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Supplement to the Treatise

WOLFGANG RUNGE: TECHNOLOGY ENTREPRENEURSHIP

How to access the treatise is given at the end of this document.

Reference to this treatise will be made in the following form:
[Runge:page number(s), chapters (A.1.1) or other chunks, such as tables or figures].

Wolfgang Runge

NANO-X GmbH

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Introduction

God created bulk, but the Devil created surface.
(Enrico Fermi, Physics Nobel Laureate)

Surface is what mankind essentially encounters and perceives with the five senses (feeling, seeing, hearing, smelling and tasting) if it interacts with its physical environment. Feeling and seeing is fundamental for the historical development of mankind and development of "understanding" which is related in German language to the German and English synonyms "begreifen" (ergreifen or greifen = grab, grip) and "grasp" – which may lead to *fingerprints on objects*.

Surface is what will change the appearance of objects to us if we put a coating or thin film on it. Colors on surfaces may induce *decorative or aesthetic* effects.

And concerning materials of objects treatment of wood has been practiced for almost as long as the use of wood itself. There are records of wood preservation reaching back to ancient Phoenicia and Greece. Alexander the Great mandated *impregnating* bridge wood by soaking in olive oil. The Romans protected the surfaces of their ship hulls by brushing the wood with tar and had also their vessels coated with pitch to protect against mussels.

Currently, for instance, surface coatings of metallic objects by various means is used to protect against *corrosion*. And it is estimated that 3-5 percent of an industrialized nation's Gross National Product (GNP) is spent on corrosion prevention.

NANO-X GmbH, founded in1999 by the chemist Stefan Sepeur and the electro engineer Reimund Krechan as a spin-out of the Institute of New Materials (INM) in Saarbrücken (Germany), is in the business of high-performance coatings of various substrates on the basis of *chemical nanotechnology*.

Through the use of silanes as bridging molecules between organic and inorganic chemicals and metals, it is possible to use various bond types and classes of materials, for instance, uniting covalently bonded organic polymer chains with ionically bound crystal lattices of nanoparticles or metallic pigments homogeneously in a single matrix. In general, for all the different possible reactions use is made of already known principles of chemistry and silane and sol-gel chemistry which is combined with nanotechnology.

Nanotechnology, first of all, *expresses a dimension*, the nanometer (1 nm = 10^{-9} m), as also microtechnology or micro systems refers to a dimension. The micrometer (symbol: µm) commonly known as a micron, is 1×10^{-6} of a meter, one millionth of a meter.

NANO-X GmbH *develops and produces* customized or standard market-ready coating materials as well as *coating solutions* often focusing on multi-functional properties.

The *services* provided by the company range from *innovation consultancy* to *target-oriented adaptation developments to production and support in the application of the desired coating solutions.* NANO-X GmbH offers a portfolio of well-engineered material solutions in a comprehensive range of products.

As nanotechnology represents *cross-industries miniaturization* to the level of atoms and molecules and as the surfaces of objects as interfaces to the environment will show a number of special features and effects it seems worthwhile to deal rather detailed with technology and market aspects.

Due to its relevance for various industries and functionalities extending over industries the overview will also provide insights into the environment and climate for entrepreneurship in nanotech around 2000 including issues of R&D and financing/funding as well as policy and society.

In this way this extended discussion presents simultaneously a complement to the authors recent work on nanomaterials of Nanopool GmbH (founded in 2001 and active in coatings)

[Runge 2010], Nanogate AG [4] and some German nanotools startups [Runge 2014a; 2014b; 2014c].

For entrepreneurship the nanotech startup's discussions will look at different periods, before the Dot-Com Recession, then a rather long period of six years between two recession for "unperturbed" development and finally the time after the Great Recession: Dot-Com Recession (March 2001 – Nov. 2001, 8 months) and Great Recession (Dec. 2007 – June 2009, 1 year, 6 months – as defined in the US).

The Technology and the Market

In 2002 the US National Science Foundation (NSF) emphasized nanotechnology to comprise "Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1-100 nanometer range, … and creating and using structures, devices and systems that have novel properties and functions because of their small size." [Tran 2004:10]

Though probably "nanomaterials" is implicitly covered by this definition, the material aspect is important as it will include "chemical nanotechnology" and particularly *nanocoatings* and *ultra-thin films*, which is the subject of the current NANO-X case.

> *Chemical nanotechnology* is the systematic production of systems, materials or components in the range of atomic or molecular dimensions with nanoscale measurements between 1 nm and 100 nm by means of chemical synthesis [Sepeur et al. 2008].
>
> Chemical nanotechnology is the controlled production of material or components (prefabricated parts) with dimensions in the atomic or molecular range, respectively, by chemical synthesis (1nm = 10^{-9} m) [Groß 2010].

Thin film coatings is of less than 100 nm to tens of microns in thickness. The *thin film process* evaporates the solvent from a dispersion at atmospheric conditions. Application techniques include spin coating, dip coating and ink-jet methods. High-velocity air streams can be used to increase the evaporation speed. The method employed to create a stable dispersion becomes very important during the formation of the film. During the evaporation phase the amount of solvent decreases significantly. If evaporation does not occur rapidly enough stabilization methods, such as the electric double layer, may not prevent particle agglomeration. This will lead to a finished film with high haze.

During the evaporation phase the nanoparticles will remain mobile and will move in response to the forces acting on them. After the solvent has evaporated, a directional component can be imparted in the film through the use of externally generated magnetic or electric fields or polarized light. Solvent evaporation is typically the most time-consuming part of film deposition and is dependent on ambient conditions and the vapor pressure of the solvent. There are pitfalls for picking systems that evaporate the solvent too quickly though.

An introductory description of the situation of nanotechnology and chemical nanotechnology was given by Runge [2006:540-563].

Different from the notion and subject of biotechnology which reflects an industry nanotechnology is an *enabling technology* [Runge:129] for many industrial sectors with the potential to transform these industries – in particular, also biotechnology – and it serves also as an *enhancing technology*.

Technology and Its Special Environment

The beginning of the 21st century encountered a massive interest of policy in nanotechnology due to its anticipated societal and economic impacts leading national governments globally to implement national initiatives and programs, for instance, in the US in terms of a nanotech-related Research and Development Act, an authorizing funding by related agencies and ministries.

Figure 1 shows that the year 2000 represents an inflection of global funding changing to a new level of dramatically increasing the amount spent per year by the governments of the world.

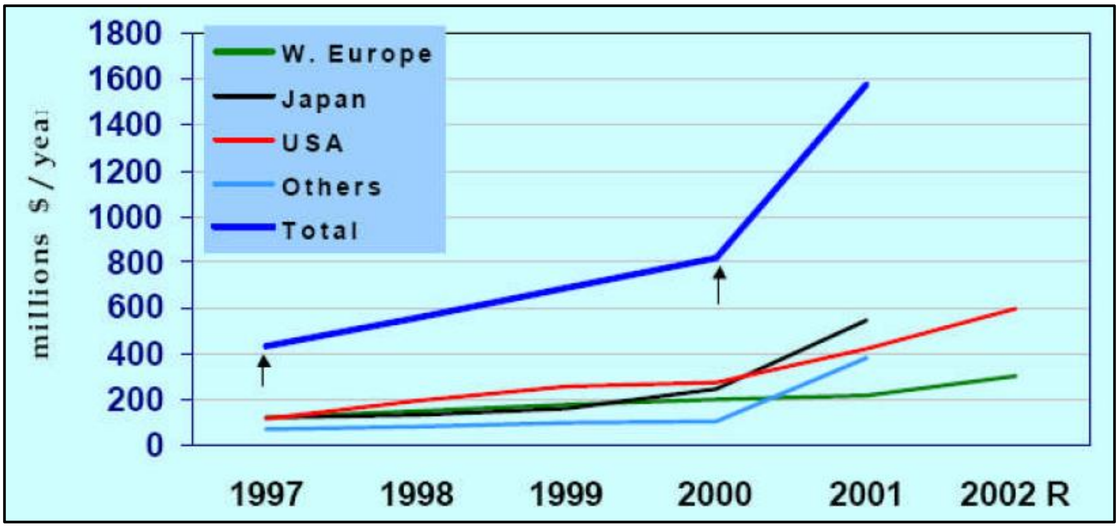
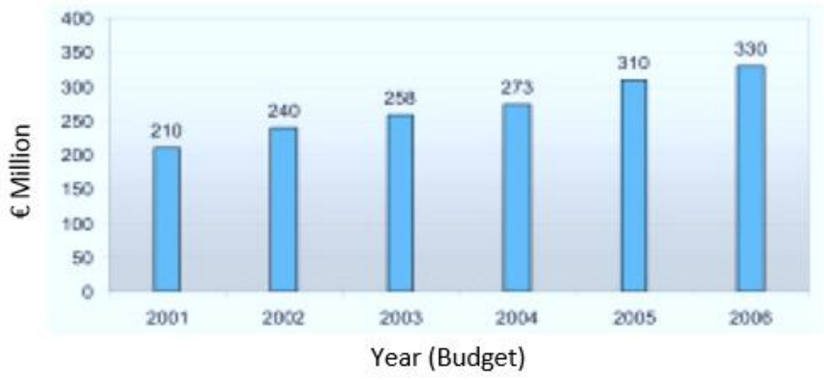


Figure 1: Global Nanotechnology Funding ($ million) [Tran 2004:15].

Massive policy, including "military", and financial activities were observed in Japan, the US, and the EU. For instance, the US provided $862 million in 2003, from $116 million in 1997 and Western Europe funded ~$650 million in 2003, from $126 million in 1997 [Tran 2004:17]. The situation in Germany is described in Table 1.

Table 1: Funding of nanotechnology by public organizations in Germany and in comparison (€, million) [BMBF 2004, 2006].

Country	2001	2002	2003	2004
Germany	210	240	250	290
EU *)	360	480	700	740
USA	420	570	770	850
Japan	600	750	800	800



*) EU data include national funding.

In Germany public funding was essentially via joint projects of organizations rather than individual firms. Corresponding funding during the pre-Dot-Com Recession in given in Table 2.

Table 2: Funding nanotechnology by the BMBF Ministry *) (€, million) [BMBF 2002].

Nanotech Funding by the BMBF	1998	1999	2000	2001
Verbundprojekte (Joint Projects) *)	27.0	31.1	32.7	52.0
Networking by Competence Centers	0.6	1.6	2.1	2.1
TOTAL	27.6	32.7	34.8	54.1

*) Verbundprojekt – Joint project: [Runge:180-181,1029,1216]; BMBF – Federal Ministry of Education and Research; joint projects usually contain public and industry partners.

In 2001 emphases of public funding were on nanomaterial (23.5 percent), optical technologies (12.6 percent), nanoelectronics (8.6 percent), micro-systems technologies (5.0 percent) and communication technologies (2.9 percent) [BMBF 2002].

Institutional funding of nanotechnology in Germany in 2001 was essentially by public sources. Private contributions of industry were rather low (Table 3) [BMBF 2002]. Institutional organizations included the German Research Foundation (DFG) as well as the various German public research organizations [Runge:166-168] and also the PTB (Physikalisch-Technische Bundesanstalt – the National Metrology Institute).

Table 3: Private and public institutional funding of nanotechnology in Germany in 2001 (€, million) [BMBF 2002].

Institutional Funding *)	Total	Public Funding	Industry Contributions
DFG Deutsche Forschungsgemeinschaft	27.0	25.2	1.5
MPG Max-Planck Gesellschaft	14.3	13.6	0.7
FhG Fraunhofer Gesellschaft	8.5	4.4	4.1
WGL Wissenschafts-gemeinschaft G.W. Leibniz	25.4	17.8	7.6
HGF Helmholtz Gemeinschaft	31. 8	26	5.8
Others (e.g. PTB)	5.7	5.7	0.0
TOTAL	112.7	93	19.7

*) DFG, the German Research Foundation, corresponds to the US National Science Foundation (NSF), the other public R&D institutions are described by Runge [2014:166-171].

Including for 2001 also project funding of the Federal Ministry of Economics (BMWi) amounting to ca. €8.0 million one obtains for the total expenditures for R&D approximate values of €217 million with €155 by public sources and €62 million by industry.

Around 2000 nanotechnology was in the early adoption phase associated with the following outlooks [Tran 2004:24]:

- New job creation opportunity
- New paradigm shift in technology development
- New applications and markets

- New intellectual property landscape
- New strategic planning
- New public relation approach.

Development of nanotechnology after the Dot-Com Recession was characterized by Tran [2004] by three features:

- *Convergence*: bridging over the convergence of physical sciences, information technology, engineering and biomedical sciences.
- *Collaboration*: bridging the global collaboration to explore the mystery of the nanoscale world and how to make use of its applications for the benefits of mankind. But collaboration includes also interactions of startups and universities and public research organizations and startups with medium-sized and large existing firms.
- *Communication*: bridging the communication gap to address key issues facing the scientific research, business development and social, environmental, health and safety implications of nanotechnology.

