the amount of volatile organic compound and other toxic chemicals people are exposed to in hotels, restaurants, commercial business facilities, university laboratories, hospitals, and private residences.
Nanocoatings enhance the performance and quality of glass substrates giving more functionality and aesthetic value. These coatings contain functionalized nanoparticles such as titanium dioxide, silicon oxide and nano silver that impart a bacteria-free surface which is anti-fouling & anti-algae. Due to the anti-sticking properties surface dirt does not adhere. Nanoscale coatings prevent fingerprints, facilitate cleaning glass doors, prevent limestone deposits in shower cabins and also offer long-term protection against glass corrosion. They have also been applied on automotive windscreens where hydrophobic and oleophobic properties greatly improve visibility in the rain, and reduced adherence of dirt and contaminants. Most products are based on fluoropolymer modified nanoparticles in solution and can be applied to the substrate by spin-coating, spraying and dip coating. GXC Coatings applies functional coatings based on nanotechnology to glass and polymer substrates for application as glass elements that are intensively used in kitchens and bathrooms.

**Food preparation and processing**

Anti-microbial nanocoatings allow for improved sanitation of food contact surfaces in processing. Surfaces with the capability to prevent microbiological contamination (salmonella, listeria, legionella) are of great interest to the food industry and nanoscale anti-microbial, easy-clean and self-cleaning coatings can enhance sanitary security in food preparation and processing. Nanocoatings have been applied mainly on a trial basis to the food processing industry on food contact surfaces. Anti-microbial nanosilver can be employed in anti-spoilage food packaging and food contact surfaces. Self-cleaning have been applied to food surface worktops, milk-tankers, floors and fridges. Cleaning cycles can be reduced by 30%-50% after being treated with a simple wipe or spray in a matter of seconds creating areas which will be bacteria free for at least 6 months. Once treated with this food safe coating, surfaces can be cleaned very easily as the soiling agents will not have adhered to the surface. Nanocoatings have been applied mainly on a trial basis to the food processing industry on food contact surfaces. Anti-microbial nanosilver can be employed in anti-spoilage food packaging and food contact surfaces. Self-cleaning have been applied to food surface worktops, milk-tankers, floors and fridges. Cleaning cycles can be reduced by 30%-50% after being treated with a simple wipe or spray in a matter of seconds creating areas which will be bacteria free for at least 6 months. Once treated with this food safe coating, surfaces can be cleaned very easily as the soiling agents will not have adhered to the surface. Nanocoatings have been applied mainly on a trial basis to the food processing industry on food contact surfaces. Companies such as Nanopool (www.nanopool.eu) have sold their coatings to both food retailers and manufacturers. Nanoscale silver coatings preserve food shelf-life.
by delaying the development of salmonella, listeria and E-coli. Food safety concerns are a main driver for adoption of anti-microbial and self-cleaning coatings in this area. Regulatory issues and consumer acceptance are likely to be a hindrance at present to adoption. Bioni CS GmbH (www.bioni.de) has developed an antibacterial coating, Bioni Hygienic that contains silver nanoparticles that destroy mold and mildew, fungi spores, and bacteria on contact for application in food industry facilities and food packages.

**Sanitary**

A number of Asia-based companies, such as Green Earth Nano Science Inc. (www.gensnano.com) produce nanoscale TiO2 coatings in a liquid solution which breaks down organic pollutants for internal and external application. The surface coatings provide air and surface eliminate biocontamination caused by Listeria, Salmonella, E.coli, Swine Flu (H1N1), Bird Flu (H5N1), SARS and mould spores. Photocatalytic oxidizers can be installed directly into products during the manufacturing process. PCO-treated surfaces are anti-microbial, remove odors, are self-cleaning and air-purifying, and anti-fogging.

Volatile organic compounds or VOCs, from sources such as building materials and furnishings, release pollutants continuously. Other sources, related to activities carried out in the home, release pollutants intermittently, such as: smoking; the use of unvented or malfunctioning stoves, furnaces or space heaters; paint and paint strippers; and the use of cleaning products and pesticides in housekeeping. VOC concentrations can remain in the air for long periods after some of these activities. Health effects from indoor air pollutants may be experienced soon after exposure or possibly years later. Immediate effects may show up after single exposure or repeated exposures. These effects may include irritation of the eyes, nose, and throat; headaches; dizziness; and fatigue. Such immediate effects are usually short-term and treatable. Sometimes the treatment is simply eliminating the person’s exposure to the source of the pollution, if it can be identified. Symptoms of diseases, including asthma, may also show up soon after exposure to some indoor air pollutants. Other health effects may show up either years after exposure has occurred, or only after long or repeated periods of exposure. These effects, which include some respiratory diseases, heart disease, and cancer, can be severely debilitating or fatal.

It is prudent to try to improve the indoor air quality in a building, even if symptoms are not noticeable, as it is one of the top five health concerns in the U.S. according to the Environmental Protection Agency. Tests on odor and VOC decomposition rates further show the effectiveness of photocatalytic oxidizing. Photocatalytic coatings are also effective on NOx Removal. When NOx and volatile organic compounds react in the presence of sunlight, they form photochemical smog, a significant form of air pollution, especially in the summer. Children, people with lung diseases such as asthma, and people who work or exercise outside, are susceptible to the adverse effects of smog, such as damage to lung tissue and reduction in lung function. Photocatalytic oxidizers degrade NOx on the surface, leaving the surface clean. Currently, PCOs can be applied to ceramic tiles using this method. With this process, the lifespan of the PCO is as long as the lifespan of the tile.

Advantages of photocatalytic nanocoatings on tiles include:

- Decomposition of bacteria, fungi, algae, moss and germs
- Elimination of odors
- Improvement of room air quality
- The original characteristics of the tile, such as resistance to abrasion, resistance to chemicals, etc., are maintained
- Requires only minimum care
- Low cleaning costs
- Free of irritating substances, non-toxic
- Environmentally friendly
- Long-term guarantee
- Varied range of products

Proven application locations for PCOs include these areas:

- Health and healthcare areas such as hospitals, assisted living facilities, and medical office buildings
- Transportation and the public sector such as airports, mass transit stations, and tunnels
- Fitness and wellness areas such as pools, spas, and saunas
- Building facades including rain screens
- Shopping and business areas including shopping malls and office buildings
- Residences in kitchens and baths.

TOTO’s CeFiONtect (www.toto.co.jp/en/products/technology/cefion.htm), is a nanostructured coatings for application in public restrooms. Diamon-Fusion International, Inc. (www.dfisolutions.com) produces multifunctional characteristics include water and oil
repellency (hydrophobic and oleophobic), and anti-fingerprinting for glass shower enclosures.

Biohygenics (www.biohygenics.com) produces anti-bacterial nanoscale photocatalytic coatings for applications in hospitals and the home. The coating destroys organic compounds on surfaces. Bacteria, spores, viruses, odors, smoke and pollutants are all destroyed. For instance their products deal with MRSA, C. Difficille, E. Coli, SARS, listeria, salmonella, and bacterial spores. CeNano GmbH & Co. KG (www.cenano.de) produces Nanofix, a limescale remover.

Cleancorp Nanocoatings (www.cleancorp.de) produces anti-bacterial nanocoatings for application in hospitals and senior residences. CTC Nanotechnology GmbH (www.ctc-nano.de) currently produces more than 76 different nanobionic products for the treatment of diverse surfaces, including kitchen surfaces made of stainless steel. GXC Coatings (www.gxc-coatings.com) applies functional coatings based on nanotechnology to glass and polymer substrates for application as glass elements that are intensively used in kitchens and bathrooms. Engineered nanoProducts Germany AG (www.e-p-g.de) manufactures hygienic nanocoatings technologies for clean and self-sterilizing surfaces.

Nanocare AG’s (www.nanocare-ag.com) Nanoflex AFP 100 is a dirt resistant Si-O2 coating for application in the home. NanoHorizons Inc.’s (www.nanohorizons.com) nano-Ag nanosilver coatings are applied to household surfaces and textiles for anti-microbial protection.

n-tec GmbH’s (www.n-tec.eu) self-cleaning coatings are applied to high humidity areas (e.g. bath rooms) and sanitary equipment: tiles, bath -tubs, shower bath, wash basin, armature made of stainless steel and chromium, shower cabinets, toilet seat, bath room furniture. Other applications are as kitchen and domestic articles: kitchen utensils, baking oven, pots and frying pans.

Percenta AG (http://de.percenta.com) produces aqueous nanocoatings for windows and glass panels, solar cells, shower cubicles, mirrors. Sarastro GmbH (www.sarastro-nanotec.com) produces anti-microbial, hygiene and anti-fingerprinting coatings. Applications areas are medicine and medical technology, hygiene surfaces, soft cleaning tissues, textiles for automotives.

Schott AG (www.schott.com) produces Easy-to-Clean coatings for household appliances and surfaces to prevent mould, fight bacteria and hide fingerprints.

SmartSilver™ is a certified nanosilver-based antimicrobial performance brand created by NanoHorizons (www.nanohorizons.com) in collaboration with leading manufacturers in the medical, apparel and household goods industries.
<table>
<thead>
<tr>
<th>Table 29: Nanocoatings in the household care industry-suppliers, intermediate developers, target market revenues</th>
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</thead>
<tbody>
<tr>
<td><strong>Intermediate developers</strong></td>
</tr>
<tr>
<td>• Cleancorp Nanocoatings</td>
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<tr>
<td>• Duraban LLC</td>
</tr>
<tr>
<td>• Nanogate Coating Systems Gmb</td>
</tr>
<tr>
<td>• Nanoproofed</td>
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<tr>
<td>• n-tec GmbH</td>
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<tr>
<td>• CTC Nanotechnology GmbH</td>
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<tr>
<td>• Nanocare AG</td>
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<tr>
<td>• NanoCover A/S</td>
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<tr>
<td>• Nanopool GmbH</td>
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<tr>
<td><strong>Product developers</strong></td>
</tr>
<tr>
<td>• Proctor and Gamble</td>
</tr>
<tr>
<td>• Unilever</td>
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<tr>
<td>• Reckitt Benckiser</td>
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<tr>
<td>• AkzoNobel N.V.</td>
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<tr>
<td>• BASF</td>
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<tr>
<td>• Dupont</td>
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<tr>
<td>• Sherwin-Williams</td>
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<tr>
<td>• DOW Chemical</td>
</tr>
<tr>
<td><strong>Target markets size according to industry estimates</strong></td>
</tr>
<tr>
<td>• Antimicrobial coatings demand was worth USD 1.6 billion in 2012 and is estimated to reach USD 3.3 billion in 2018, growing at a CAGR over 12% from 2012 to 2018 (Transparency market research).</td>
</tr>
<tr>
<td>• US anti-microbials market 2015: $1 billion (GIA)</td>
</tr>
<tr>
<td>• Target markets for anti-microbial coatings are fungicides ($6 billion global market in 2007) and disinfectants and anti-microbials ($0.8 billion USA market in 2007) (Nanogate).</td>
</tr>
</tbody>
</table>
The military and defense sector is a prime developer and market for nanocoatings. A number of nanomaterials innovations developed for the military have also found application in other markets such as textiles, marine, electronics and aerospace. Nanocoatings have many applications in the military market: to improve durability, reliability and performance of various components; to resist erosion, sliding and fretting wear or to improve surface quality; and to produce corrosion resistant coatings for combating pitting, exfoliation, oxidation and hot corrosion.

MARKET POTENTIAL
★★★★☆

The total cost for the US Department of Defence corrosion-related problems is US$20 billion per year. CNT coatings have already been trialled and graphene nanocomposite coatings show promise for protecting low-alloy steels. Superhydrophobic nanocoatings have also been developed for metal protection that reduce operational and maintenance costs by extending the useful life of military assets.

MARKET POTENTIAL
★★★★☆

Nanocoatings are under development for military applications such as protective textiles and equipment for withstanding harsh environments. Omniphobic coatings are being investigated for self-cleaning and enhanced chemical and biological agent protective clothing. The resulting fabrics have very low interfacial energy, which minimizes surface wetting by water, liquid chemicals, and attraction to dirt.

MARKET POTENTIAL
★★★★☆

Nanoscale thermal barrier coating systems are under development for aircraft surfaces (metal and fiberglass) capable of exposure to moderate short-duration heating; high temperature hard environments in military vehicles; and in military gas turbine engines to increase component life and engine performance.
The US Army in particular is conducting extensive R&D designed to lead to the development of nanomaterials systems for Army applications incorporating unique properties such as self repair, selective removal, corrosion resistance, sensing, ability to modify coatings’ physical properties, colorizing, and alerting logistics staff when tanks or weaponry require more extensive repair.

Corrosion
Nanomaterials are also allowing for significant cost savings; military equipment suffers from high maintenance costs and poor assets availability. Conventional paints are labour intensive to apply and potentially hazardous to the people working with them. These coatings have to be touched up by hand, which can hide metal damage. EnvAerospace (www.envaerospace.com) produces anti-corrosion nanocoatings for application on military equipment and components.

Protection
Military equipment and personnel must withstand some of the most demanding environments on earth. Nanostructured coating technology enables, for example, military aircraft and turbine powered vehicles and equipment to operate uninterrupted for longer by withstanding these extreme conditions. Scratch resistant coatings have been applied in aircraft cockpits. Nanoscale thermal barrier coating systems are under development for aircraft surfaces (metal and fiberglass) capable of exposure to moderate short-duration heating; high temperature hard environments in military vehicles; and in military gas turbine engines to increase component life and engine performance. Isotron (www.isotron.net) develops RADBLOCK nanoparticle coatings that can be used in protection of surfaces from the hazards associated with chemical and biological warfare agents. DryWired (www.drywired.com) produces water protective nanocoatings for mobile devices to prolong the life of electronics subjected to a wide range of environmental hazards in military applications.

Decontamination
Current decontamination processes for biological agents are complex, cumbersome and costly. To circumvent this process, nanostructured coatings systems have been developed with the continuous ability to decontaminate a surface exposed to biological agents including spores. A number of US companies have received large grants from the US Military to develop coatings for equipment and decontamination. Most companies developing nanomaterials applications applicable to the military also diversify into other sectors such as aerospace, marine, textiles and environmental remediation.
Luna Innovations (http://lunainc.com) is developing biocidal coatings to kill microscopic bacteria and fungi by slowly and steadily releasing biocide. Textile fabrics and coatings will be capable of rendering lethal biological agents harmless upon contact.

**Uniforms**

The military demand of FR treated Nylon, used in the cold weather clothing systems, is estimated at several million linear yards annually by itself – with many additional opportunities in non-military markets. The US Army is developing with NanoSyntTex, Inc. durable nonwoven fabrics that integrate blends of various fibrous webs that impart water absorbency or repellency, fire and thermal resistance, antimicrobial treatment, etc. These reinforced multilayer nonwoven composite fabrics have been engineered to be lighter in weight, significantly more breathable, and superior in tear and breaking strength. The US Army is developing with NanoSyntTex, Inc. (www.nanosyntex.com) durable nonwoven fabrics that integrate blends of various fibrous webs that impart water absorbency or repellency, fire and thermal resistance, antimicrobial treatment, etc. These reinforced multilayer nonwoven composite fabrics have been engineered to be lighter in weight, significantly more breathable, and superior in tear and breaking strength. Alexium (www.alexiumgroup.com) is producing flame retardant, oil and water repellent nylon, which it says has met key technical milestones for flame retardancy, water repellency and durability. The company is aiming to address demand from the U.S. military, which currently has 1.4 million soldiers serving on active duty and 800,000 soldiers on reserve duty. Omniphobic coating have also been developed that employ a dual hierarchical micro and nano surface structure. These coatings, developed by the US Army, have proven more durable than the commercial durable water repellent coating such as Quarcel durable water repellent (DWR) coating for at least 20 washes to water, oils, and organic solvents. This dual hierarchical micro and nanocoating is seen as a preventive technological solution for self cleaning clothing to minimize/reduce soldiers' logistic burden of field laundering, and also as an effective means to providing enhanced chemical/biological warfare agent protective clothing through minimizing a textile's attraction to solid and liquid contaminants.

**EMI/WSD Shielding**

Carbon nanotubes and graphene have been utilized for applications including electromagnetic absorbing materials for aircraft and missiles. There is a need to condense the size of electronic devices while increasing their capability, features, and speed to save space, weight, and mass, while allowing for more digital signal paths in applications ranging from unmanned aerial vehicles (UAVs) to handheld devices deployed in the military, homeland security, and law enforcement. Their increased need for greater power and energy requirements for a range of military applications, such as weapons systems, combat vehicles, ships, data centers, and military micro-grid applications.

**Anti-reflection**

Electro-optical/infrared nanosensors are being developed for a variety of defense and commercial systems applications. One of the critical technologies that will enhance EO/IR sensor performance is the development of advanced antireflection coatings with both broadband and omnidirectional characteristics. Magnolia Optical (www.magnoliaoptical.com) develops anostructure-based antireflection structures for military applications.
Table 30: Nanocoatings in the military industry-suppliers, intermediate developers, target market revenues

| Intermediate developers | • A & A Company, Inc.  
|                        | • Analytical Services & Materials, Inc.  
|                        | • Alexium  
|                        | • Applied Nanotech, Inc.  
|                        | • Baikowski Chimie  
|                        | • Diamon Fusion International, Inc.  
|                        | • Duraseal  
|                        | • Eeonyx Corporation  
|                        | • EnvAerospace  
|                        | • Isotron  
|                        | • Intumescents Associates Group  
|                        | • Luna Innovations  
|                        | • Materials Modification Inc.  
|                        | • Nanovere Technologies, Inc.  
|                        | • NCoat, Inc.  
|                        | • Perpetual Technologies, Inc.  
|                        | • Physical Optics Corporation  
|                        | • Resodyn Corporation  
|                        | • Tesla Nanocoatings  
|                        | • TDA Research, Inc.  

| Product developers | • Locheed Martin  
|                    | • NASA  
|                    | • US Army  

**Target markets size according to industry estimates**

- Global military MRO market was $66 billion in 2011, up 1.5% from $65 billion in 2010. In 2011, field maintenance makes up 48% of all military aircraft MRO or $31.7 billion followed by airframe, engine, and component MRO. North America is the biggest military aircraft MRO market at $32.3 billion or 49% of total military aircraft MRO spending followed by Europe at 22%. The vast majority of North American military MRO originates from the United States (Aeroweb).
- Global Military Aircraft Maintenance, Repair and Overhaul Market to Reach $41.66 Billion in 2013 (GIA).
- The global military aviation MRO market is estimated to value US$28.0 billion in 2012 and increase at a CAGR of 3.49% during the forecast period to reach its peak of US$39.4 billion by 2022 (Strategic Defence Intelligence).
Nanocoatings are used in a broad range of electronics & optics applications. Films and coatings incorporating silver nanowires, graphene, carbon nanotubes, quantum dots include transparent electrodes for touch screens, liquid crystal displays, e-paper and OLED devices, and thin film photovoltaics. Transparent conductive films have been incorporated into sensors on touchscreen technologies and as protective coatings on consumer electronics. Nanoscale coatings are also being used to boost the efficiency with which heat can be removed from semiconductors and other devices and add anti-static and electromagnetic shielding properties.

**MARKET POTENTIAL**

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**Conductors**

Graphene and CNTs are being developed as a potential replacement for the costly indium tin oxide (ITO) in touch screens. ITO is brittle, making it unsuitable for flexible touch screens. A network of nanostructures incorporated into films provides an inexpensive alternative, which is also flexible and stretchable. Samsung is the main technology developer in graphene this area. A number of companies are planning on having graphene in touchscreens by the end of 2014.

**MARKET POTENTIAL**

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**Waterproofing**

A number of companies are producing superhydrophobic nanoscale coatings for electronic devices, especially smartphones and tablets. There are also potentially opportunities in military applications. Liquipel, HzO and P2i are the main players in this market and their products coat Sony's Xperia Tablet Z and the Motorola RAZR range.

**MARKET POTENTIAL**

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**Anti-smudge**

Touch screen devices are routinely subjected to touch and thus commonly stained with undesirable fingerprint, skin oil, sweat and cosmetics. Anti-fingerprint nanocoatings are growing in demand as they provide material surfaces with self-cleaning, or easy-to-clean features that improve aesthetic appearance and save maintenance costs.

**MARKET POTENTIAL**

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**APPLICATIONS AND ESTIMATED TIME TO MARKET**

- Transparent conductive layers for OPV, OLED and displays (now, 1-2 years)
- Water resistant coating (hydrophobic) and oil-repellant (oleophobic) surfaces to repel water, dust, oil, and dirt on optics (Now)
- Anti-fingerprint coatings on displays (Now)
The development of future flexible and transparent electronics relies on novel materials, which are mechanically flexible, lightweight and low-cost, in addition to being electrically conductive and optically transparent. The demand for transparent conductors is expected to grow rapidly as electronic devices, such as touch screens, displays, solid state lighting and photovoltaics become ubiquitous in our lives. In electronics applications, nanocoatings form an essential part of the finished product as opposed to being the main component of the product.

**Conductive coatings**

Indium tin oxide (ITO) is the dominant transparent conductor in the electronics market for touchscreens. However it has certain limitations in application for next-generation flexible display devices:

- increasing price due to indium scarcity and processing requirements, which renders it difficult to use in low-cost, large-area electronics;
- ITO is mechanically rigid and can easily wear out or crack when used in applications where bending is involved. This renders it unsuitable for future flexible electronics applications.

To address these issues, other materials are being developed including conducting polymers, carbon nanotubes (CNTs), graphene, metal grids, and metallic nanowires.

There are around 200 companies and research institutions currently developing ITO alternatives such as metal meshes, silver nanowires, conductive polymers, carbon nanotubes, other 2-D materials and GaN. However, graphene is at the forefront of this growing market.

**Graphene**

A network of graphene nanostructures provides an inexpensive alternative to ITO, and is also flexible and stretchable. Graphene oxide films can be deposited on virtually any substrate, and later converted into a conductor. Therefore it is expected that transparent graphene films may replace rigid and brittle ITO films in touch panel screen electrodes.

Samsung is the main technology developer in graphene transparent conductors and there are a number of producers, application developers and OEMS working in the area. Chinese company Chongqing Morsh Technology is building a production facility in Chongqing that they claim will be used to produce 15” single-layer graphene films. Nissan Chemical Industries, Ltd. (www.nissanchem.co.jp) have development products intended for use with smartphone and tablet PC touch panels. The products incorporate ‘HYPERTECH,’ a functional coating comprised of our proprietary multi-branched organic nanoparticles (hyperbranched polymers).
They are planning start production by March 2014, and they have already signed an commercial agreement with Guangdong Zhengyang, an OGS maker to produce 10 million graphene based transparent conducting films (TCFs) in a year for the next five years, for application in touchscreens. Vorbeck Materials (http://vorbeck.com) and BASF (www.basf.com) are developing dispersions of highly conductive graphene for producing electrically conductive coating and compounds especially for the electronics industry. Other companies active in this sphere include Graphene Frontiers (www.graphenefrontier.com), Graphenea (www.graphenea.com) and Graphene Devices (www.graphenedev.com). Graphene Frontiers is developing methods to produce large area graphene on an industrial scale. According to Graphene Frontiers, they have solved the problems of scale: CVD Graphene films can now be mass-produced and transferred to nearly any substrate. The company claim their patent pending method for low cost production and etch-free transfer of graphene films will disrupt multi-billion dollar markets including sensors, energy storage, and flexible electronics. The company’s GF-3012 product is transparent conductive film loaded on transparent glass slides for ITO replacement. Most graphene producers are aiming for the electronics industry as the key market.