With regard to communication nanotechnology emerged as an area of development with much public attention and often *health concerns*. Hence, developments and innovations in nanotechnology will be invariably associated with discussions of related effects. A heavy public debate on this issue may strongly affect industry with regard to already existing products, but also with regard to research directions and future innovations. And one reads:

> That due to their special characteristics nanoparticles are not only useful, but can also be harmful, is obvious. But the technological developments proceed apace so that an assessment of the risk to humans and nature is hardly possible.
> (Dass Nanopartikel auf Grund ihrer besonderen Eigenschaften nicht nur nützlich, sondern auch schädlich sein können, liegt auf der Hand. Aber die technologischen Entwicklungen schreiten so rasch voran, dass eine Bewertung des Risikos für Mensch und Natur kaum möglich ist [GdCH 2014:12].)

Hence, industry must accept that developments and innovations in nanotechnology will not only be determined by technological and production progress and marketing, but are invariably associated with responses to *constraints posed by society and the public* [Runge 2006:546-547].

Gross segmentation for nanotechnology-related product markets differentiate broadly

- Nanomaterials
- Nanotools
- Nanodevices.

And it was estimated that sales of nanomaterials were $1.5 million in 1999 and grew to $430 million by the end of 2003. With this annual growth rate of 300 percent, the market size would be projected to be $1.3 billion in 2004 and $4 billion in 2005. A more conservative estimate of $1 billion in revenue in 2007 was provided by a study of the Freedonia Group [Hunt 2004].

In reaching out to the market, nanotechnology firms advantageously follow a *Research, Demonstration and Development* (RD&D) approach [Runge:1052-1053]. With the emphasis on the nanoscale dimensions the speed of demonstrations, developments or innovations achieved in the meantime led to a situation that scientific fundamentals were still being investigated while first product groups were entering the world markets [Runge:550].

> The continuously increasing public funding of nanotechnology was a strong impetus for entrepreneurship in nanotechnology. And the situation between 1997 and 2003 was as follows.

"There's *still plenty of hype*, but nanotechnology is finally moving from the laboratory to the marketplace." Companies large and small will be rushing more nano-based products from labs to the marketplace and consumers will encounter nanotechnology in more and more products.

Instead of one new phenomenon, like the Internet and Web, nanotechnology offers new possibilities for thousands of materials that already exist. Activity on the ground was feverish. Some 1,250 "nano startups" emerged around the world, half of them in the US (Figure 2). For now, nanotechnology is starting out modestly. Lux Research Inc., a New York nanotech market researcher, estimated that only $13 billion worth of manufactured goods will incorporate nanotechnologies in 2005. "That's little more than a rounding error in the global economy." [Runge 2006:547]

It was estimated that in the US nano-startups grew from 100 in 1999 to more than 1,000 in just three years [Teresko 2005]. Estimates assumed Germany to have about 200 nanotech startup companies founded in 1995 or later (whereas for the US the number was probably well over 1,000) [Von Bubnoff 2007].

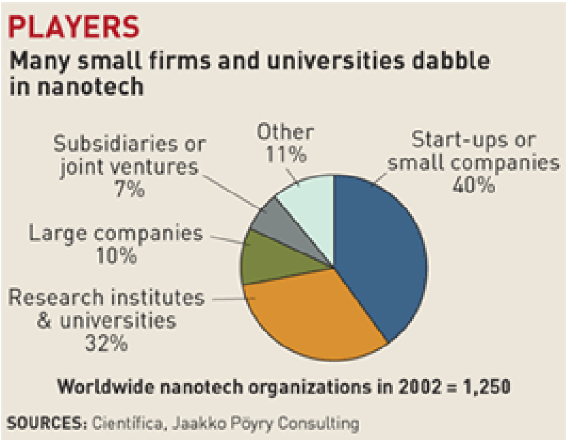


Figure 2: Organizations active in nanotechnology in 2002.

Cited in [Runge 2006:545]

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An example how a German large firm (Degussa, renamed to Evonik Industries) and other large firms approached nanotechnology is described by Runge [2006:556-559].

Roco [2012] showed that, based on related indicators, for nanotechnology globally venture capital (VC) played only a minor role (Table 4).

Table 4: Selected key nanotechnology growth indicators worldwide and in the US (in parentheses) [Roco 2012].

	Year	Patents Applications	R&D Funding (Public and Private)	Venture Capital
World (US)	2000	1,197 (405)	~$1.2 ($0.37) bil.	~$0.21 ($0.17) bil.
World (US)	2010	~20,000 (5,000)	~$18 ($4.1) bil.	~$1.3 ($1.0) bil.

Corresponding IP density (patents of "nano-type" versus total patents in industry or industry segment) may indicate potential future applications.

Nanocoatings and Sol-Gel Technology

Convictions and excitements during the period 1997-2003 about nanotechnology led in 2000 to estimations made after an international study in more than twenty countries as given in Figure 3. Accordingly, for 2009 a global market of products incorporating nanotechnology was expected to amount to value of ca. $250 billion! And it is not surprising that such a climate was associated with continuous excitements about related entrepreneurship.

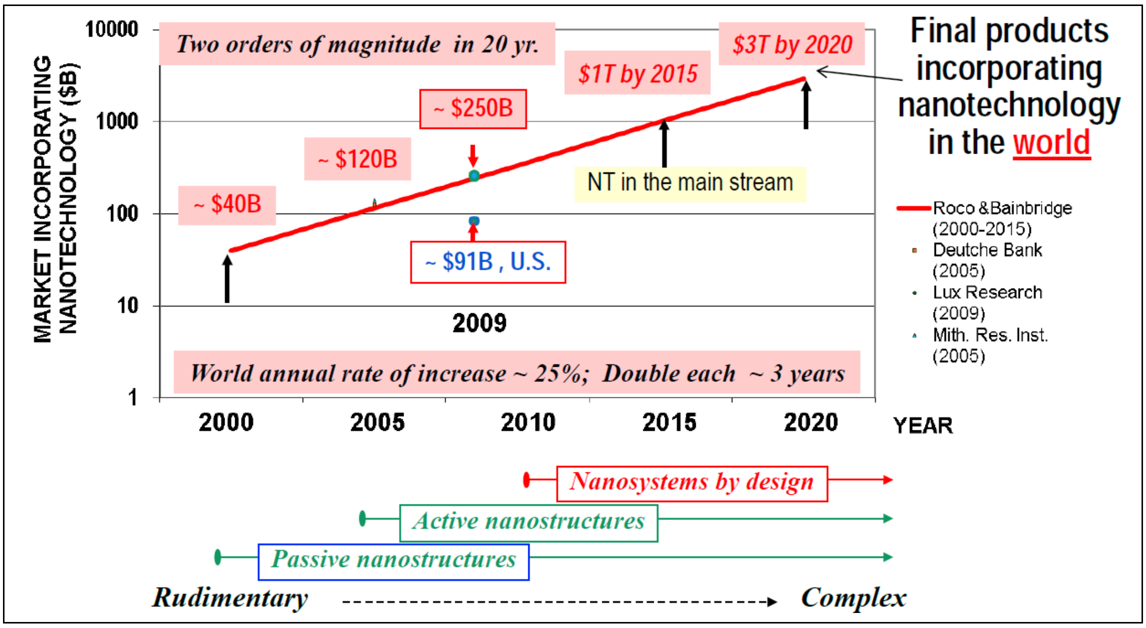


Figure 3: Worldwide market incorporating nanotechnology [Roco 2012:23].

Specifically the market size of nanotechnology products in 2002 and 2003 and expectations for 2008 according to BCC Research Inc. were of the kind as those displayed in Table 5.

Table 5: Global nanotechnology market 2002, 2003 and 2008 ($ Million) (Source: BCC, Inc.) [Tran 2004:9].

Category	2002	2003	2008	AAGR (%) 2003-2008
Nanomaterials	6,825.6	7,366.6	21,424.8	23.8
Nanotools	168.0	181.0	1,241.0	47.0
Nanodevices	0	0	6,030.0	NA
TOTAL	6,993.6	7,547.6	28,695.8	30.6

AAGR = Average Annual Growth Rate.

And correspondingly between 1997 and 2003 the *opportunities* that were envisioned for nanomaterials [Teixeira 2013] initiated the enthusiastic mood for entrepreneurship:

- Nanotechnology can produce novel materials with unique and improved properties and functions
- Nanomaterials offer unique applications in several industries, such as biomedical, electronics, textile, mechanical, energy …
- Nanocoatings and nanosurfaces are opening new market opportunities with a significant R&D investment
- Growing market sectors include nanocoatings for touch panels, household surfaces and indoor air quality, medical devices and equipment
- There is a growing opportunity for upstream suppliers who can provide innovative nanotechnology coatings
- There are also growth opportunities for coatings manufacturers that partner with technology providers to offer multiple solutions afforded by the nanoscale.

However now, a 2012 technical market research report entitled “Nanotechnology: A Realistic Market Assessment (NAN031E)” [BCC Research 2012] valued the global market for nanotechnology at nearly $20.1 billion in 2011 and reported the market to reach $20.7 billion in 2012 with the segments nanomaterials (largest market), nanotools and nanodevices. Nanotools, accounting for ca. 30 percent of nanotechnology, should be valued at nearly $4.8 billion in 2012 and $11.4 billion in 2017 (CAGR [Runge:639] 19 percent).

The previous discussions suggest that "nanotechnology" and entrepreneurship address markets which show features of *policy-driven markets* [Runge:139] in the context of *industry development* [Runge:163,180] – as was done in the US with biotechnology and information technology (IT) [Runge:139,292].

The US National Nanotechnology Initiative (NNI) spelled that out explicitly: Create a general purpose technology (similar IT – bottom-up, science opportunity-born for a general purpose technology) [Roco 2012].

> Relatedly one must be aware that political programs and actions targeting *industry creation* may achieve characteristics of *self-reinforcement*: The created industry organizes itself to establish lobbying and pressure groups to further support or even enlarge the level of the program [Runge:75].

This aspect was also emphasized (specifically for the US) by Redpath [2004]:

"There is much hype in the nanotech field. Many people are projecting what early stage fundamental research *might* lead to in terms of applications. In the hands of some promoters of the field, the timelines have been shrunken and the degree of uncertainty as to whether or not any real applications will actually come to pass has also been reduced. There is now a nanotech lobby, as well as other nanotech organizations that have a vested interest in keeping the expectations high."

In Germany the related industry association is the Deutscher Verband Nanotechnologie e. V. (DV Nano, German Association of Nanotechnology).

The way *molecules and atoms assemble on the nanoscale into larger structures* determines important material properties, such as the electrical, magnetic, optical, physical-mechanical, chemical and biological properties. Furthermore, it is also possible to engineer fine (non-nano) particles with customized features for specialized applications through a unique microstructure of nano-*sized holes or pores*. Hence, *the notion of nano-structures in material may refer to both, particles and holes.*

Concerning nano-holes, for instance, membranes may allow the passage of some molecules or substances while blocking others ("nano-porosity"). A network of related supramolecules can act as a molecular filter and catalyst. A thin-film material with nanometer-sized cavities can be manipulated to allow the passage of certain molecules but not others depending on size, shape and other properties.

For *fast developing science and technology* new firms worked collaboratively with prospective customers to identify an unsatisfied need and apply the company's proprietary technology and products to solve a problem. In most cases, the materials will be custom engineered to the customer's application.

As nanotechnology cuts across scientific disciplines and industries "**chemical nanotechnology**" provides opportunities for innovation through co-evolutions with other industries rather than following only a "chemical path." [Runge 2006:540-551]

Specifically, **nanocoatings** and **nanosurfaces** had been identified during the 1997-2003 period as promising opportunities in the chemical nanotechnology area. But, chemical nanotechnology, concerning research and innovation, was affected by a large number of uncertainties and risks. Approaches to participate in or enter the scene cover almost all conceivable options and configurations. Relatively acceptable forecasting was almost non-existing. There were essentially no prior experiences; there were many "gurus" rather than "experts".

> From a chemical point-of-view *nanotechnology* shows up as the purposefully controlled manipulation ("engineering") of scales of less than 100 nanometers to achieve *size-dependent and arrangement-dependent (structure, shape) properties and functions of matter or surfaces of matter*, respectively, – *material* with ultra-thin films or layers with nanoparticles as there surfaces.

Structures for nanoparticles can be classified according to the order along three-dimensional axes which may make them "isotropic" (equal particle structures along all the dimensions) or "anisotropic" (at least one structural pattern along an axis is different from the others).

"Nanoparticles" are clusters of particles, consisting of several to hundreds of atoms or molecules. Hence, their size ranges between atoms/molecules and solid states of crystals. Their physical and chemical characteristics are also different from those of these two extremes.

New materials with nanoparticles possess clearly modified macroscopic characteristics in relation to conventionally manufactured products if they are composed of larger units or are embedded into a product-specific environment.