UK-based graphene producer Haydale (www.haydale.com) is producing conductive inks in collaboration with Gwent Electronic Materials for application in flexible electronics. Bluestone Global Tech (http://bluestonegt.com) is producing Grat-FilmTM for application in touch panels and LEDs. Chinese company Powerbooster Technology is utilizing the film in graphene-based flexible touch panels for mobile devices. The company has stated that it plans to invest $150 million over three years to incorporate graphene into mobile devices. Graphene Laboratories, Inc., sells graphene conductive films via the Graphene Supermarket (www.graphene-supermarket.com). Sony is also at the forefront of production. In 2013 it announced fabrication of high-quality 100m long graphene transparent conductive film with a sheet resistance as low as 150 Ω/sq. However, large scale production of low sheet resistance and high optical transparency graphene films that are electrically stable over time has yet to be fully established. The scalability, reproducibility and cost effectiveness of integrating them into practical devices is currently under development. Also, graphene’s success in transparent conductors is also dependent on the development of competing alternative materials, such as thin metal films, metal nanowire films, conducting polymers and various other forms of hybrid films, as well as other 2D nanomaterials that are coming to prominence. Other companies developing nanocoatings and films for electronics and optics applications include Graphene Devices Ltd. (www.graphenedev.com), Graphene Nanomaterials (www.graphenea.com), Intel Corporation who are developing epitaxial graphene films for interference devices (www.intel.com), Silver nanowires/inks. Nanoscale siliver and copper are used as electrically conductive fillers for making electrical circuits on rigid substrates and flexible polymer foils. ClearJet (www.clear-jet.com) produces a silver nanoparticle-based ink, providing a highly conductive, transparent solution, enabling the industry to greatly expand flexible and large-screen applications, with a unique, low-cost solution. Cima NanoTech (www.cimananotech.com), a developer of the SANTE® Self-Assembling Nanoparticle Technology, and Fujimori Kogyo, a manufacturer of high quality opto-electronic films and materials are mass producing SANTE® Films. Cambrios Technologies Corporation has announced a partnership with sensor-maker Shin-Etsu Polymer Co., Ltd. to develop large area touch sensors made with Cambrios’ ClearOhm™
ClearOhm™ coating material for Ultrabooks and tablet computers. Carestream Advanced Materials develops FLEXX films, silver nanomaterial coatings that are applied by roll-to-roll coating. The combination of the coating method on plastic PET substrates produces a film more flexible and cost-effective than ITO alternatives. Carestream Advanced Materials' films can be used with touch panels, OLED lighting and displays, flexible displays, printed electronics and photovoltaics.

Amogreentech’s (www.amogreentech.com) conductive ink, is a nano metal dispersion ink specialized for printed electronics application such as RFIDs, solar cell, display and various patterning applications.

Ferro’s (www.ferro.com) Nano Silver 7000-95 offers cost-efficient performance and high-volume availability that can enable broader commercialization of advanced technologies such as radio frequency identification (RFID), flexible displays, and printed, flexible circuits.

NanoMas Technologies, Inc. (www.nanomastech.com) produces NanoSilver™ and NanoGold™ conductive inks. NanoMas also provide inorganic nanoparticle and polymer semiconductor inks, electroluminescent (EL or LED) inks for PE applications. NanoMas also have the technologies to mass produce high quality carbon nanotubes and carbon nanofibers.

Umicore (www.umicore.com) produces nanosilver as ink precursor or finished ink for printed electronics, RFID-labels and Flex-PCB’s.

**Carbon nanotubes**

Nanotubes are being applied as transparent conductive films and field electron emission electrode coatings. Nanoshield from Eikos is designed for EMI shielding applications. Eikos (www.eikos.com) employs proprietary water-based inks to make nanotube coatings. These inks take advantage of the colloidal nature of the carbon nanotubes to form dispersions with long shelf life and predictable handling.

SouthWest NanoTechnologies, Inc. (SWeNT) produces carbon nanotubes using a patented catalytic method called CoMoCAT® in fluidized bed reactors. The company’s SWeNT® CG 200 SWNTs are used in conductive coatings for electronics applications. TOP Nanosys (www.topnanosys.com) also produces SWNT transparent conductive films. C3Nano (http://c3nano.com) is another company developing transparent electrode material for applications including flexible displays, touch screens, solar cells and smart windows.
<table>
<thead>
<tr>
<th>Table 31: Nanocoatings in the electronics industry-suppliers, intermediate developers, target market revenues</th>
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<tbody>
<tr>
<td><strong>Intermediate developers</strong></td>
</tr>
<tr>
<td>• Aculon, Inc.</td>
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<tr>
<td>• ALD Nanosolutions</td>
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<tr>
<td>• Alnair Labs Corporation</td>
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<tr>
<td>• Aneeve Nanotechnologies LLC</td>
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<tr>
<td>• Applied Nanotech, Inc.</td>
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<tr>
<td>• C3Nano, Inc.</td>
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<td>• C-Voltaics</td>
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<td>• Cima NanoTech</td>
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<td>• ClearJet</td>
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<tr>
<td>• Delmic BV</td>
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<tr>
<td>• DryWired</td>
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<tr>
<td>• Dupont Microcircuit Materials</td>
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<tr>
<td>• Eikos, Inc.</td>
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<tr>
<td>• Fujimori Kogyo</td>
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<tr>
<td>• Fujitsu Laboratories</td>
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<td>• Graphene Devices Ltd.</td>
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<td>• Graphene Industries Ltd.</td>
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<td>• Graphenea Nanomaterials</td>
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<td>• Honjo Chemical Corporation</td>
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<td>• Hzo, Inc.</td>
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<td>• Liquipel</td>
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<td>• LP2i</td>
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<td>• Nissan Chemical</td>
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<td>• PolymerPlus, LLC</td>
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<tr>
<td>• TECO Nanotech Co., Ltd</td>
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<td>• TOP Nanosys</td>
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<tr>
<td>• Unidym, Inc.</td>
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<td>• XinNano Materials, Inc.</td>
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<tr>
<td><strong>Product developers</strong></td>
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<tr>
<td>• Samsung Electronics</td>
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<td>• IBM</td>
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<td>• Intel</td>
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<td>• Motorola</td>
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<tr>
<td>• Sony</td>
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<tr>
<td>• Texas Instruments, Inc.</td>
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<tr>
<td><strong>Target markets size</strong></td>
</tr>
<tr>
<td>• Transparent electrode market 2011: $4 billion. 2013: $26 billion. 2015: $58 billion (ORNL)</td>
</tr>
<tr>
<td>• Global conductive coatings market 2012: $9 billion. 2019: $19 billion (Nanomarkets)</td>
</tr>
<tr>
<td>• Global electronics coatings and films market, in 2010 is estimated to be $3 billion (University of Sheffield)</td>
</tr>
<tr>
<td>• Global data storage market 2010: $110 billion (Observatory Nano)</td>
</tr>
<tr>
<td>• The electronic displays market, in 2010 is estimated to be $100 billion. Touchscreens account for approximately 13% of this total. (Engineer Live)</td>
</tr>
<tr>
<td>• Global printable electronics market 2008: $2.8 billion. 2015: $24.25 billion (MarketsandMarkets)</td>
</tr>
<tr>
<td>Target markets size</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------------</td>
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<tr>
<td>• Printable electronics market 225: $300 billion. RFID Tags market 2011: $5.84 billion (IDTechEx)</td>
</tr>
<tr>
<td>• Plastic electronics market 2020: $120 billion (Department for Business Innovation and Skills UK)</td>
</tr>
<tr>
<td>• Global RFID tags market 2017: $18.7 billion (GIA)</td>
</tr>
<tr>
<td>2011, the global sales revenue of memory ICs was just over US$62 billion (Companies and Markets)</td>
</tr>
<tr>
<td>• IC sales 2013: $300 billion (IC Insights)</td>
</tr>
<tr>
<td>• Flexible electronics market 2015: $62.5 billion (USDC Flexible Displays Report)</td>
</tr>
<tr>
<td>• In 2017, $7 billion for transparent conductive coatings, ITO-dominated (Clearjet)</td>
</tr>
<tr>
<td>• Touch Display Research estimates the ITO replacement market to reach 4B$ by 2020.</td>
</tr>
<tr>
<td>• The global market for electromagnetic interference/radio frequency interference materials and technologies is expected to reach $4.5 billion in 2011 with an increase to nearly $5.2 billion in 2016. The conductive coatings market is predicted to increase from $1.7 billion in 2011 to nearly $1.9 billion in 2016 (Surmet).</td>
</tr>
</tbody>
</table>
## Nanocoatings market supply

### Table 32: Nanocoatings market supply chain

<table>
<thead>
<tr>
<th>Tier</th>
<th>Supply Chain and Companies</th>
</tr>
</thead>
</table>
• Sales directly to application developers  
• Sales directly to OEMs |
| 1    | Tools and equipment providers  
• Sales to manufacturers and application developers |
| 2    | Research Labs  
• Development of production methods  
• Collaboration with materials companies and product developers |
| 4    | Intermediate developers (e.g. PPG, Dupont, Diamon Fusion, Nanogate, Nanokote, GXC Coatings, Nippon Soda, n-tec GmbH)  
Application developers/Large Materials Companies  
• Purchase nanomaterials from producers and incorporate into products  
• Produce materials in-house or in collaboration with materials producers/research centres  
• Collaboration with OEMs to develop final product  
• Direct sales to markets |
• Develop products in house—materials purchased from graphene producers  
• Develop products in collaboration with intermediate developers  
• Direct sales to end user markets |
Advenira Enterprises Inc.

DESCRIPTION
Advenira Enterprises Inc., is a Sunnyvale, CA based company.

PRODUCTS
The company has developed a novel Solution Derived Nanocomposite (SDN™) technology that allows for low-cost/high-throughput multifunctional coatings deposition on practically any type/shape/material substrate. At present there are several standard approaches for depositing functional nanocomposite films: physical vapor deposition, PVD; chemical vapor deposition, CVD; and several methods for applying a limited number of liquids, in particular the sol-gel process. The latter has many advantages, but its use is limited because the solution precursors have short useful lives. SDN technology is a modification of the sol-gel method that has overcome problems maintaining the precursor solution in its initial state.

TARGET MARKETS
SDN technology has many applications. It can be used to apply coating during manufacture of low-emission architectural glass, for solar cells, displays, microelectronic equipment, and packaging and antibacterial materials.

ADDRESS
Advenira Enterprises, Inc.
788 Palomar Ave.
Sunnyvale, CA 94085
USA
Tel: +1 408-732-3950

WEB
www.advenira.com
Analytical Services & Materials, Inc.

DESCRIPTION
AS&M has a Specialty Coating Division that has developed innovative nano-composite and sol-gel coatings, AeroKret (formerly Aerocoat K) and Wearcoat, to mitigate erosion, corrosion, cavitation, weathering and wear.

PRODUCTS
AeroKret (formerly Aerocoat K) is Hybrid inorganic- organic elastomeric nanocoating system (primer + topcoat) designed for erosion, corrosion, and cavitation protection that cures at room temperature. It adheres well to most surfaces. It is supplied as ready to spray solution and ready to trowel paste.

TARGET MARKETS
• Aerospace
• Manufacturing
• Marine
• Mining and Mineral Processing
• Oil and Gas
• Power
• Waste Treatment

ADDRESS
Analytical Services & Materials, Inc.
107 Research Drive
Hampton, VA 23666-1340
USA
Phone: +1 (757) 865-7093

WEB
www.asm-usa.com
Beneq Oy

DESCRIPTION
Beneq Oy, based in Finland, is a supplier of industrial production and research equipment for thin film coatings used in solar photovoltaics, flexible electronics, strengthened glass and other emerging applications.

PRODUCTS
Beneq equipment and thin film experience is used for improving the efficiency of crystalline silicon and thin film solar cells, producing transparent conductive oxide (TCO) coated glass and making touch screen glass more durable. Beneq has introduced several innovations within its coating technologies, including true roll-to-roll atomic layer deposition (ALD) and high-yield atmospheric aerosol coating (nAERO®). Beneq provides in-house coatings based on nAERO® aerosol coating. The equipment requirements for aerosol coatings are defined case-by-case, depending on the applied coating material or materials (such as sol-gel based anti-reflective (AR) coatings).

TARGET MARKETS
• Displays
• Energy
• Flexible Electronics
• Glass Coatings
• Jewelry
• Lighting (LED and OLED)
• Medical
• Minting
• Optics
• Solar (PV and CSP).

ADDRESS
Beneq Oy
P.O. Box 262
FI-01511 Vantaa
Finland
Phone: +358 9 7599 530

WEB
www.beneq.com
Bioni CS GmbH

DESCRIPTION
Bioni’s core business is the development, production and marketing of multi-functional paints and coatings to enhance the walls, facades and roofs of buildings.

PRODUCTS
Working with research scientists at the Fraunhofer Institute for Chemical Technology, Bioni CS GmbH developed an anti-bacterial coating, Bioni Hygienic that contains silver nanoparticles that destroy mold and mildew, fungi spores, and bacteria on contact. The nanoparticles are stabilized with additives and integrated homogeneously into the polymer matrix. Anti-microbial activity does not decrease with time because the solid nanoparticles are not volatile, like many commonly used biocide additives.
Good anti-microbial, anti-viral, and anti-allergic performance has been demonstrated through independent testing. The waterborne, volatile organic compound (VOC)-free, and nearly odorless coating is resistant to disinfectants, acid, and solvents; permeable to water vapor; nonflammable; exhibits good washability; and comes in a wide range of colors.

TARGET MARKETS
The coating has application in medical facilities and sensitive building applications such as schools, bathrooms, food industry facilities, and retirement homes. Additional applications being explored include dental implants, synthetic bones, catheters, artificial heart valves, food packages, and toys.

ADDRESS
Bioni CS GmbH
Lessingstraße 21
D-46149 Oberhausen
Germany
T: +49 2086217553

WEB
www.bioni.de
Buhler Partec

DESCRIPTION
Buhler Nanotechnology develops and manufactures dispersions of nanoscaled metal oxides by combination of chemical and mechanical expertise. Buhler Nanotechnology is part of Buhler Group, a global leader in the field of process engineering. Buhler operates in over 140 countries and has a total payroll of about 7,800 worldwide. In fiscal 2010, the Group generated sales (turnover) of CHF 1.9 billion.

PRODUCTS
Buhler Nanotechnology converts agglomerated metal oxide nanopowders into stable nano dispersions using a chemomechanical process. The process combines chemical surface modification and mechanical stress. The technology enables dispersing nanoparticles into various liquids like water, organic solvents, monomers, and product formulations. Buhler formulates such dispersions further into ready-to-use additives to achieve highest performance, efficiency and compatibility.

Major Products
• Oxylink™ is a formulated additive for water based coatings. It results in improved resistance properties such as solvent rub, blocking, humidity, and efflorescence resistance. In addition it accelerates drying without reducing the open time.

TARGET MARKETS
Titanium and zinc nanoparticles are used for UV light protection products for lacquers and cosmetics. Zirconium nanoparticles are used in dental applications. Other materials PARTEC incorporates into products include organic pigments, carbon nanotubes, and the aforementioned inorganic oxides.

They have customers in the sectors of electronics, textiles, varnishes, cosmetics and the paint industry. Nanodispersions from Bühler are to be found, for example, in flat screens and in automotive parts. Food has been identified by the company as a potential area of application. The company has patents covering their Nanobatch process.

ADDRESS
Partec Business Unit
Bühler AG
CH – 9240 Uzwil
Switzerland
T: +41 71 955 28 73

WEB
www.buhlergroup.com
Cambrios Technologies Corp.

DESCRIPTION
Cambrios is developing electronic materials for the display industry.

PRODUCTS
The company’s proprietary nanostructured materials can be deposited using existing production equipment to achieve enhanced performance of display devices and components at lower manufacturing cost. The company’s first product is ClearOhm™ coating material that produces a transparent, conductive film by wet processing. ClearOhm™ films have improved properties by comparison to currently used materials such as indium tin oxide and other transparent conductive oxides.

TARGET MARKETS
Applications of ClearOhm™ coating material include transparent electrodes for touch screens, liquid crystal displays, e-paper, OLED devices, and thin film photovoltaics.

ADDRESS
Cambrios Technologies Corp.
930 East Arques Ave.
Sunnyvale, CA 94085
USA
T: +1 6504505100

WEB
www.cambrios.com
Clariant

DESCRIPTION
Clariant is a global leader in the field of specialty chemicals. Headquartered in Muttenz near Basel, Switzerland, it generated sales of around CHF 8.1 billion in 2006. Its operative business is organised into five divisions: Textile, Leather & Paper Chemicals, Pigments & Additives, Functional Chemicals, Life Science Chemicals, and Masterbatches. In Germany, Clariant is represented by several companies, including its largest company worldwide, Clariant Produkte (Deutschland) GmbH.

PRODUCTS
Clariant develops functional nano-coatings based on polysilazanes and organically modified polysilazanes. These enable particular effects to be achieved such as gas barriers on foils, protection against corrosion, anti-fog anti-fingerprint, anti-graffiti, photocatalysis, easy-to-clean or heat-dissipating.

TARGET MARKETS
Easy-Clean Coatings
Innovative coatings based on composite organic-inorganic nano-particles derived from sol-gel technology allow a broad spectrum of surface modifications. The company offers a versatile range of Easy to Clean (ETC) coatings for the protection of glass, ceramic and metal surfaces. All products are based on fluoropolymer modified nano-particles in solution and can be applied to the substrate by spray application or wiping.
Dispersing Agents
A comprehensive range of dispersing agents for nano-particles based on polymer and surfactant chemistries is available.
Organo-polysilazanes
In addition to its four divisions, Clariant operates so-called incubator business such as organopolysilazane technology. The polysilazane-containing coatings are extremely useful as easy to clean, anti-graffiti, anti-corrosion, heat resistance, high hardness and scratch resistance, and reduction of UV-degradation of underlying pigmented coatings.

ADDRESS
Clariant Produkte (Deutschland) GmbH
Industriepark Höchst
D 561 65926
Frankfurt
Germany
T: +49 61 96757 7893

WEB
www.clariant.com
CMR Coatings

DESCRIPTION
The company is privately owned business founded in November 2004.

PRODUCTS
The company produces scratch resistant and abrasion resistant coatings for vehicle and protective environments. They functionalise translucent water lacquers with nanoparticles incorporated into epoxies and plastic films (e.g. vehicle films, furniture films, various protective foils) as well as technical textiles. The average thickness of coatings of plastic films is 25-50µm and the wet lacquer systems are applied via rolling, blade coating, spraying and moulds.

TARGET MARKETS
Main industrial customers are in the plastics industries in general and the foil-industry. CMR has also developed varnish-systems to coat surfaces of metal, leather, artificial leather and wood. The company does not license IP and have their own sales and distribution network. They have their own sales and distribution network and they make special compositions according to customer requirements.

ADDRESS
CMR Coatings
Braasstr. 7
31737 Rinteln
Germany
T: +49 5751968337

WEB
www.cmr-coatings.de
Cotec GmbH

DESCRIPTION
For more than ten years Cotec GmbH in Nidderau has been developing and marketing systems, processes, materials, equipment and wear and tear parts for PVD & CVD thin film and sputter applications (PVD and CVD: physical or chemical vapor deposition).

PRODUCTS
The product portfolio comprises coating materials such as oxides, fluorides, metals, mixed or customized substances, elements for thermal and e-beam evaporators, APS (advanced plasma source) and ion-source parts, crucibles, boats, cathodes, calotte-segments and vibrating quartz crystals. They also offer tungsten filaments, aluminium coils, and sputtering targets of different metals, which possess, like all manufactured materials, a specified degree of purity. These materials enable the production of high-tech, optically active coatings with nanometer-scale precision.

TARGET MARKETS
Easy-to-clean coating affords protection against mechanical stress, watermarks, fingerprints, dust, grease and many other things besides. Added value and additional benefit are created by interface modification with 3D-nanotechnology (anchoring group, molecular chain and functional group).

The use of Cotec's ultra-hydrophobic and oleophobic coating material DURALONUltraTec in combination with HCS machines (hydrophobic coating systems) ensure a long lasting easy-to-clean coating. The effect will persist over the entire service life of the treated product. Cotec also supplies plasma treatment and nanocoating systems configured for various surface modifications, thus making it possible to secure highly adhesive, corrosion-proof or friction reducing coatings.

ADDRESS
Cotec GmbH
Siemensstrasse 11
D-61130 Nidderau
Germany
T: +49 6187907480

WEB
www.cotec-gmbh.com
CTC Nanotechnology

DESCRIPTION
CTC Nanotechnology GmbH is a supplier of systems for nano-bionic surface finishing, developing new types of solutions for steel/stainless steel and plastics, such as anti-fingerprint, scratch-resistant, hydrophobic and oleophobic coatings and paints, as well as vapor-permeable surface coatings.

PRODUCTS
CTC Nanotechnology GmbH currently produces more than 76 different nanobionic products for the treatment of diverse surfaces. The range is divided into three quality grades: consumer, commercial and industrial.

TARGET MARKETS
The products are used for refining industrial surfaces such as facades or glass, and in easy-to-clean and self-cleaning treatments for vehicle windscreens, paintwork, wheel rims or kitchen surfaces made of stainless steel, etc.

ADDRESS
CTC Nanotechnology GmbH
Dörrmühle 4
D-66663 Merzig
Germany
T: +49 5452 93595 21

WEB
www.ctc-nanotechnology.com
De Cie GmbH

DESCRIPTION
The company is a privately owned business producing easy-to-clean and anti-fog coatings.

PRODUCTS
Surfaces such as glass, leather, metal, stone and wood are coated. The nanomaterial for the Anti-Fog coating is nanoscale titanium dioxide and hybrid polymer. For easy-to-clean hydrophobic coatings, silane, ethoxycarbosiloxane, organic polymers, tantaloxid and SiO2 are used. Transparent hard coatings for plastic materials are also developed. Sol-gel process is used for producing the coating and the average thickness of the coating is 30-100nm, depending on application.

Company products include:
• Stone and wood protection: Nano-Stein-Protector
• Wood protection: Nano-Teakholz-Protector
• Glass and ceramics: Nano-Glas-Protector
• Textiles and leather: Nano-Textil-Leder-Protector

TARGET MARKETS
Products are sold at sufficient high margins to cover the development-and production expenses. They are priced preferentially by functional benefit and not to the measurement categories like volume, quantity or mass. The company possesses low mass marketing capabilities.

ADDRESS
De Cie GmbH
Homburger Landstr
148 A, D-60435
Frankfurt
Germany
T: +49 699543020

WEB
www.decie.de
Diamon-Fusion International

DESCRIPTION
Diamon-Fusion International, Inc. (DFI Nanotechnology), is a developer and exclusive licensor of patented hydrophobic nanotechnologies.