> This is similar to the situation with "common" polymers which are not consistently amorphous (non-crystalline). Polymer properties are related not only to the chemical nature of the polymer, but also, among other factors, to the extent and distribution of crystallinity or mixing in "additives".

Dealing with coatings or "nanocoatings" implies basically differentiation by substrate to be coated, such as glass, metal, wood, plastics, paper, fabrics/textiles, etc. or object like can coating.

In general, nanoparticles can improve the surface properties of a coated substrate drastically. One of the most investigated effects are the improved scratch and abrasion resistance, but UV-absorption, biocidal effects and others are also of interest.

Chemical nanotechnology as an *enhancing technology* [Runge:129] appears often as a path extrapolation of current technologies. And, many chemical firms with a coatings business use nanotechnology as a *factor of product differentiation*. Winners in chemical nanotechnology could be expected to be those that can reach across old boundaries and create novel hybrids.

Correspondingly, developing an understanding of *structure-property and structure-function relationships at nanoscale* is a central topic of research in chemical nanotechnology.

Concerning commercialization there is no "nanotechnology market", but there are *nanotechnology value systems* (Figure 25) along which innovation in chemical nanotechnology can be discussed.

A "nanotechnology value system" referring to nano-enabled products with some examples from chemical nanotechnology [Runge 2006:551] is given in Figure 10 adding nanotools for nanoanalytics and nanopositioning as enabling technologies embracing the value system to characterize, research, monitor and control related nanoscale objects or products in terms of chemical composition, structure and topography.

Three (German) startups addressing such nanotools focusing on atomic force microscopy (AFM) and scanning probe microscopy (SPM) are presented as cases by Runge [2014a; 2014b; 2014c]. For the current case Sepeur et al. [2008] mention, for instance, SPM and scanning or transmission electron microscopy (SEM, TEM) as nanotools for nanoanalytics of nanocoatings.

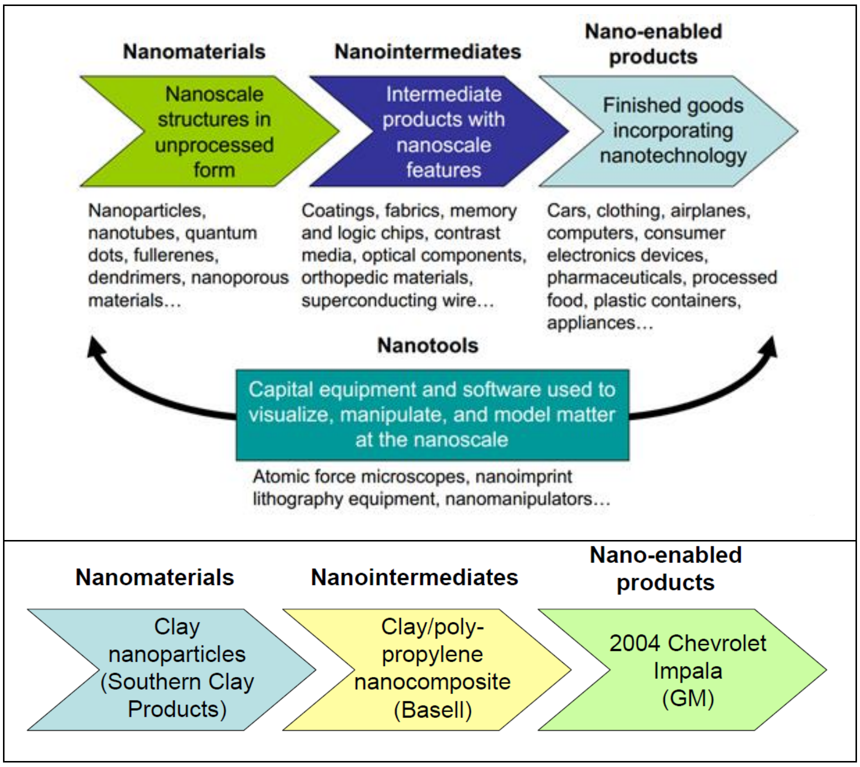


Figure 4: A nanotechnology value system for nano-enabled products with examples from chemical nanotechnology [Abkemeier 2007] and an example value system for a specific nano-enabled product [Holman 2007].

Around 2000 some viewed Scott Rickert from the US as a role model entrepreneur for (chemical) nanotechnology. But, "for starters, his company's history is measured in decades, not months, and his company makes a profit on real products." [Teresko 2005].

Rickert's company, Nanofilm LLC, was founded as Flexicrystal in 1983 (Table 19) with a focus on ultra-thin films. Cincinnati-based LensCrafters became Nanofilm's first customer. In addition to coating lenses, Nanofilm also coated sunglasses, binoculars, camera lenses and rifle scopes It was one of the few profitable nanotech startups and grasped an investment in 2000 by Carl Zeiss Vision, Inc., the US subsidiary of the German high-performance optics company and [Runge 2006:236,554,562; Runge:8,45,191,265,308]. [2]

> Partnering and alliances are fundamentally important for companies seeking to *enhance existing products* with nanotechnology.

"Rickert says partnering is a critical factor in building and sustaining Nanofilm's success. For example, Rickert's business partners provide Nanofilm-designed application equipment that use Nanofilm's consumables. 'We give away the design by letting them use it for our benefit.' He says learning to farm out the equipment and concentrate on supplying the coating technology was a tough, valuable business lesson." [Teresko 2005

A number of different approaches can be used to achieve nanocoatings including, for instance, vapor deposition, pulsed laser deposition, atomic layer deposition (ALD) and electrochemical deposition.

Chemical vapor deposition (CVD) is one of the most common processes used to coat almost any metallic or ceramic compound, including elements, metals and their alloys and intermetallic compounds. The CVD process involves depositing a solid material from a gaseous phase; this is achieved by means of *a chemical reaction between volatile precursors and the surface of the materials to be coated*. As the precursor gases pass over the surface of the heated substrate, the resulting chemical reaction forms a solid phase which is deposited onto the substrate. The substrate temperature is critical and can influence the occurrence of different reactions.

There are several types of CVD process, including atmospheric pressure chemical vapor deposition, metal-organic chemical vapor deposition, low pressure chemical vapor deposition, laser chemical vapor deposition, photochemical vapor deposition, chemical vapor infiltration, chemical beam epitaxy, plasma-assisted chemical vapor deposition and plasma-enhanced chemical vapor deposition.

Atomic Layer Deposition (ALD) offers precise control down to the atomic scale. It is similar to chemical vapor deposition (CVD) except the ALD reaction breaks the CVD reaction into two half-reactions, keeping the precursor materials separate during the reaction [Wikipedia-1].

Atomic layer deposition (ALD) is a thin film deposition technique that is based on the sequential use of a gas phase chemical process. The majority of ALD reactions use two chemicals, typically called precursors. Through the repeated exposure to separate precursors, a thin film is slowly deposited. Concerning entrepreneurship here, for instance, US ALD startup Cambridge Nanotech, Inc. is discussed by Runge [801-805].

In contrast to chemical vapor deposition, the precursors are never present simultaneously in the reactor, but they are inserted as a series of sequential, non-overlapping pulses. In each of these pulses the precursor molecules react with the surface in a self-limiting way, so that the reaction terminates once all the reactive sites on the surface are consumed. Consequently, the maximum amount of material deposited on the surface after a single exposure to all of the precursors (a so-called ALD cycle) is determined by the nature of the precursor-surface interaction. By varying the number of cycles it is possible to grow materials uniformly and with high precision on arbitrarily complex and large substrates.

There are several possibilities available when considering a change from an established coating system without nanoparticles to a coating system that contains nanoparticles. The easiest way is the *use of a nanoparticle concentrate as an additive* for existing coating systems.

A related process, the **sol-gel process** will be carried out in solution and is viewed as one of the most attractive ones for nanocoatings. It is a chemical way to deposit coatings on a substrate and can be used for a large range of applications [Schmidt 2001].

It is an old technology. In 1939 the German firm Schott applied for a patent which probably was the first to show the commercial applicability of the sol-gel process – antifogging for glass and increased scratch resistance. This technology was further developed in 1969 and until 1985 Schott developed 50 different types of coatings for glass [Wiemann].

A key role for this process is silane-technology (Figure 5) focusing on [Schmidt 2001]:

- Using silicate-like networks with organic functionality to build up new matrices
- Utilizing nanoparticles to implement further functionalities
- Building multi-functionality.

Furthermore, there is the inherent stability and flexibility of the siloxane (Si-O-Si) bond.

Often for industrial processes combining several functionalities or properties in a very thin layer is a considerable challenge.

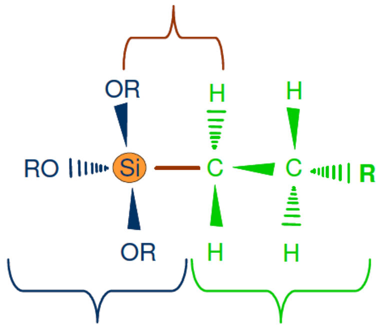
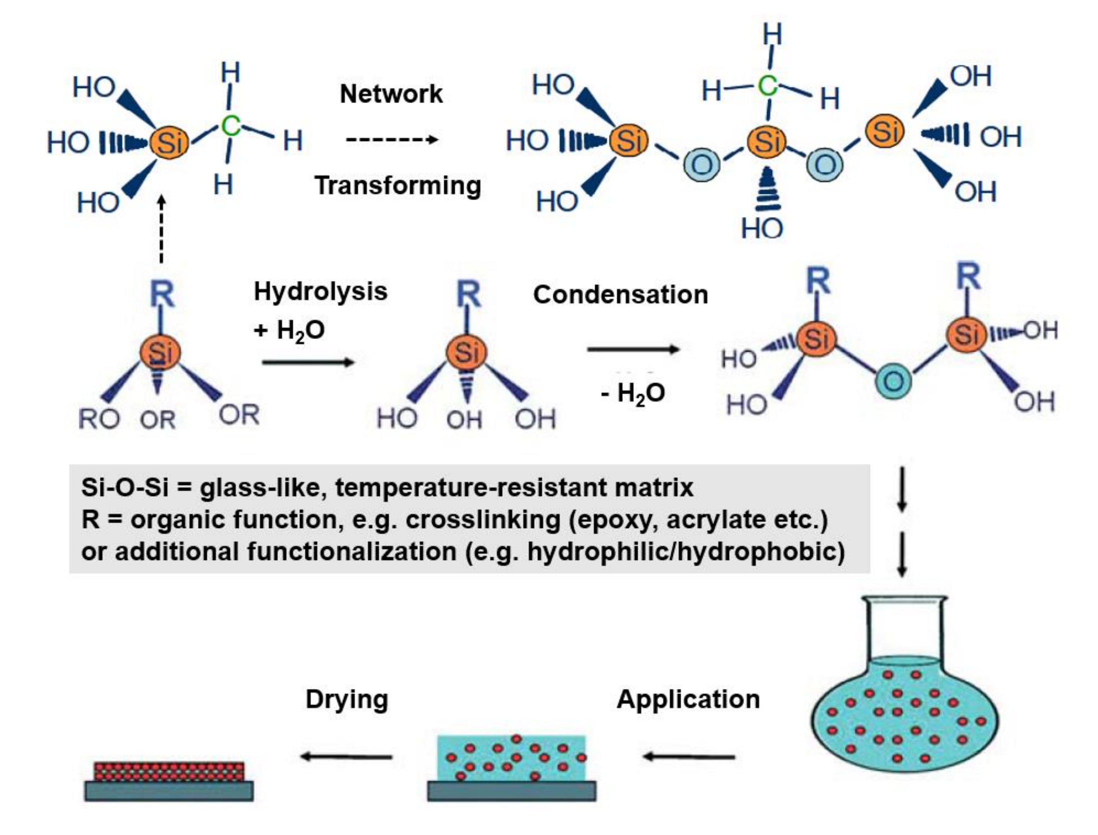
Bridging Bond	
	Inorganic Reaction Organic Function Organic Reaction Interconnection of Particles Network with Covalent Bonds
Inorganic Structure **Organic Structure**	

Figure 5: Illustrating the specialty of Si(licon) for the sol-gel process [Sepeur et al. 2008].

A simplified presentation, disregarding details of hydrolysis and condensation of tetraalkyl orthosilicate and any network transforming and also co-condensation with metal alkoxides (Al, Ti, Zr) or Li, Na, K, B-salts, is given in Figure 6 [Sepeur et al. 2008].