PRODUCTS
The company’s flagship product Diamon-Fusion® provides multi-functional characteristics that include: water and oil repellency (hydrophobic and oleophobic), impact and scratch resistance, protection against graffiti, dirt and stains, fingerprint protection, UV stability, additional electrical insulation, protection against calcium and sodium deposits and increased brilliance and lubricity for application in the automotive industry.

TARGET MARKETS
• Interiors
• Construction
• Automotive.

ADDRESS
DFI-DIAMON-FUSION INTERNATIONAL, INC.
9361 Irvine Boulevard
Irvine, California 92618
USA
Tel: +1 888 344 4334

WEB
www.dfisolutions.com
DFE Chemie GmbH

DESCRIPTION
DFE Chemie GmbH produces nanocoatings or metal surface treatment.

PRODUCTS
FEPORID® 388 is a nanotechnology based pickling inhibitor used as an additive to acid to protect steel surfaces against acid attack. This prevents the all too typical over-pickling and thus results in a higher surface quality of the steel.

TARGET MARKETS
• Steel

ADDRESS
DFE Chemie GmbH
Reisholzer Werftstraße 76
40589 Düsseldorf
Germany
Tel.: +49 (0) 211 497 696 31

WEB
www.dfe-chemie.com
Engineered nanoProducts Germany AG

DESCRIPTION
The company is a spin-out from the Institute of New Materials in Germany.

PRODUCTS
• Advanced metal coating technologies (Protection for metal surfaces, new styling possibilities and new functions)
• Hygienic technologies for clean and self sterilizing surfaces
• Nanocomposite parts for optics, plastic and coating technologies, including foil coatings, e. g. for light management
• Nanobinder technologies for high-performance high-temperature insulation and the improvement of oil and gas production.

TARGET MARKETS
The company's coatings are applied to the automotive and aircraft industry, in industrial plants, architecture, optics and multimedia, environment, and life sciences.

ADDRESS
Engineered nanoProducts Germany AG
Max-Planck-Str. 2
66482 Zweibrücken
Germany
T: +49 6332481920

WEB
www.e-p-g.de
Eurama Corporation

DESCRIPTION

PRODUCTS
The company produces oil repellant, Anti-Fingerprint and Easy-Clean nanocoatings.

TARGET MARKETS
• Displays

ADDRESS
Eurama Corporation
#318-1, Sinjeong-dong Yangcheon-gu
Seoul 158-070
Korea
T: +82 - 2 - 26495460

WEB
www.eurama.co.kr
Evonik Hanse

DESCRIPTION
Evonik is active in over 100 countries around the world. In fiscal 2010 more than 34,000 employees generated sales of around €13.3 billion and an operating profit (EBIDA) of about €2.4 billion.

PRODUCTS
The company produces nano-scale SiO2 particles for incorporating in 2-pack polyurethane coatings. TEGOTOP®

TARGET MARKETS
• Exteriors
• Interiors.

ADDRESS
Evonik Industries AG
Rellinghauser Straße 1-11
45128 Essen
Tel: +49 201 177-01

WEB
http://hanse.evonik.com/
FN Nano Inc

DESCRIPTION
The company is a photocatalytic coatings producer.

PRODUCTS
The company produces nano-scale FN® photocatalytic coatings to combat sick building syndrome.

TARGET MARKETS
• Exteriors

ADDRESS
FN Nano Inc
5303 Louie Lane #22
Reno, NV 89511
USA
Phone: +1 (775) 825 - 7080

WEB
http://fnnanoinc.com
Green Earth Nano Science, Inc.

DESCRIPTION
The company has an easy to apply, green, environment friendly, transparent coating for exterior applications. The photocatalyst coating is a water-based coating containing Titanium dioxide (TiO2). MCH Nanosolutions is the exclusive distributor of Green Earth Nano-TiO2.

PRODUCTS
The nanoparticles of titanium are synthesized, crystallized and dispersed directly in the water based solvent by means of proprietary advanced chemical hydrosynthesis technology, making the solution very stable and superior to similar products. Coating does not contain any VOC’s (volatile organic compounds) making the product green, environment friendly and totally non-toxic to the environment.

Product Benefits
• Keeps the building exterior clean for many years
• Protects the surface from dust, acid rain and air pollutant damage
• Purifies the air pollutant near and on the surface (e.g. car exhausts NOx, formaldehyde, benzene, VOCs)
• Decomposes the organic pollutant on the surface
• Reduces the energy consumption for cooling the building in summer
• Restrains from mildew or algae growth
• Fights the bacteria and virus on the surface and in the air near the coated building
• Absorbs the UV from sun and then protects the surface from UV damage
• Restrains the dust electrostatic absorption

TARGET MARKETS
Photocatalyst coatings have proven to combat Bird Flu and SARS infections in high risk areas. Hundreds of hospitals and thousands of buildings in Asia and recently in Europe were coated to protect property against deadly infections and environmental pollution damage. Gens-Nano-TiO2 coating transforms a treated surface into an antibacterial, anti-fungal, mold free surface, while purifying the air. Self-cleaning and other functions will work in the presence of light to protect a building’s interior and exterior from environmental contamination. The company is open to joint development programs and possible licensing. They hold a number of patents.

ADDRESS
Green Earth Nanoscience, Inc.
181 University Ave, Suite 2200,
Toronto, Ontario,
M5H-3M7
Canada
T: + 416 8000969

WEB
www.gensnano.com
Description
Company was founded in 2003 and is based both in Japan and USA. Green Millennium Inc. is the international sales and marketing office of SAGA-KON Corporation, one of the most prominent research institutions of photocatalyst technology in Japan.

Products
The company produces photo catalytic coating for a range of applications. Titanium dioxide is deposited on surfaces such as tile, glass, metal, paint, concrete and plastic. Film thickness of about 1 microns has been deposited. The technology has been applied to food processing.

Target Markets
Applications include self-sanitizing surface, self-cleaning coating, reduction of air pollution, waste water treatment.

Address
Green Millennium, Inc.
425 W. Allen Ave.
#111 San Dimas
CA 91773
USA
T: + 1 9093058882

Web
www.greenmillennium.com
GVD Corporation

DESCRIPTION
The company is a spin-out from MIT.

PRODUCTS
GVD's flagship product is Exilis™ PTFE, an ultra-thin, pure PTFE (polytetrafluoroethylene) fluoropolymer coating. Exilis™ PTFE is chemically indistinguishable from bulk, conventional PTFE (Teflon® PTFE).

TARGET MARKETS
- Low-friction surfaces for seals and gaskets
- Lubricious surfaces for medical devices
- Biocompatible passivation for implantable medical devices
- Environmental insulation and protection for circuitry
- Elimination of stiction in MEMS and microfluidic devices
- Rapid, reliable release of molded parts from their molds
- Surface modification for separation filters.

ADDRESS
GVD Corporation
45 Spinelli Place
Cambridge, MA 02138
USA
T:+1  (617) 661-0060

WEB
http://gvdcorp.com
GXC Coatings

DESCRIPTION
GXC Coatings applies functional coatings based on nanotechnology to glass and polymer substrates. Applications of such coatings are in automotive, optics, microtechnology, sensors, safety, instrument covers, windows and glazing.

PRODUCTS
The company applies functional coatings based on nanotechnology to glass and polymer substrates. Applications of such coatings are in automotive, optics, microtechnology, sensors, safety, instrument covers, windows and glazing. The company’s easy-to-clean or self-cleaning coatings protect value add parts made of glass, plastic or metal from dirt or facilitate the cleaning thereof.

- Easy removal of dirt
- Increased value of your product
- Reduction of cleaning costs and work load
- Value-added comfort
- Premium positioning
- Self-cleaning of outside surfaces (modified product)

Areas of use
- Glazing in the industry and at home
- Control windows in machinery, maritime and plant construction
- Glass elements that are intensively used in kitchens and bathrooms
- Headlights and lighting covers used outside
- Windscreens

TARGET MARKETS
- Glazing in the industry and at home
- Control windows in machinery, maritime and plant construction
- Glass elements that are intensively used in kitchens and bathrooms
- Headlights and lighting covers used outside
- Windscreens

ADDRESS
GXC Coatings
Im Schleeke 27-31
38642 Goslar
Germany
T: +49 5321343086

WEB
www.gxc-coatings.de
Hemoteq AG

DESCRIPTION
Hemoteq is the designer and manufacturer of ultra-thin coatings for medical devices.

PRODUCTS
The company specializes in nanocoating technology for medical devices. Hemoteq’s range of adaptable, biocompatible polymer coatings can be adjusted to release a drug of choice according to a preset elution profile. Several biodegradable and biostable coating platforms (Ouverture, Repulsion, ProTeqtor) and a polymer free coating (PacliTeq) have been developed to fit a range of applications, e.g. drug-eluting stents for patients with coronary artery disease.

Drugs locally released from the surface of an implanted metal stent prevent reocclusion of dilated and scaffolded arteries, a problem frequently seen with uncoated stents. Hemoteq’s composed coating solutions employing a biomimetic nanocoating (Camouflage), a nanothin synthetic basecoat resembling the outermost layer of living cells permanently masks the drug eluting device from the body’s defense mechanisms and bears the potential to further boost clinical benefit.

TARGET MARKETS
Applications are as biomimetic and drug releasing coatings.

ADDRESS
Hemoteq GmbH
Adenauerstraße 15
Würselen 52146
Germany
T: +1 492405455000

WEB
www.hemoteq.de
Inno-X

DESCRIPTION
The Inno-X produces coatings and additives to functionalize surfaces and materials for industrial applications.

PRODUCTS
The company produces water based nanocoatings for wood and mineral surfaces to reduce the use of cleaning agents and extend the lifetime of the product. The coatings are ultra-thin, invisible and have a water vapor passable structure.

TARGET MARKETS
- Exterior protection
- Textiles
- Paint
- Plastic/Polymers
- Agriculture
- Corrosion Protection for Aluminum, Magnesium, Zinc
- Corrosion Protection for Metals
- Heavy Corrosion Protection for Steel

ADDRESS
Inno-X
Tutilostrasse 36b
St.Gallen
Switzerland, 9011

WEB
www.inno-x.ch
Integrated Surface Technologies, Inc.

DESCRIPTION
Integrated Surface Technologies™ produces Repellix™, a ceramic nanocomposite coating for Printed Circuit Boards (PCBs).

PRODUCTS
Repellix nanoscale ceramic coatings are used to watersafe electronic devices.

TARGET MARKETS
• Electronics
• Military

ADDRESS
Integrated Surface Technologies, Inc.
1455 Adams Street, Suite 1125
Menlo Park, California 94025
USA
T: +1 6503241824

WEB
www.insurftech.com
InterLotus Nanotechnologie GmbH

DESCRIPTION
Founded in 2005 InterLotus develops, formulates and produces special coating systems based on inorganic binders (sol-gel).

PRODUCTS
Different topcoats and primers have been developed. The primers are in use under PVD coatings (Physical Vapor Deposition), conventional topcoats, as well as under coatings with high inorganic content. The systems are distinguished through a very good chemical bonding (covalent) to the substrate. The primer can also be formulated with a specially designed link to the topcoat.

Properties include:
• high corrosion protection
• high transparence
• water repellant
• easy-to-clean
• anti-finger-print
• abrasion-resistant
• high temperature resistance
• no delamination
• photo catalytic
• etc

TARGET MARKETS
Products are used in industrial coil coating processes on zinc and aluminium in various forms. Other applications are on mineral surfaces, as well as a homecare products.

ADDRESS
InterLotus Nanotechnologue GmbH
Bockumer Straße 7, 45711 Datteln,
Germany
T: +49 2363 365005

WEB
www.interlotus.de
ISTN, Inc.

DESCRIPTION
ISTN, Inc. was founded in 1997 by Dr. Arthur Yang. Researchers at ISTN Inc. are experts in optical functional coatings and customized water treatment technologies. The company specializes in the development of organic-inorganic nanocomposites using surface-modified nanopore silica.