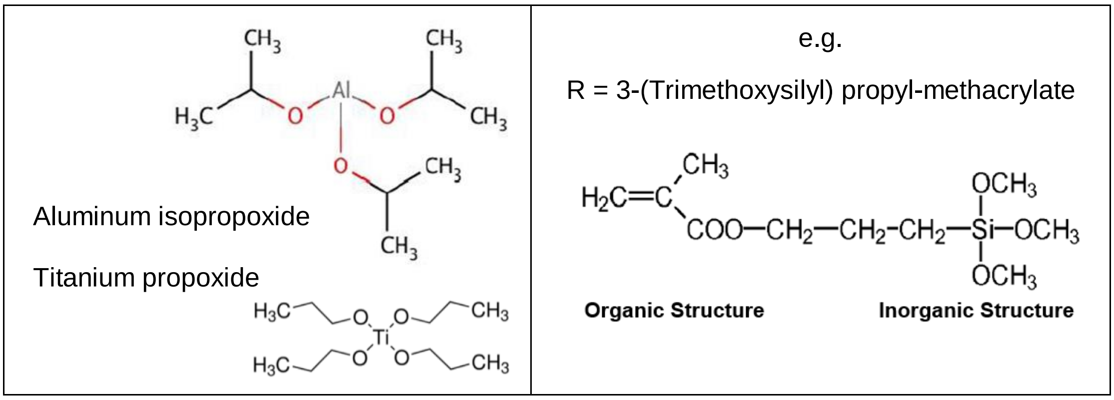


Figure 6: Principles of the sol-gel-process (Source: NanoX_Broschure_deutsch.pdf, File of 1/18/2006).

The organic structure of the model molecule in Figure 6 and Figure 7 (left) can be used for functionalization as well as polymerization into existing organic networks. Silane technology thus offers a broad diversity of possibilities to prepare coating material according to a given required profile.

The coating materials are largely water-based and free from (organic) solvents. By adjustment of rheology and solids content the systems may be adapted individually to almost all common coating processes, such as dipping, flooding, spraying or spinning or printing. Correspondingly hardening of such materials can be achieved at room temperature (RT), heat (IR) and light (UV, electron beams) (Figure 7, right). This provides a wide spectrum of optimizing nanocoatings materials' properties – and innovations.

Functionality may also be achieved by nanoparticles in the layer (like photocatalytic coatings or UV protection). Using, for instance, in Figure 7 (left) for the nanoparticles silver as a metal (Me = Ag) one obtains anti-bacterial properties of the coating.

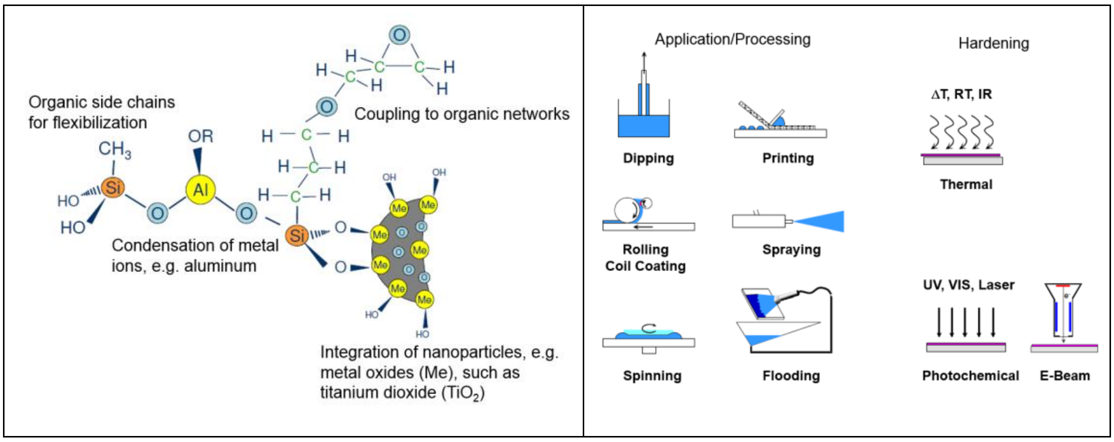
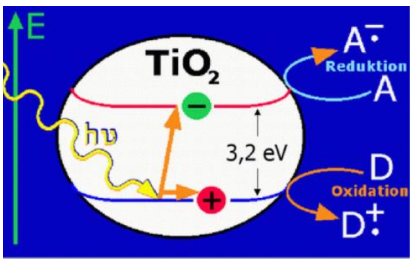


Figure 7: Functionalization and processing of coating material and its hardening [Groß 2010; Sepeur 2003; Sepeur 2009].



If Me = Ti the titanium dioxide has semiconductor properties and UV light excites electrons so that this constellation forms the basis for photocatalytic effects (Table 6)

Source: [Gehrke et al. 2013]

The structure in Figure 7 corresponds to an organic-inorganic nanocomposite – organic and inorganic components in a network. A *nanocomposite* is a matrix to which nanoparticles have been added to improve a particular property of the material representing many variations of nano-mixed and layered materials. Typically, the structure is a matrix-filler combination where the fillers like particles, fibers, or fragments surrounds and binds together as discrete units in the matrix.

A summary of the variability of the sol-gel process concerning post-processing of the sol intermediate and transforming it in into various forms of gels and final states is presented in Figure 8. But, often surfaces have to be pre-processed, prepared for the coating which may depend on the substrate and the method of the coating process.

Generally, dealing with sol-gel processes for coatings means integrating four area of science and technology:

- Glass chemistry
- Silicone chemistry
- Organic polymer chemistry and
- Ceramic materials technology.

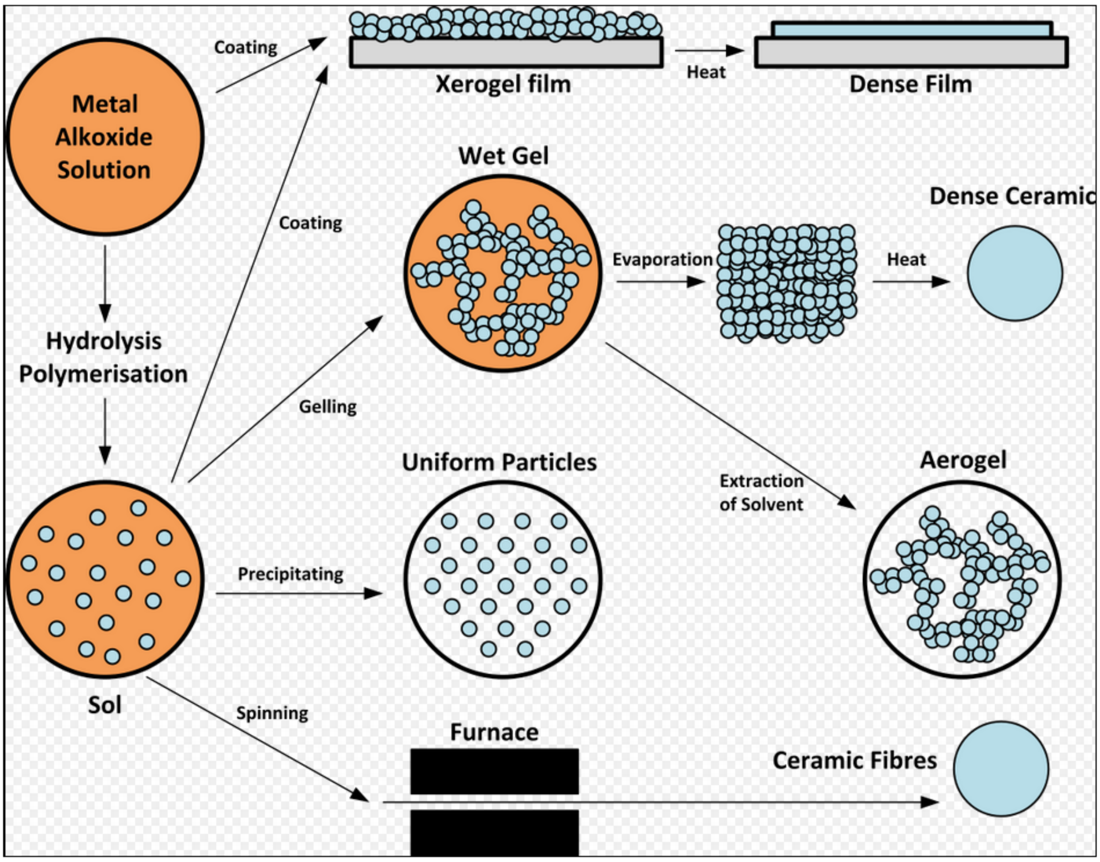


Figure 8: Schematic representation of different stages and routes of the sol-gel technology [Wikipedia-2].

Concerning aerogel materials (primarily silica) the vast majority of these *nanoporous* materials is used for insulation, but applications emerged in optics, electronics, catalysis; polymers for separation media; polymers, silicon, or carbon for drug delivery systems; carbon, polymer, hydroxyapatite, etc. and medical device coatings [Holman 2007].

The market for nanoporous materials was given to be $54 million in 2005 and assumed to increase to $690 million in 2010 [Holman 2007].

Processing benefits and addressed properties *or functionalities* by the sol-gel method is presented in Table 6.

Table 6: Processing benefits and addressed properties or functionalities of sol-gel products.

Processing Benefits	Addressed Properties
• Variety of raw materials • Low temperature process • High purity materials • Simple application methods • Low equipment investment • Spectrum of optimizing coatings materials' properties – and innovations	• Hydrophobic surfaces • Oleophobic surfaces • Anti-fingerprinting • Anti-microbial surfaces • Anti-fouling surfaces • Easy to clean surfaces • Self-cleaning (bionic and photo-catalytic) surfaces • Protective transparent coatings • Corrosion resistance • Low friction • Chemical resistance • Antistatic surfaces • Conducting/semi-conducting surfaces; • Extreme mechanical wear resistant properties • UV protection

Moreover, nanomaterials lead to new functionalities, completely innovative characteristics and the possibility to achieve *multifunctional coatings* and *smart coatings*.

For entrepreneurs, “nano” spells funding, via state funds or private investors; for universities and other research organizations it means research grants.

The situation for chemical nanotechnology suggests an *innovation model* combining *demand pull and technology push* [Runge:114-115,120-121] as a way to quickly exploit the advantages in nanotechnology science and translate these into customer value. The many question marks concerning nanotechnology and related uncertainties and risks have created a diversity of innovation approaches and configurations, not for large versus small companies, but *involving large and small companies* (Figure 2).

As nanometer-scale materials started making money, intellectual property issues were heating up – as described by Runge [2006: 551-552] and cited below.

Companies from startups to multinationals were aggressively locking up critical and basic nanotechnologies. The *race was to protect nanotechnology intellectual property (IP)* or to *license or buy it from universities*, companies, or other groups. Small nanotechnology firms benefited from big companies' desire to explore new materials for electronic, but also other applications.

Having strong IP is important for companies building a base in nanotechnology. For startups in particular it is critical not only for protecting their turfs, but also for attracting the financing they need to exploit their inventions. For nanotechnology expectations are that *there will be unimaginable innovations based on early discoveries*. Hence, through locking up patents one can claim a piece of the action going forward.

To be successful in this IP strategy companies need to develop *intelligence strategies* covering *thorough understanding of the patent landscape*; *monitoring* patent publications, issuances, licenses, and litigation; and *develop concrete IP strategies* that allow them to increase their chances of future profitability.

If nanotechnology tracks other emerging technologies, patent litigation is in its future. As new players come in they sometimes either focus too much on obtaining patents or they ignore the patents of others, expecting to clean up any conflicts later. This would be comparable with both the biotechnology and semiconductor industries, which experienced a huge rise in litigation after producers had established a market and began to make money.

Due to the cross-disciplinary nature of nanotechnology patenting nanotechnology is associated with difficulties to write patents that give full measure of protection to inventions. It is important to find a way to perceive it across technical lines and then claim it in such a way that one maximizes protection.

Nanotechnology funding reached $12.4 billion worldwide in 2006 [Holman 2007], but “Exits for Venture Capitalists in Nanotechnology Remain Elusive.”

- Government $6.4 bil.
- Corporate $5.3 bil.
- Venture Capital $0.65 bil.

In the US venture capitalists had invested $2 billion in nanotech startups since 1995 and $480 million in 2005 [Holman 2007].

“VCs run hot on nanotech as a field for innovation but cold on the performance of individual nanotech start-ups – and most don’t recognize the five key ways in which nanotech deals differ from other sectors.” [Lux Research 2005].

“A lot of those companies that have gotten funded in the past 12 to 18 months were at it five or six years ago." "It's really a long-term situation.” Making it even tougher is the fact that many nanotech startups are years from having a product on the market. A lot of early nanotech companies choose not to go the venture capital route because it is hard money to get to. Venture capitalists do not really understand the nanotech value proposition. The timelines are too long for a lot of VC funds. "The venture community is struggling first to understand nanotechnology and to be able to look far enough out to understand how it's going to provide a return of the type they are looking for." [D'Errico 2006].

And venture capital still remained a drop in the bucket of total nanotech investment, outstripped by corporate R&D spending and government funding by a factor of 19x. Only 9 percent of venture-backed nanotech startups have achieved exits till 2006. Many VC partners that have made significant nanotech investments see their deals as high-risk placements with little visibility to an exit [Lux Research 2006].