PRODUCTS
ISTN's Anti-Stain Hard Coat is a permanent oleophobic and hydrophobic coating designed to reduce the buildup of contaminants on treated plastic surfaces. This primerless hard coat is non-fluorinated and is quickly cured by Ultra Violet light. With its superior oil and water repellent properties, stains such as permanent markers, fingerprints, lime scale, and salt residue can be cleaned off with ease and without the need of harsh cleaning chemicals.

TARGET MARKETS
- Architectural / Building Displays
- Advertisement Signage
- Cabinets and Display Cases
- Televisions
- Portable Electronics Displays,
- Automotive Applications
- Marine Applications.

ADDRESS
Industrial Science and Technology Network (ISTN, Inc.)
2101 Pennsylvania Avenue
New York
PA 17404
USA
Phone: +1 7178430300

WEB
www.istninc.com
ItN Nanovation AG

DESCRIPTION
ItN Nanovation was formed in 2000 and currently has over 60 employees. Main focus is the production of nano scaled powders and their further processing to ceramic special products. Know-how exists in the processing of the nanoparticles to new, innovative products in the areas filter systems, surface refining, sensors, energy supply and medicine engineering. In its ceramic coatings business segment, ItN Nanovation manufactures ceramic protective and catalytic coatings containing nanoparticles: its Nanocomp and Nanocat product lines. These newly developed ceramic surfaces are simply applied to metals, ceramic or mineral surfaces using common spraying or dipping procedures. Special training is not required for application.

PRODUCTS
The bactericidal Nanozid® Layer uses a concept which permanently destroys germs without contaminating the environment and without the development of resistant pathogens. Only light is needed, which electronically stimulates the nanoparticles in the coating and destroys spores and bacteria through reactions on the surface.
The coating can be fixed with the traditional coating methods (e.g. dipping, spraying) on floor or wall tiles, door handles etc. and is especially suitable for door handles in public buildings, in air conditioning equipment and in hospitals for extensive sterilization, e.g. of operating rooms.

TARGET MARKETS
The nano-powder with the brand name Nanozid is added to paints and lacquers used to coat operating tables, door knobs and door handles in hospitals (e.g. “clean rooms”) and surfaces in sanitary facilities. In addition to their obvious utility in the clinical sector, biocidal coatings have numerous applications in the food and beverage industries and in HVAC systems, which frequently serve as vehicles for the spread of infectious diseases. The company license intellectual property to development partners and customers for their products. They possess over 230 patents. Russian company Rusal Irkaz, an aluminium smelter based in Irkutsk, has successfully finished testing Nanocomp Metcast, nanocoatings developed by Rusnano’s project company ItN Nanovation AG of Germany. The coatings will be applied to casting machinery to extend the service life of molds and lengthen the intervals for maintenance of casting conveyors. Rusnano acquired a 29.9% stake in ItN Nanovation AG in May 2011.

ADDRESS
ItN Nanovation AG
Untertürkheimer Straße 25
66117 Saarbrücken
Germany
T: +49 6815001460

WEB
www.itn-nanovation.com
Kriya Materials B.V.

DESCRIPTION
Kriya Materials focuses on high-end coating materials and dispersions comprising its proprietary metal oxide dispersions.

PRODUCTS
Kriya Materials partners with NanoSpecials, an established nanoparticle producer to provide customers high-end coating solutions.

TARGET MARKETS
The product range includes coatings with antistatic functionality, solar coatings, optical coatings and transparent scratch-proof coatings for the film industry.

ADDRESS
Kriya Materials B.V.
Postbox 18
Geleen
6160MD
Netherlands
T: +31 (464) 764226

WEB
www.kriya-materials.com
Life Air Iaq Ltd.

DESCRIPTION
The company is Indoor Air Quality, specializing in air purification technology by using “Photo-Catalytic Oxidation” (PCO).

PRODUCTS
PCO technology uses Titanium Dioxide and UV light to decompose and oxidize pollutants such as bacteria, viruses, volatile organic compounds, formaldehyde, nitrous oxides (NOx), and sulfur oxides (SOx).

TARGET MARKETS
The company’s products have already been used in offices, hospitals, cigar rooms, and hotels. The nanocoating technique as well as the physical application of PCO technology is patented and recognized by the Hong Kong Innovative Council. The performance test was done by The Hong Kong Polytechnic University.

ADDRESS
Life Air Iaq Ltd.
Unit 7, 1/F, Fu Hang Industrial Building,
1 Hok Yuen Street East, Hunghom,
Kowloon
Hong Kong
T: +1 8525270106

WEB
www.lifeairiaq.com
Lotus Leaf Coatings

DESCRIPTION
Lotus Leaf Coatings manufactures and distributes proprietary superhydrophilic and superhydrophobic coatings. The company’s technology, a superhydrophobic formulation, was developed with Sandia National Laboratories and the University of New Mexico.

PRODUCTS
HydroPhil™ is a patent pending micro/nano scale material with superior hydrophilic, water loving properties that can be applied to most surfaces and materials.

TARGET MARKETS
• Optics
• Micro-electronics
• Solar Panels
• Textiles
• Sanitation
• HVAC
• Fluid Dynamics
• Consumer Products
• Anti-Fogging

ADDRESS
609 Broadway Blvd. Suite 208
Albuquerque, New Mexico 87102
UNITED STATES
T: + 505.346.1492

WEB
www.lotusleafcoatings.com
Millidyne Oy

DESCRIPTION
Millidyne specializes in advanced materials and surface treatment technologies featuring benefits such as enhanced hygiene and cleanability, corrosion and wear resistance, and novel electrical properties.

PRODUCTS
Millidyne’s Avalon family includes easy-to-clean, anti-microbial coatings for metal, glass, ceramic, and plastic surfaces.

TARGET MARKETS
They have readily available, mature and well tested technology /solution among other things for: Inorganic soils on high or low energy surfaces (e.g. lime scale on bathroom fittings. Suitable for all stainless steel, glass, and ceramic surfaces, Avalon 22 is ideal for clean rooms, bathrooms and toilets, lifts, kitchens, equipment, as well as surfaces that are repeatedly touched by people, such as keyboards, door handles, and light switches. The company holds a patent for the Avalon coatings which are available for licensing.

ADDRESS
Millidyne Oy
Hermiankatu 6-8 G
FI-33720 Tampere
Finland
T: +35833177450 www.millidyne.fi

WEB
www.millidyne.fi
Nadico Technologie GmbH

DESCRIPTION
NADICO Technologie GmbH was founded in 2002. NADICO Technologie GmbH is a specialist in research and development of photocatalytic surfaces treatments.

PRODUCTS
The company produces TitanShield® and TitanProtect® photocatalytic nanocoatings.

TARGET MARKETS
• Interiors
• Exteriors

ADDRESS
NADICO Technologie GmbH
Haus-Gravener Str. 155
40764 Langenfeld
Germany

WEB
www.nadico.de
Nanocare AG

DESCRIPTION
The company are private owned, producing easy to clean and anti-fingerprint coatings. Their main product line is used for protecting stoneware.

PRODUCTS
The company produces easy to clean and anti-fingerprint coatings. The products are sold under trademark. Sol-Gel based processing methods are used for preparing the thin film coatings. Precursor materials of silicon, titanium, aluminium or zircon are so condensed that the smallest particles emerge. These are either processed as nano-powder or stabilised as a colloidal solution. Hybrid materials, modifiers and stabilisers enable variations and allow adaptation to different surfaces and functionalities.

TARGET MARKETS
The products are sold under five different trade names – Nanoflex, Easy Glass, Nanoflex APF 100, Nanoflex SG 80, Top CERAM. The substrates coated range from glass, ceramic, plastic, textile, concrete, stainless steel, porcelain. Coating thickness ranges from 100 – 500 nm. Lifetime of coatings depends on abrasion; some coatings can last up to 8 years. The company does not have their own sales and distribution network, and mainly use wholesalers.

ADDRESS
NanoCare AG
Werkstrasse 3
D-66763 Dillingen
Germany
T: +49 6838974914 0

WEB
www.nanocare-ag.com
NanoCover

DESCRIPTION
NanoCover A/S is a Danish Company, established in 2004. NanoCover A/S specialises in the production, distribution, sales and development of NanoCover, a series of surface treatment products. They are a public company with over 1800 shareholders.

PRODUCTS
NanoCover products are based on chemical nanotechnology and the majority of the products are sol-gel based. The company’s product line includes lacquer seal, aluminum rim preparation and seal, textile and leather, plastic seal, multicovers, anti-mist glass, anti-mist plastic, car glass, clearview, a/c cleaner, marine seal, marine glass, floor seal, wall seal, bath tiles, and glass self-cleaning for various uses in automobile, marine, home, and fire protection.

TARGET MARKETS
The company’s products are mainly used in household care, marine and automotive applications. R&D is based in Germany with production in Denmark and Germany. The company has a patent for their sol gel based coatings. NanoCover A/S is currently represented in Denmark, Norway, Sweden and England. Their products are also distributed in Asia and they would be open to a partnership or licence agreement for the USA.

ADDRESS
NanoCover A/S
Fredensborg Kongevej 58
DK-2980 Kokkedal
Denmark
T: + 4548484300

WEB
www.nanocover.com
Nano Hygiene Coatings Ltd.

DESCRIPTION
Privately owned company, based in the UK.

PRODUCTS
The company develops easy-clean and antimicrobial coatings. The sol gel process is used for producing formulation. It can be applied using spraying, dipping, painting, rolling, flow casting. Thickness of coating is 5 micron without pigment and 15 microns with pigment. Life expectancy is generally higher in non-corrosive environments.

Easy clean coatings
The coatings are generically “easy-clean”, deposited from solution, oven-cured and chemically bond with the substrate to form a durable ceramic surface coating. An air-cured coating is also available. The coatings (approx. 5-12µm) are, dense, completely non-porous, tough and glass-like with active self-cleaning properties. The coatings are hydrophobic and oleophobic as well as being highly resistant to scratches, acids, organic solvents and other chemicals. These coatings can be applied to a variety of metal substrates including aluminium, stainless steel, brass, magnesium and ceramics as a permanent non-stick, easy-clean protective layer. Coating can be undertaken during manufacturing or in-situ for aftermarket applications.

Anti-microbial coatings
The company has developed a new coating called 4MED, with hydrophobic and oleophobic properties. These properties make the surface non-stick and stain-resistant. The combination of a hydrophobic/oleophobic surface and active antimicrobial functionality has synergistic benefits, which contribute to improved hygiene and infection control strategies.

TARGET MARKETS
The company’s coatings are being developed for a wide variety of industries, including medical, healthcare, food and drink, dairy, HVAC, rail etc. Development is mainly done in the UK and liquid formulations of up to 1 tonne are sold.
The main target market is medical hygiene, for medical devices and surface hygiene. A secondary hygiene market being looked at is for surfaces in hotels and catering. The USA market is under development. They have conducted milk testing on coated and uncoated surfaces.

ADDRESS
Nano Hygiene Coatings Ltd.
5 Mildmay Close
Stratford upon Avon
Warwickshire
CV37 9FR
UK
T: +44 8707 657 961

WEB
www.nanohygienecoatings.co.uk
Nanokote

DESCRIPTION
Nanokote, a division of Australian company Micronisers Pty Ltd works in the research and development of commercial applications for nanotechnology.

PRODUCTS
NK-TC 01 is a coating material that exhibits very high abrasion resistance, high chemical resistance and easy to clean surface properties. The coating material is applied to concrete and cement based substrates to give an opaque satin-gloss or matt finish.

TARGET MARKETS
• Glass coating for shower screens and glass pool fencing.
• Anti carbonation concrete coating and anti graffiti coating.
• Stainless steel anti corrosion coating.

ADDRESS
NANOKOTE PTY LTD
Registered Office Micronisers
Address:
6-8 England Street
Dandenong
Victoria
Australia
3175
Telephone: +61 3 9768 3277

WEB
www.nanokote.com.au
**Nanophos SA**

**DESCRIPTION**
NanoPhos SA is a nanotechnology company which focuses on the development of innovative products that protect and waterproof common surfaces.

**PRODUCTS**
The company co-develop with Keraben LIFEKER®, a line of self-cleaning and self-sterilizing ceramic tiles. These properties of LIFEKER® tiles are provided by the use of the SurfaShield® coating technology developed by NanoPhos, which is activated simply by the energy of surrounding light (either sunlight or artificial lighting) without the use of dangerous chemicals.

**TARGET MARKETS**
- Construction and exterior protection

**ADDRESS**
PO Box 519
Science & Technology Park of Lavrio
Lavrio 19500
Attica, Greece
T: +30 22920 69312

**WEB**
www.nanophos.com
Nanopool GmbH

DESCRIPTION
The company manufactures ultra-thin nano layers, consisting of SiO2 molecules.

PRODUCTS
Nanopool GmbH develops SiO2 nanolayering technology (SiO2 = pure glass). Their product-literally “liquid glass” can be applied to virtually any type of surface to give the surface new properties. These properties include:
- Easier to clean
- Chemical-free cleaning – just use water
- Biostatic or anti bacterial-dependent on variant used
- Abrasion resistance
- Stain Resistant
- Corrosion resistant
- Moisture resistant
- Protection from spills of acids, fats and oils
- Heat tolerant -40 to 450°C
- UV Stable
- Free of nano particles
- Invisible and undetectable.

TARGET MARKETS
Nanopool GmbH's liquid glass can be applied to virtually any type of surface to give the surface new properties including easier to clean, chemical-free cleaning – just use water, biostatic or anti-bacterial dependent on variant used, abrasion stain corrosion and moisture resistant, protected from spills of acids, fats and oils, heat tolerant -40 to 450°C, UV Stable, free of nano particles while remaining invisible and undetectable.

ADDRESS
Nanopool GmbH
Zum Felsacker 76
D - 66773 Hülzweiler-Schwalbach
Germany
T: +49 68318902712

WEB
www.nanopool.biz
Nanopool GmbH

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ADDRESS
Nanopool GmbH
Zum Felsacker 76
D - 66773 Hülzweiler-Schwalbach
Germany
T: +49 68318902712

WEB
www.nanopool.biz
Nanops

DESCRIPTION
Nanops is a fully integrated European nanotechnology Company based in Belgium, and offers full service by combining in-house R&D, in-house production facilities, logistics and distribution to the benefit of the construction industry.

PRODUCTS
Nanops wide range of solutions goes from the delivery of nano raw materials to the production of finished products with, more in particular, coatings for steel and concrete structures. Different photocatalytic coatings, easy-to-clean coatings and coatings with a high chemical resistance are some of Nanops’ specialties.

TARGET MARKETS
• Anti-Graffiti
• Chemical
• Cleaning
• Corrosion
• Mechanical
• Thermal

ADDRESS
KOB NV
President Kennedypark 31 c
B-8500 KORTRIJK
BELGIUM

WEB
www.nanops.eu
Nanosol AG

DESCRIPTION
Nanosol AG is a coating company specialized on the coating of medical devices. They were founded in September 1995 as a spin-off company from the Institute for New Materials (INM). Since January 2001 they have been based in Balzers the Principality of Liechtenstein.

PRODUCTS
The main field for the company is non-stick coatings, scratch resistant coatings and customer tailored developments of materials in the field of sol-gel chemistry. Organically modified silica is coated on glass, steel and aluminium. Sol gel based coatings solution produce a 1-4 micron thickness layer which is being manufactured for large-scale application. The easy to clean surfaces is made by wet-chemical coating with subsequent heat-treatment. Organically modified metal oxide films form the base, reinforced by nano composite structures. The hydro- and oleophobic effect is obtained by perfluorinated organic molecule chains in the nano composite sol-gel coatings.

Application specific materials are synthesized by the proper choice of suitable starting compounds and process parameters. The resulting coatings consist of a three-dimensional cross-linked inorganic part (such as a silica network) combined with an organic part. The organic material acts either as a surface modifier (example: alkyl, phenyl) or as cross linker (example: acrylic, epoxy). The properties of such coating systems can be adjusted to obtain a wide range of glass-ceramic or polymer-like properties. The incorporation of nanoparticles into these materials significantly enhances the abrasion and the scratch resistance.

TARGET MARKETS
- Paint and Varnish Industry
- Pharmaceutical chemistry
- Medical devices and diagnostics market
- Inside and outside coatings of tubes and canulas
- Biocompatible coatings
- Easy-to-clean coatings
- Scratch resistant coatings.

The company holds a patent for their nano composite sol-gel coatings. The coatings are compliant with existing European legislation and no hurdles are envisaged for the USA. The company do not license out the technology.

ADDRESS
Nanosol AG
Landstrasse 16
FL-9496 Balzers
Liechtenstein
T: +423 388 11 50

WEB
www.nanosol.com
Nanosys GmbH

DESCRIPTION
The company was founded in 2001 and produces super-hydrophobic, super-adhesive, super-hydrophilic and super-hemostatic nanocoatings.

PRODUCTS
NanoPerli is the company’s main product, a nanoscale chemical coating for various substrates and functions, for corrosion resistance, water repellency of raw, varnished, waxed, oiled and painted wood or wood materials, the hydrophobic treatment of sandstone, bricks, concrete and glass, which improve the adhesion of coatings on all types of plastics. The coating is also anti-adhesive.

TARGET MARKETS
- Wood
- Glass/Ceramics
- Mineral surfaces
- Textiles/Leather
- Anti Graffiti
- Flooring
- Plastics/Coatings
- Metal

ADDRESS
NanoSys GmbH
Dorf 31-32
p.o. box 135
CH-9427 Wolfhalden
Switzerland
T: +41 718900975

WEB
www.nanosys.ch
Nano-Tex, Inc.

DESCRIPTION
Nano-Tex is headquartered in Emeryville, Calif, with operations in Belgium; China; England; India; Italy; South Korea; and Turkey. Nano-Tex develops and markets a family of nanotechnology-based textile treatments.

PRODUCTS
The company develops SiO2 coatings for textiles. Nano-Tex offers a family of textile enhancements that become inherent to the fabric to deliver superior performance characteristics without compromising the comfort, look or feel of the fabric. The company’s products include Resists Spills (liquid-repellent), Coolest Comfort (moisture wicking for synthetics and wrinkle-free cotton), Resists Static (first permanent anti-static treatment for synthetics) and Repels and Releases Stains (market’s best-performing anti-stain treatment).

TARGET MARKETS
Nano-Tex treatments in products are sold by more than 100 leading apparel and interior furnishings brands, including New Balance, Gap, Old Navy, Target, Hugo Boss, Paul Stuart, Rene Lezard, Lee, Nike, Champion, Levi and Simmons.

ADDRESS
Nano-Tex
2220 Livingston Street, #201
Oakland
California 94606
USA
T: +1 5104342700

WEB
www.nano-tex.com
Nanovere Technologies specializes in the development and formulation of Self-Cleaning & Car Key Resistant coatings based on nanotechnology.

The company specializes in the development of clear coatings based on nanotechnology materials and concepts. The coatings are available in a 2K package with convenient 1:1 mixing by volume. The product is available in a high gloss clear, high gloss black, high gloss white, matt finish clear. The company claim their Zyvere Nanocoatings outperform all automotive OEM coatings, automotive aftermarket coatings and aerospace coating competitors:
- 53% higher scratch resistance: 6H pencil
- 60% improved clean ability
- 476% higher chemical resistance
- 100% gloss retention over 5+ years.

The company’s nanocoatings were specifically designed to extend the life of important Automotive Aftermarket Paint, Automotive OEM Paint, Industrial Paint, Military and Marine Paint surfaces by producing an ultra-scratch resistant and self-cleaning paint surface.

Nanovere Technologies, LLC.
4023 S. Old US 23, Suite 101
Brighton, MI 48114
USA
Phone: +1 (810) 227-0077

www.nanocoatings.com
Nano-X GmbH

DESCRIPTION
Privately owned coatings company founded in 1999.

PRODUCTS
X-Clean Brand
- Easy-to-clean surfaces with nano-effect in the areas of protection against soiling for glass, ceramics and metal, protection against graffiti and demoulding aids, to name but a few
- Self-cleaning surfaces through the bionic effect or photocatalytic effect for interior and exterior applications
- Scratchproof and abrasion-proof coatings for plastics, metals etc.
- Multi-functional coatings to protect metals from corrosion
- Anti-fingerprint coatings for surfaces of stainless steel
- Catalytically active surfaces as coatings to decompose odors, soot or dirt
- Protective coatings to prevent dewing and fogging.

TARGET MARKETS
Industrial applications are mainly in automotive for oxide scale protection and easy to clean coating for automotive glass, as well as the steel industry.

ADDRESS
NANO-X GmbH
Theodor-Heuss-Straße 11a
D-66130 Saarbrücken-Güdingen
Germany
T: +49 681959400

WEB
www.nano-x.de
Nanoyo Group Pte Ltd

DESCRIPTION
The company is a manufacturer of a TiO2 Titanium Oxide water based coating under the brand nanoYo.

PRODUCTS
The company produces photocatalytic nanoTiO2 coatings. They have developed ‘nanoShield TiO2 Coating Liquid’ that utilizes the photocatalytic effect of nano-titania to incorporate anti-bacterial, anti-microbial, UV protection, odour removal, self-cleaning and anti-static properties to any type of substrate or fabric. This product line could be easily used in any type of surface ranging from glass, ceramics and plastics to textiles and fabrics.

TARGET MARKETS
• Anti-bacterial
• Textiles

ADDRESS
Nanoyo Group Pte Ltd
Block 1003 Bukit Merah Central
#06-19 Technopreneur Center
Singapore 159836

WEB
www.nanoyo.co
NTC Nanotech Coatings GmbH

DESCRIPTION
The company is privately owned business producing sol gel coatings for electronics, automotive and façade engineering. The company was founded in 2000 as a spin-out from the Leibniz-Institut fuer Neue Materialien (INM).

PRODUCTS
The company produces scratch resistant, corrosion resistant and easy to clean coatings. NTC mainly focuses on coatings for light metals (Aluminium and Magnesium) and various kinds of steel, such as technical parts for cars and aircrafts as well as engine parts and production areas for food technology. The dry layers are very thin with values of 3 -10mm following hardening. The materials are resistant to a large number of chemicals.

TARGET MARKETS
Heat exchangers, and air conditioning systems.

ADDRESS
NTC Nanotech Coatings GmbH
Dirmingerstr. 17
66636 Tholey
Germany
T: +49 6853400224

WEB
www.ntcgmbh.com
n-Tec GmbH

DESCRIPTION
The company is privately owned and involved in the development, production and sale of surface coatings in the nanoscale range.

PRODUCTS
The company produce easy-to-clean, photocatalytic, anti-fingerprint, anti-scratch coating properties for metals, glasses and polymers with automotive application as head lights, windows, felloe, varnishes as well as the vehicle industry in general. Main products are:
• x-photocat PSC: Photocatalytical self-cleaning and superhydrophilic coating for metals, glasses and polymers
• x-photocat PSCF: Photocatalytical self-cleaning and superhydrophilic coating with “Easy to Clean” properties for metals, glasses and polymers

TARGET MARKETS
• Sanitary equipment: Armatures made of steel, soap and paper dispenser, binds, doors
• Kitchen and household appliances: kitchen sink, exhaust ventilation, hearth blind, refrigerator, mixer, coffee machine)
• Buildings: Doors, gates, door-handle, elevators, letter-box, entry-phone
• Metal cupboards and furniture
• Articles for daily use made of stainless steel, cooper, brass or bronze

ADDRESS
n-tec GmbH
Siemensstraße 13
D - 84051 Altheim
Germany
T: +49 8703989764

WEB
www.n-tec.de
Optitune

DESCRIPTION
The OptiTune line of dual-reflectance films combines high solar energy rejection with low internal reflectance.