In the US venture capital investment is so low that all VC nanotech investment from 1998-2004 is approximately equal to the amount that the government spent on nanotechnology in 2004 alone [Crawley et al. 2012].

The situation that VC accounts for less than 5 percent of overall nanotechnology funding has not yet changed. Requirements and challenges for investing venture capital in nanotech firms were broadly summarized recently [EuroNanoForum 2013] and given in Table 7.

Table 7: Requirements and challenges of potential investments in nanotech firms.

Requirements	Selected Challenges of Nanotech Investment
• Management: market oriented, focused, open for counseling and if applicable reorganization, willing to sell • IP with the company. Already existing product patents would be ideal • Technology with a great market and the potential to displace existing technologies • Market access in limited space of time and with limited financial requirements possible • Company phase: Early stage/mid stage, most favorable shortly before market entry with a matured product, no investment in seed stage • Low valuation of the company • Geographic region • Portfolio of companies that return money back in 3-5 years • Best cases are expected to return 10 to 100 times the original investment	• Risk comes from not knowing what you are doing • “I only invest in companies whose business is fully familiar to me.” • High investment requirements • Burn rate: Average ≈ €50,000 – €300,000 Nanotech ≈ €500,000 – €2 mio. • Scalability from lab to industrial scale • Long R&D phases, duration and success difficult to estimate • Nanotech firms cannot meet the timeline • Platform technology: Time-to-product (concept): 3 to 4+ years, Time-to-market (customer) 5+ years • Peak of company-value Average (IT) ≈ 1-2 years Nanotech ≈ 4-8 years • IP risks

Nanomaterials and Nanocoatings Markets

The ultra-thin nanofilms, nanoscale coatings and nanostructured surfaces market (generically referred to as nanocoatings) has witnessed substantial growth in the last decade. There has been a huge increase in applications of new nanocoatings technology over the past years across numerous industrial sectors.

Actually nanoscale films are sub 100-nm layers of polymers, metals or ceramics which are self-assembled or deposited on surfaces. There are many notable advanced nanomaterials for coatings for which, however, you have had to develop processing methods for industrial applications.

The key element that nanocoatings provide is protection-from, for instance, ice, dirt, pollutant, UV, fire, heat, bacteria, marine life, touch and corrosion. These factors cost global industry billions in maintenance and loss and can pose a significant public health hazard. For example, direct corrosion costs account for 3-5 percent of a country’s GDP worldwide.

Nanocoatings do offer a number of *environmental benefits* as they are low in VOCs (volatile organic compounds, such as organic solvents) – this factor is likely to also determine their growth over the next few years.

Market research now differentiates essentially the following *market segments for nanocoatings’ products and application areas* which require usually different functionalities as shown in Table 8 and will exhibit different sensitivity towards economic (recession) effects.

In the context of chemical nanotechnology sometimes there is special consideration of *markets for sol-gel products*.

Table 8: Major end use-markets of nanocoatings.

Medical & Healthcare	Food manufacturing (manufacturing and packaging)	Packaging (special objects, e.g. can coating)
Marine (ships)	Water treatment	Electronics (components, screens and displays, plastic and metal parts
Buildings & construction (pipes, facades, bridges)	Automotive (paint surface treatments – color and protection, metal parts, metal structures, windows, mirrors and lamps, plastic hoods)	Energy (wind power structures and blades, glass surfaces on solar panels),
Aerospace	Consumer Electronics (displays and plastic and metal parts)	Sanitary
Medical (hydrophilic and hydrophobic coatings; medical devices, implants, medical equipment & tools and others)	Textiles & Leather	Oil and Gas (pipes)
Tools	Military (broad range of applications)	Other (specialty coatings)

Product innovation plays a key role as the *fragmented nature of the market* results in companies developing new products to *gain competitive advantage*.

In general, a complete and consistent record of market value (or volume) for nanocoatings is rather difficult. This is due to the fact that the function-determining proportion of the nano-scale layer systems in the added value of the product is mostly not quantifiable:

> Coating or surface functionalization represents only a part of the production process that is usually carried out in a value-added stage of primary (raw) and intermediate products (Figure 25).

For instance, complexity will be associated based on the economy of the used coating processes (Figure 7, right). Considering the *value-added stage of end-products*, significant market value shows up for products whose functionality is essentially determined by the nano-layer.

Furthermore, as the nanocoatings field is highly fragmented concerning markets and functionalities inconsistent segmentations make different reported quantitative results often incompatible. Furthermore, there are issues of segmentations in how far multi-functional nanocoatings is clearly separated or included in other sub-clusters.

> Correspondingly one should consider results and other reporting of market research reports very critically (cf. Figure 3 and the "Realistic Market Assessment").

Forecasting is often simply extrapolating by the average annual growth rate of 25 percent given by Roco [2012] for final products' markets.

It was estimated that sales of *nanomaterials* was $1.5 million in 1999 and will grow to $430 million by the end of 2003. With this annual growth rate of 300 percent, the market size would be projected to be $1.3 billion in 2004 and $4 billion in 2005. A more conservative estimate of $1 billion in revenue in 2007 was provided by a study of the Freedonia Group [Hunt 2004].

According to a report [Reportlinker 2009] *nanocoatings* already represented a significant niche market in 2008 with global revenue exceeding $600 million. And it was predicted that the market will exceed $6.5 billion in 2015. Regenerative self-cleaning and self-healing coatings were assumed to be the next wave of potentially disruptive technologies that are beginning to impact the market. Key markets impacted were assumed to include packaging, textiles, household care, building and construction, healthcare, automotive, aerospace and defence and electronics.

Research and Markets [2010b] reported that nanoscale anti-microbial, easy-clean and self-cleaning coatings were approximately $711 million in 2009 and totaling ca. $2.367 billion per annum in 2015. The market for nanoscale anti-microbial, easy-clean and self-cleaning coatings were forecasted to grow across all sectors over the next few years, with the medical, household care and food processing markets all experiencing large growth, driven by the need for improved sanitary facilities and also pushed by the vast improvements these coatings offer as germ and dirt repellers. These would find their way into *brand products*.

Similarly, according to Future Markets [2010b] the market for nanostructured coatings was valued at $980 million in 2009 with revenues in the *household care sectors* were seen to be approximately $145 million. The global market for nanostructured coatings was given to be $1.317 billion in 2010 and was estimated to be valued at $3.515 billion in 2015.

The medical, household care and food processing markets all experiencing large growth, driven by the need for improved sanitary facilities were also pushed by the vast improvements nanostructured coatings offer, from both a *protective and destructive perspective*.

The *military market* will remain the largest market with anti-corrosion coatings increasingly applied. Anti-corrosion coatings will also drive revenues in the oil and gas industry, for protective surfaces in pipelines and harsh environments. The world market for abrasion, wear and corrosion resistant nanocoatings was $352.4 million in 2010 [Future Markets 2010b].

Main end user markets for nanostructured coatings in 2010 were in construction and exterior protection (mainly in anti-weathering coatings), military and defense (anti-corrosion coatings for military vehicles and protective textiles for soldiers), household cleaning (easy clean and anti-microbial coatings for household surfaces applied as pre-coats or after treatment sprays) and automotive (anti-corrosion, thermal barrier and hydrophobic coatings).

Nanocoatings can be viewed as being a special complement of the general paint and coatings industry. Currently, the global nanocoatings market is conservatively estimated to be worth approximately $2-2.5 billion per annum [Future Markets 2014].

Coatings (and paints) usually provide *protective and decorative aspects of functionality* and contain

- Binders (resins)
- Solvents
- Pigments and
- Additives (to affect processability, physical properties of the coating or, for instance, a component like an extender improving adhesion of pigments).

According to Jenkins [2013] the global paint and coatings industry took in $106.1 billion in revenue in 2011 on a volume of 33.1 billion liters of product. Key characteristics of that industry are as follows [Jenkins 2013]:

- Coatings demand tends to follow overall economic activity – a strong correlation exists between gross domestic product (GDP) per capita and coatings demand.
- End-use segments for coatings are diverse and very fragmented compared with other industries.
- The global coatings industry has become increasingly consolidated over the past two decades, and the trend toward consolidation will continue.
- Migration away from solvent-based coatings to water-based coatings (VOC regulations!) has largely happened already for the decorative paint segment, but the transition is still occurring in the industrial coatings market segment. Often, the move there is toward high-solids, solvent-based technologies and powder coatings.
- The decorative-coatings market segment dominates, with 56 percent of the volume sold and 44 percent of the value. Other coatings market segments include general industrial (10 percent by value), auto OEM coatings (8 percent of value); powder coatings 8 percent, wood coatings (6 percent) and others.

The global fragmentation of the global coatings markets is specifically segmented for outdoor coatings considering fundamental climatic conditions. A high humidity weather, for instance, in South-East Asia requires different coating functionalities compared with a dry climate with aggressive sunshine in Australia,

In terms of special requirements for products also the coating process may impose special requirements, as will be described below for coil coating and can coating.

In 2014 the overall nanocoatings market was still recovering from effects of the Great Recession on the paints and coatings industry. The recovery in the world is expected to drive demand for architectural coatings. The growing *focus on energy efficiency and eco-friendliness* as indicated by the growing popularity of green construction is expected to spur demand for environment-friendly powder coatings, high solid coatings, radiation (UV/EB) coatings and waterborne coatings.

Shifting demand towards nanocoatings instead of polymer coatings is mostly due to superior properties and also low VOC emissions are expected to be *major driving forces for the nanocoatings* market: Nanocoatings are opening new market opportunities in the global coatings arena.

Regionally, North America leads the world's nanocoating consumption, accounting for more than 40 percent of global demand. The European market is likely to see significant growth due to stringent VOC regulations on the paints and coatings industry and increasing raw-material costs for conventional coatings. The so-called REACH legislations in the EU consist of regulations regarding harmful VOC emissions from paints and coatings, which are expected to fuel nanocoatings market demand.

Growth in Asia Pacific will be in the electronics, automotive and healthcare industries, due to low-cost labor and technological advancements [PaintSquare 2014].

The global nanocoatings markets' growth can be attributed to the emergence and development of new and existing applications. These market segments are fairly fragmented due to presence of the number of market participants, but also the number of functionalities and their combination as well as the variations of substrates and materials for the surfaces.

Table 9 provides an overview of some market research results on the situation of nanocoatings and associated projections of further development ("To" column). Data for 2008/2010 are presumably collected before the Great Recession. Hence, they can be assumed to not cover the recession effects and therefore are too high. Correspondingly, values for the global market of nanostructured coatings and thin films 2011/2012 could be between $2.5 billion and $1.4 billion.

Table 9: Results of global market research on nanocoatings for the period 2008-2012.

Subject	**Value, Year**	**Value, Year**	**To**	**Comment** (e.g. Fastest Growth, Biggest)	**Ref.**
		$227.5 M 2011	$1.4 B 2016	**Fastest**: ext./int. household protection, medical, textiles; **Biggest**: military (anti-corrosion), oil & gas	[Electronics CA 2011]
Nanoscale coatings and thin films	$2.4 B 2009		> 13 B 2016	**Fastest**: ext./int. household protection, medical, textiles; Driver: increased demands for protective/repellent coatings	[Jenkins 2013]
Nanocoatings	>$600 mil. 2008		$5 bil. 2013; $6.5 bil. 2015		[Research and Markets 2008; Reportlinker 2009]
Nanostructured coatings	$980 mil. 2009	$1.317 bil. 2010	$3.515 bil. 2015		[Future Markets 2010b]
Nanocoatings	$2.4 B 2009	$3.6 B 2010			[BMBF 2011]
Nanocoatings		$1.49 bil. 2012 255 ktons	$8.17 B 2020 1,262.9 ktons 2020 309.5 ktons, 2013	**Fastest:** anti-fingerprint coatings (in electronics and automotive applications), anti-microbial coatings (in healthcare and building) – in 2013 90.9 kilo tons and revenues of $541.6 mil. **Biggest:** healthcare (increased use of anti-fingerprint and anti-microbial coatings), 43.7 kilo tons in 2013	[PaintSquare 2014] referring to [Grand View Research 2014]
Nanocoatings				**Fastest:** medical and healthcare 14% of the global demand in 2012, electronics, energy **Biggest:** anti-microbial nanocoatings (29.6% of global demand in 2012), second easy-to-clean and anti-fouling, medical and healthcare, automotive	[Transparency Market Research 2014]

Table 10 shows some market data using functionality as the basis for segmentation.

Table 10: Nanocoatings markets according to specific segments [BMBF 2011].

Market Type	2010	2009
Easy-to-clean, self-cleaning, anti-bacterial/microbial	$764 mil. a)	$711 mil. c)
Anti-fog	€300 mil. a)	
Wear and corrosion resistant	$352 mil. a,b)	
Automotive	$246 mil. e)	$133 mil. d)
Photocatalytic coatings	€1 bil. a)	$848 mil. a)
Household care sectors	145 mil. b)	

a) [BMBF 2011], b) [Future Markets 2010b], c) [Research and Markets 2010b],
d) [Research and Markets 2010a], e) [Future Markets 2011].

According to Grand View Research [2014] anti-microbial coatings are mostly used in the packaging, food manufacturing, water treatment and medical & healthcare applications of the nanocoatings market. They offer protection from microorganisms. Anti-microbial nanocoatings are anticipated to grow during the forecast period due to increasing demand from the medical and healthcare sector.

The self-cleaning segment includes both bionic and photocatalytic nanocoatings and are expected to witness growth as they provide Lotus leaf effect to products.

In the nanocoatings market anti-fouling & easy-to-clean coatings are expected to grow with increasing use in electronics, automotive, marine and food manufacturing applications. In addition, these nanocoatings also inhibit fungal and algae growth.

On account of their increasing *usage in different industry segments*, the overall anti-fouling sector is anticipated for high growth over the forecast period [Transparency Market Research 2014]. The same is true for nanocoatings for the automotive industry.

Anti-fingerprint coatings are expected to be the fastest growing product segment, owing to extensive use in medical & healthcare and electronics applications.

> "Product innovation plays a key role as the fragmented nature of the market results in companies developing new products to gain competitive advantage." [PaintSquare 2012]

Nanostructured coatings are beginning to find widespread application in the *automotive industry* as paint additives allowing for new coloration effects and greater hardness (scratch resistance) and durability. Coatings of different materials 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. By reducing wear and friction nanoscale protective 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. The current market is estimated to be around $133 million, rising to $330+ million by 2015 [Research and Markets 2010a].

Exploitation of *nanomaterials* covers an entire spectrum of applications from polishes, glass treatments and color changing paint, nanofilled polymers and resins, and nanostructured ceramics and coatings, offering higher performance and/or additional functionality, such as wear and erosion resistance, light-weighting, reduced friction, toughening, UV resistance, corrosion control and aesthetic enhancement, to batteries for electric vehicles and advanced electronics and sensors. The conservative estimate for nanotechnology and nanomaterials enabled products in the automotive industry for 2010 was $246 million. By 2015, estimates are $888 million (conservative) [Future Markets 2011].

As the current case, NANO-X GmbH, uses essentially sol-gel technology for its products (Figure 5 - Figure 8) additionally some related market aspects shall be considered.

In 2006 the total market for *sol-gel-based nanomaterial* was valued at $1 billion and $1.4 billion for 2011 [BMBF 2009a].

Recent data concerning industry for nanocoating products using a sol-gel process are displayed in Figure 9 – with the sanitary, automotive and textile industries emerging. In Table 11 estimated revenues to be gained in 2014 regarding sol-gel products in different industries or with different functionalities are given.

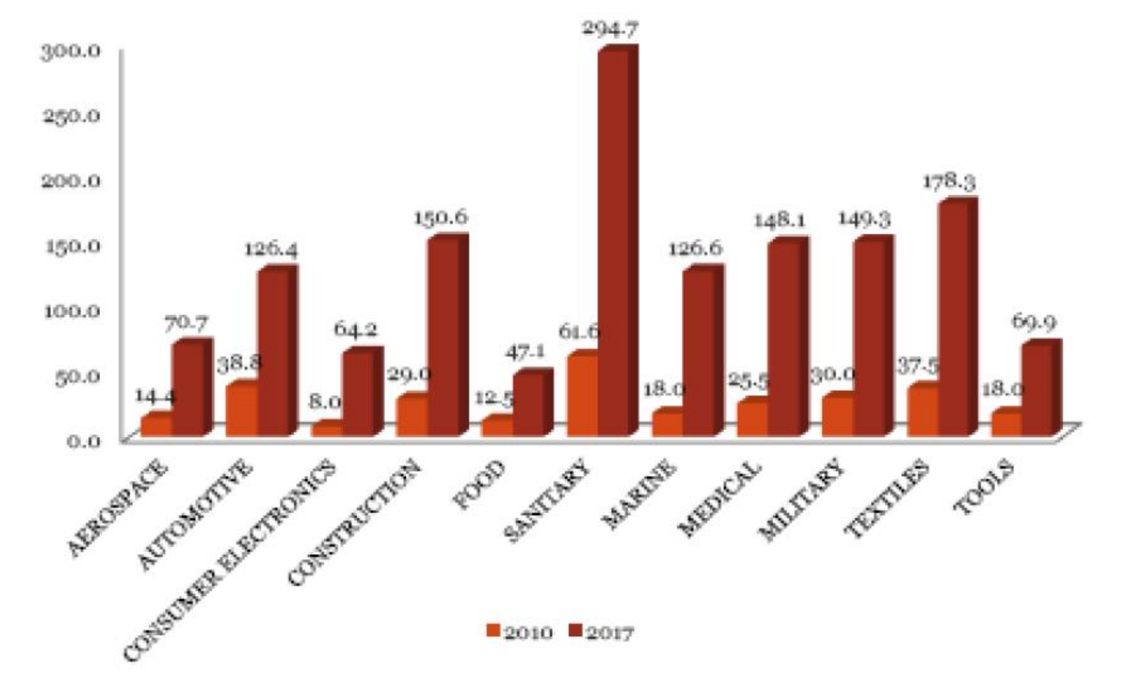


Figure 9: The commercial role of sol-gel nanocoatings for various industries (Source: [Xiao 2014] citing The World Market for Sol-Gel Nanocoatings, Future Markets Inc, June 2011).

Table 11: Estimated easy-to-clean, anti-fingerprint and anti-bacteria sol-gel nanocoatings addressable market size in 2014 [Xiao 2014].

Application	Revenue ($ Million)
Automotive	60.1
Consumer Electronics	23.6
Construction	73.7
Sanitary	172.5
Food (Anti-bacteria)	40.1
Medical (Anti-bacteria)	134.4
Anti-bacteria (Others)	197.8
Textile, metal, construction	€50 (2010) [BMBF 2011]

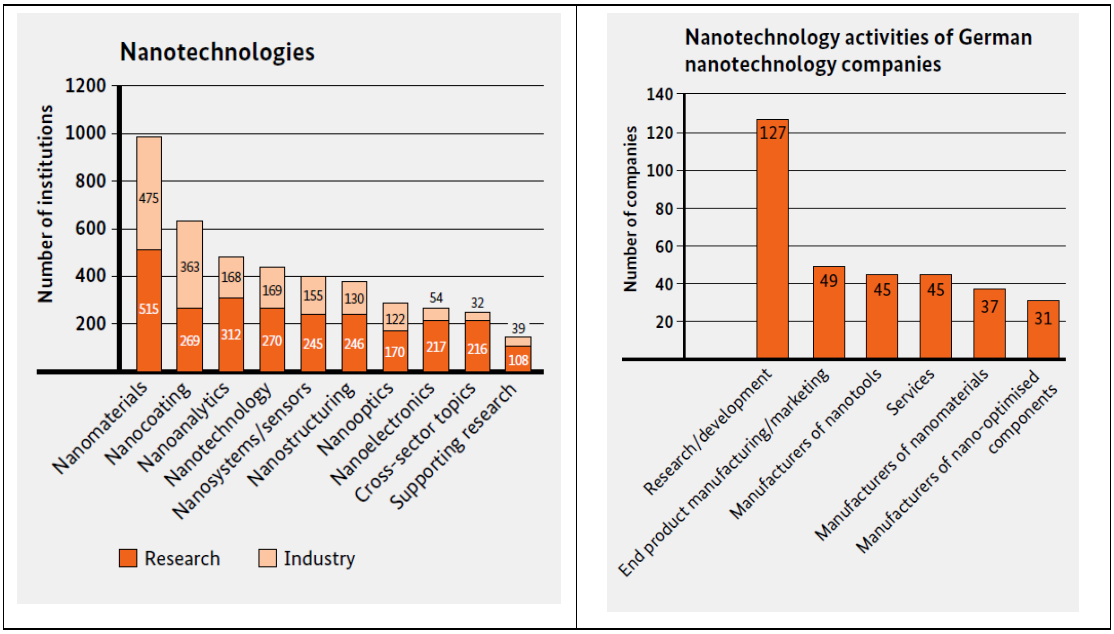
Ten highly promising products incorporating nanotechnology (2000-2010) with safety concerns of cosmetics, food, disinfectants ... are [Roco 2012]:

- Catalysts
- Transistors and memory devices
- Structural applications (coatings, hard materials, chemical-mechanical planarization – CMP)
- Biomedical applications (detection, implants, ...)
- Treating cancer and chronic diseases
- Energy storage (batteries), conversion and utilization
- Water filtration
- Video displays
- Optical lithography and other nanopatterning methods
- Environmental applications.

The global situation of nanotech of 2002 (Figure 2) and issues of R&D, financing and proportions of the roles of startups versus industry participants in the fields' further developments (Table 1, Table 2, Table 4) can be illustrated by the situation in Germany in September 2013 (based on almost 2,300 institutions; Figure 10) using a report of the BMBF [2013].

The below Figure 10 shows in the upper left cell assignments to nanotechnology sub-areas of almost 2,300 German nanotechnology institutions from the research sectors (networks, research institutes, university research) and industry (SMEs and large companies). Institutions may be assigned to more than one sub-area.

The corporate landscape in nanotechnology in Germany is diverse both in terms of structure and areas of interest and covers every sector of the value system. Based on a random sampling of the 173 companies in the upper right cell Figure 10 shows classification according to their position in the value system of the nanotechnology activities of German nanotechnology companies (multiple classification is possible).



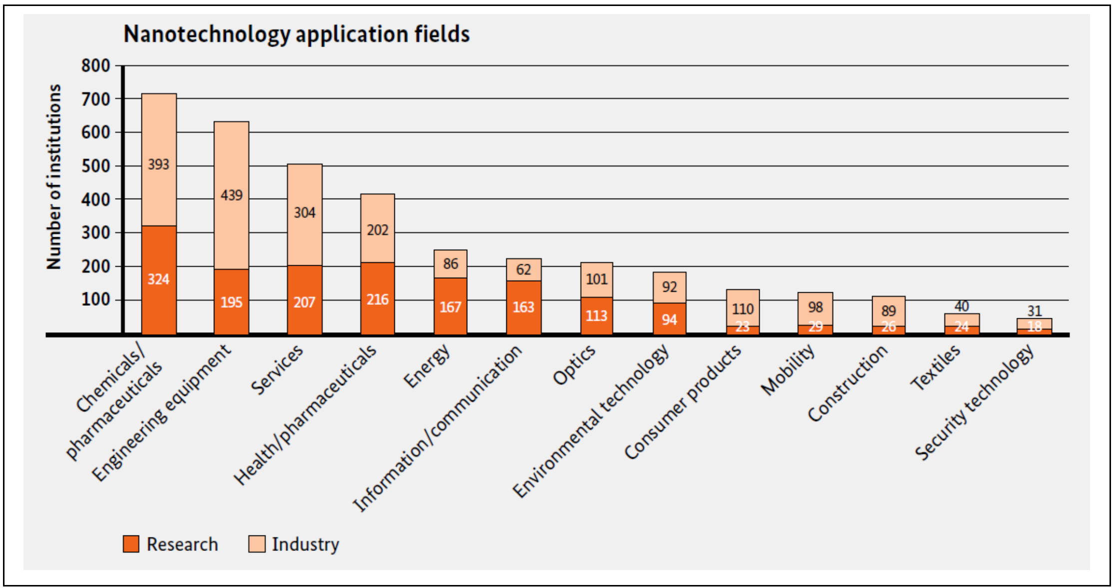


Figure 10: Characteristics of the nanotechnology area in Germany by 2013 [BMBF 2014a].

In the bottom row Figure 10 shows attribution to nanotechnology application fields of German nanotechnology institutions from the research sectors (networks, research institutes, university research) and industry (SMEs and large companies).

Considering all there is plenty of room for niches to be occupied by entrepreneurs.

Awards and Publicity

NANO-X is a highly awarded company in rather diverse fields – *often together with its cooperation partner*. A summary of awards is given by Sepeur [2012]. More details are given in the text.

Already in 2003 the firm HJS won the German Environmental Award (Deutscher Umweltpreis) of the "Deutsche Bundesstiftung Umwelt (DBU) for the development of the Diesel particulate filter based on sintered metal – the sintered metal filter (SMF®) – provided by the former President of Germany Johannes Rau [HJS 2003].