PRODUCTS
Optitune’s nanocoating technology; providing the combined benefits of anti reflection, anti finger smudge, power optimization and long term durability for glass silicon and plastic substrates.

TARGET MARKETS
• Anti Reflective Coatings for Solar Devices
• Anti Reflective & Heat Mgt Building Glass
• Touch Panel Coatings
• Easy Clean and Anti Reflective
• Thin Film Silicon Coatings.

ADDRESS
Optitune International Pte, 20 Maxwell Road,
#05-08 Maxwell House
Singapore 069113
Tel: +65 6319 0003

WEB
www.optitune.com
Panahome

DESCRIPTION
Panahome Corporation is a Japan-based company primarily engaged in the housing business. The Company is involved in the basic design of housing under the name Panahome, as well as the manufacture, construction and sale of housing system materials.

PRODUCTS
The company produces KIRATECH tile for exterior walls that employ advanced photocatalytic technology.

TARGET MARKETS
• Construction

ADDRESS
1-1-4, Shinsenrinishi-machi
TOYONAKA-SHI, OSK 560-8543
Japan
Tel: +81-6-6834511

WEB
www.panahome.jp
DESCRIPTION
Percenta AG was established in 2001, and went public in 2007. A 9 person team is based at the head office and work with a range of contractors across the world.

PRODUCTS
Percenta AG offers a wide range of coatings with protective, easy to clean, and photo catalytic properties. Their products contain nanoparticles primarily made of ceramics, glass and titanium dioxide to be used on materials such as wood, stone, glass, leather and metal. The mechanism and properties are similar to the Degussa TegoTop coating. The company sells in bulk quantities. Currently there are over 200 products being researched. Large orders have been received from automotive companies such as Mercedes. Development work is carried out in collaboration with Max Planck, Franhoufer and 2 other chemistry laboratories. They are expanding business rapidly into Middle East, Africa and United States. The company business model hinges heavily on marketing and distribution. Water repellent coatings are the biggest cash cow for the company, mainly for automotive, bathrooms and sealants market.

TARGET MARKETS
Current applications range from anti-tarnish and self-cleaning coatings on:
- Glass: windows and glass panels, solar cells, shower cubicles, mirrors
- Synthetic Materials: synthetic glazing, diver’s and swimming goggles, motorbike windshields, helmet visors, ski goggles
- Wood & Stone: masonry, terracotta, wood, natural stones, marble
- Stainless Steel: kitchen, furniture, lights and door handles, music equipment
- Cookware
- Antibacterial cleaning and sealing
- Textile & Leather.

The company is targeting to introduce its products to a number of countries. The cost of the product is calculated based on costs per kilogramme of the base material, filling loss (2%), trading unit, seal closing device, labelling, outer packaging, packing. The product is processed directly from a 200-litre barrel or a 1000-litre container.

No patents on existing product. The majority of raw material patents belong to Degussa who supply. They are planning on patenting of 36 products in the pipeline for novel products such as golden ink for writing which has a niche market. One person is dedicated to dealing with the companies IPR issues worldwide. The company also licenses for manufacturing.

ADDRESS
Percenta AG
Gildestrasse 5a
D-24960 Glücksburg
Germany
T: +49 4631444080

WEB
http://de.percenta.com
PJI Contract Pte Ltd.

DESCRIPTION
PJI Contract is a specialist contractor for industrial polymeric floors, protective coatings, and linings.

PRODUCTS
PJI Contract Pte Ltd has licensed the patented TiO2 manufacturing process developed by the Singapore Institute of Manufacturing Technology (SIMTech), a research institute of A*STAR for the Delta Nano range of products.

TARGET MARKETS
Exteriors

ADDRESS
29 Woodlands Industrial Park E2
NORDIX
Singapore 757461
Tel: (65) 6766 0900

WEB
www.pjicon.com.sg
PureTi, Inc.

DESCRIPTION
PURETi, Inc. is a privately held, US based company formed in 2004 that has developed, patented and commercialized what it believes to be the most advanced and cost effective set of environmentally friendly, photocatalytic surface treatments available on the world market today.

PRODUCTS
PURETi produces a water based solution that air dries to form an invisible, well adhered, ultra thin, long lasting coating that actively protects all surfaces to which it is applied from the buildup of any organic matter - including bio-film, bacteria, molds or fungi.

PURETi solutions have been tested by an EPA-approved independent lab and found to be non-toxic (fish can swim in the 99% water PURETi solutions with zero mortality) and free of any VOCs, semi-VOCs, or heavy metals. PURETi solutions have been tested by the National Sanitation Foundation and found to be remarkably effective in their self-cleaning and functionality. PURETi's ability to rapidly and effectively decompose nicotine (the single best marker for smoke odor) has been tested and confirmed by a leading independent US testing laboratory.

PURETi
• Aqueous, amorphous, titania, film-former that holds nano particles (as small as 6 nm) of anatase TiO2 in a stable suspension
• High surface area of titanium dioxide particle
• Rate of photocatalytic oxidation is enhanced by increased surface area
• Mode of action may be the targeting of the cellular membrane by the hydroxyl radicals, thus increasing permeability, disrupting metabolism, waste excretion and membrane stability

TARGET MARKETS
PURETi products can be applied to virtually any surface, including buildings, signs, solar panels, sidewalks, outdoor furniture, holding tanks, boats, and planes.

ADDRESS
Pureti
261 Fifth Avenue
New York, NY 10016
USA
T: +1 2126855400

WEB
www.pureti.com
Resodyn Corporation

DESCRIPTION
Thermal Spray Business Unit designs, manufactures and markets proprietary equipment for the application of advanced foams, protective and structural coatings for NASA, the military and a variety of industrial companies.

PRODUCTS
The company's thermal processing technology is used to produce superhydrophobic and corrosion resistant nanocoatings.

TARGET MARKETS
- Military and commercial aircraft coatings
- No skid coatings on deck surfaces found on ships
- Bridge understructure corrosion protection
- Exterior protection of structures such as guard rails and signs
- Nano reinforced coatings for blast protection

ADDRESS
Resodyn Corporation
130 N. Main Suite 600, Butte, MT  59701
USA
T: +1 4064975254

WEB
www.resodyn.com
Ross Technology

DESCRIPTION
Ross is a steel fabricator with more than 50 years of experience in making parts and items for other industries, such as steel shelving and racks.

PRODUCTS
The company is producing super hydrophobic nanocoatings, NeverWet.

TARGET MARKETS
• Aerospace
• Household
• Military

ADDRESS
Ross Technology Corporation
104 North Maple Avenue
P.O. Box 646
Leola, PA 17540-0646
USA
T: +1 8003458170

WEB
www.rosstechnology.com/divisions_nanotech.htm
Sarastro GmbH

DESCRIPTION
Sarastro GmbH was founded in 2001 and is a spin-out from Lebniz Institute of New Materials. Core competences are in applied chemical nanotechnology for medicine, medical techniques, life science, hygiene, cosmetics and food.

PRODUCTS
Sarastro produce anti-microbial, hygiene and anti-fingerprinting coatings. Lifetimes of OEM coatings are several years while end consumer products are few months (application dependent). Materials and applications patents are held by the company. Application patents are jointly held by industry partners.

TARGET MARKETS
Applications areas are medicine and medical technology, hygiene surfaces, soft cleaning tissues, textiles for automotives.

ADDRESS
Sarastro GmbH
Zum Schacht 7
66287 Quierschied-Goettelborn
Germany
T: + 49 682580 890

WEB
www.sarastro-nanotec.com
Schott AG

DESCRIPTION
Schott AG is a leading manufacturer of special glass powders that feature specific physical, chemical and bioactive properties.

PRODUCTS
The coating developed by SCHOTT that consists of a hydrophobic sol-gel layer, a glass-like network builder and hydrophobic siloxanes, is sprayed on and its thickness is in the range of nanometres. The inorganic network ensures that the layer offers sufficient mechanical stability. The organic functional siloxanes are linked chemically to the network in order to ensure that the functionality is retained, despite thermal and mechanical stress.

TARGET MARKETS
The company produces Easy-to-Clean coatings for household appliances and surfaces to prevent mould, fight bacteria and hide fingerprints.

ADDRESS
Schott AG
Hattenbergstrasse 10
55122 Mainz
Germany
T: +49 6131662411

WEB
www.schott.com
SiO2 Nanotech

DESCRIPTION
SiO2 Nanotech, LLC was incubated in March 2010, from SiO2 Associates, an informal partnership. The company is currently commercializing its platform technology VitreOxTM. SiO2Nanotech holds exclusive licenses to several platform technologies including VitreOxTM, ProteinKnoxTM, and HemoClearTM.

PRODUCTS
Utilizing its patent-pending Vitre-products, the technology of SiO2 Nanotech - licensed from Arizona State University - addresses fogging on sportswear visors and goggles, windshields as well as medical devices during procedures.

VitreOxTM can be deployed in 2 fashions:
• As a permanent thin fluid film device (TTFDTM) on new optical surfaces to control fogging
• As an applicable TTFDTM on existing surfaces

VitreOxTM controls droplet formation and thus fogging by physically changing the way the surface responds to condensation, ensuring the surface remains transparent.

TARGET MARKETS
• Sportswear visors and goggles
• Windshields.

ADDRESS
SiO2Nanotech
1475 N. Scottsdale Rd. Suite 200,
Scottsdale, AZ 85257
USA
Phone: 602-565-3447

WEB
www.sio2nanotech.com
Surfactis Technologies SAS

DESCRIPTION
Surfactis Technologies was founded in August 2004 as a spin-off from INSERM (National Institute for Health and Medical Research), in order to provide industrial partners with innovative solutions for preventive hygiene, especially within the oral care and industrial hygiene sectors.

PRODUCTS
The company has developed functional nanocoatings for prevention of bio film, lubrication and cell adhesion. Surfactis bisphoshonic molecules bind oxide surfaces as self assembled monolayer. Due to their high affinity for oxidized surfaces, they have developed polyvalent, simple and cost effective protocols adapted to the covalent functionalization of a wide range of metals or alloys such as iron, stainless steel, silicium, titanium, copper, zirconium, brass, aluminium, aluminium oxide.

The properties of the company’s molecules are:
• Inhibition of biofilm formation
• Ease the removal of biofilm
• Long term protection of treated surfaces
• Non toxic and non biocide
• Novel principle of action

On an untreated surface, the biofilm is dense and bacteria are embedded in a large amount of exopolymer, favouring resistance to antiseptic treatment. When treated with Surfactis molecules, a strong decrease (>90%) of microbiological contamination is observed. Moreover, Pseudomonas fluorescens are isolated, so that disinfection can be easily performed by antiseptic solutions.

TARGET MARKETS
Industrial lubricant and medical implant markets are of interest though still in development stage. Surfactis is engaged in the development of a unique offer for industrial formulations to prevent microbiological contamination (salmonella, listeria, legionnella). Such chemical formulations for surface treatment will enhance sanitary security for agricultural and foodstuff industries and for healthcare professionals.

The company’s IP portfolio consists of: 3 pending patents covering the functionalization process, a broad range of molecules, their synthesis process and their industrial applications.

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T: +33 241349503

WEB
www.surfactis.com
CONTENT
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