	**2003** Deutscher Umweltpreis 2003 [Sepeur 2009] High-temperature protection for sintered metal
 warema	**2003** Innovationspreis Selbstreinigende Raffstorelamellen [Sepeur 2003] Innovation Award for Venetian blinds and roller shutters

  The EAFA Trophy	**2005** Winner of the EAFA Alufoil Trophy 2005 [Groß 2008; Sepeur 2009] – Figure 21 (cf. also [Innovations-Report 2004])
In 2006 NANO-X wins the Steel Innovation Award in the category "Steel in Research and Development" (“Stahl-Innovationspreis in der Kategorie „Stahl in Forschung und Entwicklung") [NANO-X]. Scaling Protection of 22MnB5 Steel [Sepeur 2006a] Anti-scaling [Sepeur 2009]	**2006** Stahl-Innovationspreis 2006 Preis im Bereich Forschung und Entwicklung: Verzunderungsschutz (anti-scaling) (Verzunderung: Hochtemperaturoxidation – Scaling: High temperature oxidation) (Figure 14)
 Empower Deutschland-Preis Kategorie Innovativstes mittelständisches Unternehmen für NANO-X GmbH	**2007** Empower Deutschland-Preis (Empower Germany Award) Most innovative mid-size company of the Federal State of the Saarland Four firms were awarded; each won €10,000 [Saarland 2008]
Saarländischer Staatspreis für Design 2009	**2009** Staatspreis für Design (Award of the Saarland State for Design 2009) concerning multi-functional anti-fingerprint coating for stainless steel surfaces “x-clean AF” [Saarland 2009]
 reddot design award winner 2009	**2009** reddot design Award Winner (for Metten “Belpasso” product) Metten – Stein & Design is a German concrete block manufacturer

	2010 JEC Innovation Award for self-cleaning (JEC Group is a non-profit association promoting and developing the composites industry worldwide)
 	**2011** Kerona GmbH received the "German Raw Material Efficiency Award" ("Deutscher Rohstoffeffizienz Preis") for the zinc preserving approach to corrosion protection developed together with NANO-X [Kerona]. Kerona was also a nominee for the Umwelttechnikpreis Baden-Württemberg 2011 for corrosion protection by TITANID [Umwelttechnikportal]
NANO-X developed together with ElringKlinger AG a new technology, CleanCoat catalyst, for coating, helping to decrease the use of heavy and precious metals, such as platinum.	**2012** German Raw Material Efficiency Award ("Deutscher Rohstoffeffizienz Preis") for NANO-X and ElringKlinger AG [Deutsche Rohstoffagentur 2012; Anonymus 2012]

NANO-X even became a sort of poster-child for nanotechnology. According to Kittl [2009], in his book on a *presumed future of nanotechnology* in the *style of a science-fiction story* he envisioned to have joined NANO-X by the end of 2008 through a silent partnership of $100,000 (ca. €77,000) which was converted into a share of 20 percent when NANO-X was searching for an angel investor.[1] And Kiittl also pretended to have made the biggest profits with nanotechnology shares and nano-funds.

The Entrepreneurs

Dr. Stefan Sepeur (born 1969) passed his final examination (Abitur) at the Warndt Gymnasium Völklingen (Saarland, Germany) in 1988 [Warndt Gymnasium]. He studied chemistry at the University of the Saarland (1989-1994) and already during his studies he was engaged as a research assistant at the Institut für Neue Materialien gGmbH (INM gemeinnützige GmbH) (Institute of New Materials) in Saarbrücken [Wikipedia-3].

After his diploma thesis entitled ("Synthese von fluormodifizierten, partikelhaltigen anorganisch-organischen Nanokompositen" – Synthesis of fluorine-modified particle-containing inorganic-organic nanocomposites) he performed his doctoral thesis in the context of an industry cooperation: “Entwicklung von abriebfesten, wasser- und chemikalienbeständigen Beschichtungsmaterialien auf Basis des Sol-Gel-Prozesses für PMMA und verfahrenstechnische Anpassung der Systeme an einen Vakuumtiefziehprozess” (Development of abrasion-resistant, water and chemical resistant coating materials on the basis of the sol-gel process for PMMA and procedural adaptation of the systems to a vacuum deep drawing process) [Saarland].

Already while performing his doctoral theses Stefan Sepeur was promoted to Group Leader and later to Head of Materials and Process Development (Werkstoff- und Verfahrensentwicklung) of the INM. In this position, he was in charge of eighty employees (chemists, process engineers, electrical engineers, mechanical engineers, materials scientists, physicists, technicians, etc.) and oversaw development activities in many areas of nanotechnology (coatings, binders, functional surfaces). He also directed the adaptation and process development of coating technologies as part of his management function of the coating center NMO (New Materials for Surfaces). His promotion was completed in 2001 at the University of the Saarland.

In October 1999 he teamed up with the electrical engineer Reimund Krechan to found NANO-X GmbH [Saarland]. Before foundation Stefan Sepeur had also directed the Application Center at the INM Leibniz Institute [Kappler 2009].

Proximity to industry, patents, personnel management and financing were familiar to him. "We have used the expertise of the Institute to conduct own science and to develop products," said Stefan Sepeur [Leibniz Wissenschaftsgemeinschaft 2009].

Checking the DEPATISnet:database of the German Patent and Trademark Office (DPMA – Deutsches Patent- und Markenamt) provided eighteen patent families with Stefan Sepeur as a co-inventor and the Institut für Neue Materialien (INM) as the patent assignee (search string in expert mode: IN=((Sepeur(w)Stefan)) AND PA=((inst?(2w)neue(w)mat?))). In the database of the European Patent Office (EPO) seventeen patent families were listed.

On the other hand, concerning 1998 patent applications there are added three patents showing Stefan Sepeur as a co-inventor, but Bayer AG as the only patent assignee (Appendix: Table 20).

For the entrepreneurship case the *macro-environment* for founding NANO-X is outlined above. The *micro-environment* shall be described below.

The INM is one of 86 research institutes of the public Leibniz-Society financed by the German Federal Government and the federal states [Runge 2014:167-169]. In particular, owners of the INM gGmbH is the University of the Saarland (51 percent) and the Federal State of the Saarland (49 percent). There is a strong orientation towards cooperation with industry.

Chemical nanotechnology as a tool for synthesis and processing of nanomaterials is INM’s core competency associated with vertical interdisciplinarity. INM is one of Europe's leading advanced nanotechnology materials research institutes.

In Figure 11 the structure of the INM and its position in a competence center as a basis and hub for technology transfer and innovation is displayed.

According to its current Web site key characteristics of the INM are:

- Annual budget 2012: 19,000 T€ (T = thousand)
- Third party funds: 3.500 T€ (18 percent; Schubert [2006:5] reports ca. 40 percent)
- Industrial projects: over 400 (since foundation).

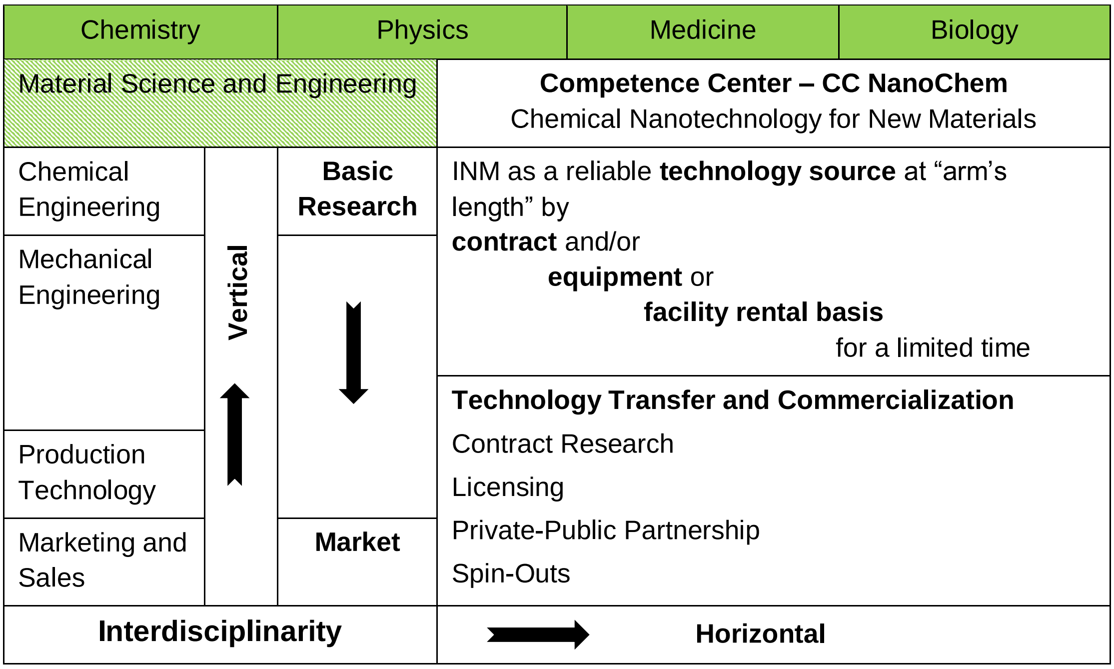


Figure 11: Interdisciplinarity of the INM as a basis for technology transfer and innovation [Schubert 2006].

In 1998/2000 there was an entrepreneurial climate at the INM with regard to nanotechnology researched at Saarbrücken University and implemented by INM's previous director Prof. K. Helmut Schmidt, who promoted spin-out formations. Between 1995 and 2003 there were eleven spin-outs, partially based on INM-licenses, for instance, Nanogate AG, inomat GmbH and sarastro GmbH [Kappler 2009].

Nanogate was founded in 1998 as a GmbH (LLC) utilizing some INM-licenses. The operative start of the spin-out was in 1999. And in 1998 sales were DM250,000 (€125,000) and jumped to DM1.5 million (€750,000) in 1999. The venture capital firm 3i identified Nanogate's potential early on, backing the 1998 spin-out from Saarbrücken University/INM.

Prof. Dr. Helmut Schmidt studied chemistry at the Technical University of Munich (TUM). After his diploma (1989) and doctoral (1973) theses he was a postdoc at the Free University of Berlin and der Northwestern University Evanston, Illinois/USA. From 1975 to 1990 he was engaged at the Fraunhofer-Institut für Silicatforschung (Fraunhofer Institute of Silicate Research, ISC) where he became Managing Director in 1981.

In 1990 he accepted a position as professor of materials science and director of the Institute of New Materials (INM) at Saarbrücken. His research interests included sol-gel techniques for glass, ceramics and nanocomposites and the synthesis of nanoparticles, coating techniques and microsystems technology. Prof. Schmidt is the author of numerous papers and holds over 100 patents [Schmidt 2001].

In the context of the INM environment education and experience of Stefan Sepeur can be summarized as follows.

- Long-term education of firms' founders out of the INM in chemical nanotechnology
- Application know-how in the fields of easy-to-clean, self-cleaning, corrosion protection, catalysis, scratch resistance, anti-fogging, tribology etc.
- Basic insights into patenting, leading personnel, project management etc.
- Experience in coatings technologies and setting up processing technology and facilities by management of a coating center.

Due to its previous high level position in INM one can assume that Stefan Sepeur is also experienced in writing project proposals for public (research) grants and that he also knows whom to address in public committees making grant approval decisions.

Dr. Sepeur likes very much selling. Early on he enjoyed selling, for instance, his old cars, and bargaining. Correspondingly, as a co-founder he keeps direct contacts with customers. And he has a very large number of network of contacts (customers and contacts of the research, industry and political environments; some 1,200 names are in a corresponding database) [Sepeur 2009].

After co-founding NANO-X Dr. Sepeur continued to keep his high level of scientific competence. In 2008 he together with Nora Laryea, Stefan Goedicke und Frank Groß co-authored the book "Nanotechnology" which actually deals with "Chemical Nanotechnology" [Sepeur et al. 2008]. Dr. Sepeur (co-)authored also more than one hundred publications in scientific journals, and articles in the trade, public and daily press [Anonymus 2009].

In 2008 Dr. Sepeur became a member of the Scientific Board of the INM and reviewer for the BMBF (Federal Ministry of Education and Research). Striving for a "Habilitation" [Runge:ii] at the University of the Saarland Stefan Sepeur would like to further spread the achieved knowledge and expand his scientific competence [NANO-X].

Currently Stefan Sepeur acts also as a welcomed expert for the German Federal Ministry of Education and Research whenever the future of nanotechnology is a concern [Leibniz Wissenschaftsgemeinschaft 2009].

According to the author's searches there is no information on Reimund Krechan (born 1968) publicly accessible except that he is an electrical engineer who worked in the INM [Jung 2001; Saarland] and that later as a co-founder and managing director of NANO-X he became the Head of Production and Technology (Produktion und Technik) of the startup [Kappler 2009].

Remarks Concerning Corporate Culture

Corporate culture in small organizations finds expression as the cooperation of interacting personalities and is determined by "potentiality" (What could be achieved by developing resources and removing constraints [Runge:61]).

Not only for foundation and the early years of its existence the development of NANO-X so far proceeded without external financings. The two co-founders clung to their conviction: The firm's development will be based on own financial resources and income from selling products.

Generally, the co-founders of NANO-X want to keep their independence, whether it is technology or finances. Corresponding statements are heard from co-founder Reimund Krechan: "Permanently, I have been addressed by venture capital firms, but so far I have rejected their offers," Krechan said. "Money makes only lazy" (in German "Das Geld macht nur bequem") [Jung 2001]. This means, further development of the firm will follow *organic growth* [Runge:681-683] based on own financial resources and income from selling products.

There was rather early a relatively broad range of people with diverse educational backgrounds working for NANO-X: chemistry, electrical and mechanical engineering and machine construction, chemical and process engineering, administration, marketing and sales [Sepeur 2003, Sepeur 2006b].

But NANO-X achieved relatively fast a stabilized corporate culture [Sepeur 2009] which probably was set up by hiring a number of former employees of the parent organization INM and, concerning the leadership team, people who became partners with ownership in the LLC/GmbH (cf. next sub-chapter).

As ca. 40 percent of the employees work in R&D [Anonymus 2009] NANO-X has essentially a *research culture* [Runge 2006:628-632], which in universities or public research institutes is different from an industrial research culture in established firms [Runge:183-184].

Leadership continuously communicates to employees about the company's situation. Leadership seems to follow participative management of the firm among all four (later five) owners ("Gesellschafter") through openly discussing issues and making decisions upon mutual agreement.

Employee development requires continuous learning and initiative (every employee knows what he/she has to do for the benefit of the firm). On their path to receive delegation, employees are early exposed to "external situations" contacting customers or cooperation partners. Generally it takes 1-2 years for new employees to behave and act according to the NANO-X corporate culture [Sepeur 2009].

Employees from production engineering, process engineering and quality assurance usually have customer contacts. The team of competent and top-level members of staff provides services ranging from innovation consultancy to the development and production of high-tech coating materials [Nano in Germany].

For economic success of the firm all employees share the success in terms of special financial awards (not just the project team that formally is associated with the success).

Business Idea, Opportunity, Foundation and Product Developments

Apart from the above described various chemical and processual possibilities and, hence, the tremendous field of variables the basis of commercializing chemical nanotechnology is illustrated by Dr. Sepeur of NANO-X as follows: "By varying the composition, shape, size or surface finish nanoparticles can be put into new forms as small building blocks. This provides completely new, previously unknown freedoms of material design." [NanoBioNet 2008]

Based on the broad scientific, technical and management experiences gained during his professional life in the INM, INM's entrepreneurial climate and the favorable conditions to exploit the envisioned opportunities of chemical nanotechnology, Dr. Sepeur's entrepreneurial mindset and probably also the example of Nanogate led to the foundation of NANO-X.

NANO-X was formally founded by Stefan Sepeur and Reimund Krechan based on only their own initial capital of DM50,000 (€25,000) on August 18, 1999 [NANO-X]. The startup was officially registered on October 13, 1999 as NANO-X Innovative Coating Service GmbH as a limited liability company (LLC – GmbH) in Völklingen (Saarland, address: Gewerbe-Technologie-Zentrum, Rathausstraße 75--79).

> "We have used the expertise of the Institute to conduct own science and to develop products," said Stefan Sepeur [Leibniz Wissenschaftsgemeinschaft 2009].
>
> The inception of the startup followed "sales through production, not development!" and "innovation as a basis for market (competitive) advantage and higher added value." [Sepeur 2003; Sepeur 2009]

It is not known (to the author) whether INM licenses were used for foundation of NANO-X; after all Dr. Sepeur appears as a co-inventor of ca. 18 INM patents.

The expected *innovative (nano)coating* materials based on chemical nanotechnology may have the following *properties* that counter-act shortcomings or defects of surfaces:

- Prevention of *surface defects* by, for instance, easy-to-clean, self-cleaning (Catalytic-Clean-Effect®), corrosion protection, abrasion protection, UV-protection and more

- Coated component parts *get an added value* by longer durability, larger areas of application, multi-functionality, less expenses for cleaning, higher security and
- Multi-functionality.

But also *innovative design effects* for nanocoatings were envisioned.

Spin-outs' development in terms of hiring new employees rely often, at least for the second level leadership personnel, on employees of the parent organization. And one can assume that related people were well known to the founders. This is also observed for NANO-X. During the first three years the leadership team of NANO-X was established in this way.

Frank Groß and Nora Laryea joined NANO-X in 2000 [Sepeur et al. 2008]. Both became also partners (shareholders) of NANO-X in 2000 so that the ownership structure of the GmbH (LLC) was [Sepeur 2006a]:

- Dr. Stefan Sepeur (52 percent)
- Reimund Krechan (35 percent)
- Dr. Frank Groß (8 percent)
- Dr. Nora Laryea (5 percent).

Dr. Groß studied chemistry at the Saarland University to achieve a diploma degree (dealing with low-friction sol-gel coatings for polymers) and a doctoral degree (Dr. Ing.; in the field of special glass for optical waveguide amplifiers) at the INM. From 1998 till 1999 he was in charge of an R&D group in the department of Dr. Sepeur at INM.

Since 2000 Dr, Groß has been with NANO-X where he was responsible as Department Leader for developing the business of *easy-to-clean, catalytic and self-cleaning coatings* for industrial applications [Sepeur et al. 2008].

Dr. Nora Laryea (studied chemistry at the Martin Luther University in Halle/Merseburg (1900-1995). After graduating she became a scientist at the Institute of New Materials (INM) in Saarbrücken from 1996-2000. In 2001 she received a PhD at the University of Saarland. Since 2000 Dr. Laryea has been an employee and shareholder of NANO-X GmbH [Sepeur et al. 2008] (also using European Coatings Journal 10/2007 as a source).

She received the doctoral degree dealing with development of flexible hard coating based on inorganic-organic nano-composites. Between 1998 and 2000 she was group leader in INM for the development of radiation curing nanocoatings and since 2000 was NANO-X Department Leader for *hard coatings, textile impregnation and binders* as well as responsible for quality assurance.

Dr. Stefan Goedicke, later a co-author of the nanotechnology book [Sepeur et al. 2008], studied chemistry at the Saarland University from 1989 to 1995 and completed a semester abroad at the University of Surrey (Guildford, UK). After his graduation he did his doctoral thesis at the INM. In industrially sponsored projects he was engaged with the development of inorganic binders based on sol-gel and chemical nanotechnology for fire protection, high-temperature resistant coatings, heat insulation and modification of dental fillers. Since 2001 he is in charge of an R&D Department of NANO-X and dealt with the development of *coatings for corrosion protection and high-temperature corrosion detection* as well as *special applications* [Sepeur et al. 2008].

Though the focus is on R&D and production, the ultimate goal of NANO-X is production of the developed materials and generating related patents to protect the technology.

In 1999 overall NANO-X had five employees [NANO-X]. And it developed its way to the market by stringent *customer-orientation* following a "*customer as the innovator*" approach (Figure 12) which is also applied by nanotools startups in the scanning probe microscopy (SPM) area [Runge 2014a; 2014b; 2014c].

NANO-X started 1999 alone in a hall of the World Cultural Heritage "Völklinger Hütte" (Völklingen hut, for coal mining). An old shower room served as a laboratory, the first laboratory line was a second hand kitchen line. There was an old computer and the first company car was an old Ford "Probe" sports coupé. This car was used to transport a complete range of roof tiles over a distance of 500 km.

The first project targeting "Easy-to-Clean" started with the firm Metten – Stein & Design, a German concrete block manufacturer (in North Rhine-Westphalia). Revenue in 1999 was DM100,000 (€50,000) [NANO-X; Sepeur 2009].

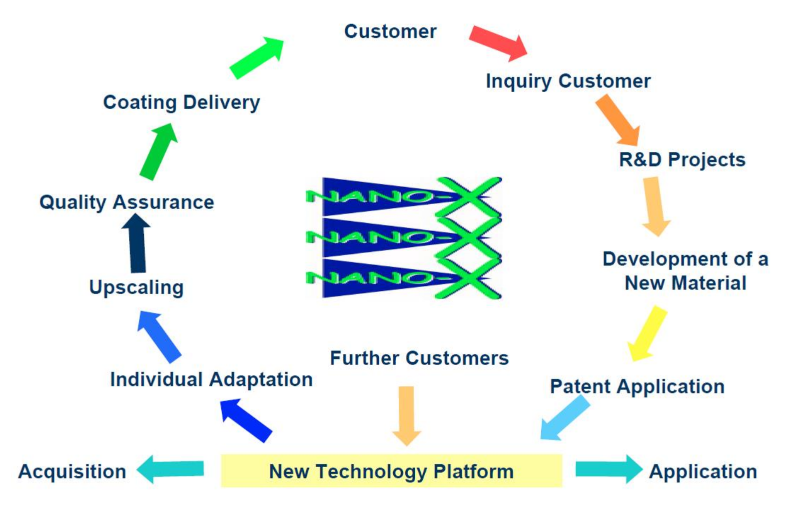


Figure 12: The way to the market and innovation [Sepeur 2006a].

A need of the customer induces a common R&D project which, via a new platform technology, may lead to either a customized product or a standard product as a new offering. A key aspect here is that the technology will be protected by patents.

Industry-oriented development and implementation was done by selecting competent key customers (market or technology leaders). And there was learning of market-specific requirements or working these out cooperatively [Sepeur 2003; Sepeur 2009].

> "Depending on our customers we work our way into totally new subject areas." [Anonymus 2009].

In year 2000 in Germany [NANO-X; Sepeur 2009] much interest in nanotechnology emerged generally with R&D departments of various organizations. The startup was busy. Concerning technology NANO-X applied for patents and revenue was gained via R&D projects (more than DM1 million – €500,000 – with eight employees). And NANO-X relocated to nearby Überherrn into an old dilapidated chemistry-related hall.

To *get attention* NANO-X participated in the Hannover (Industry) Fair and got an article in the newspaper BILD which is a German mass medium with a very high circulation [Sepeur 2009].

Production started and out of the spectrum of functionalities (Figure 13) the first tons of products were distributed. The products' emphases were on Easy-to-Clean (for the firms Metten – Design & Stein as well as both tableware and facilities producer Villeroy & Boche) for concrete block coating and Lotus-Effect® (Erlus AG [Runge 2006:237-238]) for coating/sealing of roof tiles (clay roof tiles). These were distributed via trucks in more than 20 IBC-containers (Intermediate Bulk Container for transport and storage of liquid substances, 950 liter).

Together with specialists from different industrial segments the NANO-X team initiated a "*Cooperation-X*" of various new nanotech ventures, such as nanomedx (Homburg, Saar, later sarastro GmbH), inomat GmbH (Blieskastel, later Bexbach), Genthe-X-Coatings (GXC, Goslar), x-coat (Freudenstadt), and n-tec (Regensburg) [Phänomen Farbe 2001]. Genthe-X-Coatings belonged to the automotive supplier Genthe Glas AG, which became insolvent as a result of the Great Recession in 2009. But Genthe-X-Coatings GmbH survived as GXC Coatings GmbH. It provides toll coating services and contract research dealing with functional (nano)coatings for markets such as automotive, safety/protection, and sensors/display.

NANO-X gave up very soon most of these participations; it kept inomat and GXC. Later, in 2005, Kyowa Hakko Chemical Co. Ltd. (Tokyo Japan) also became a cooperation partner in the sense of Cooperation-X and it was envisioned this partner to become a hub for operations in Asia [NANO-X].

The *venture cluster* around Saarbrücken and the INM did not consist of only INM spin-outs, but also established firms showed up here, such as Bühler PARTEC GmbH, the Business Unit Nanotechnology of Bühler AG located in the Science Park 2 of Saarbrücken. The AG is a Swiss company operating as a holding, Bühler Group, in over 140 countries with 10,600 employees and revenues of CHF2.3 billion in fiscal 2014.

The company traditionally makes industrial grinders, mills, extruders and related equipment used in a range of industries, including the chemical processing industry, to formulate resistant coatings. But it set up a commercial partnership with the INM to move into nanotechnology hoping thus to *move up the value system* (supply chain) and to improve the margins on its sales. Hence, nanotechnology was seen as a means of rekindling growth in the company [SwissInfo.ch 2002].

With 20 employees in 2007 it offered its tailored nanoparticle formulations (Buhler-Tailored Nanobatch: Development and production of customized nanoparticle dispersions)) and tailored converting processes for nanoparticle formulations (Buhler Tailored Nanoprocess: Development and launch of a customized nanoparticle dispersion production process). Those formulations may be both in the form of liquid dispersions or solid masterbatches [Saarland 2007c].

The key technology of Buhler PARTEC GmbH is the chemical surface modification of nanoparticles using the SMSM technology (Small Molecule Surface Modification) in connection with a dispersion device, such as agitator bead mills, mixers, twin screw extruders and the like. In 2015 Nanopool GmbH acquired the nanotech division of the Swiss company Bühler AG [Runge 2010].

In 2001 [Sepeur 2003; Sepeur 2009] interest in the new coating materials came from many areas of industry, such as the automotive, construction, food or cleaning industry. As a response to demand NANO-X relocated again into an own building in Saarbrücken (borough Güdingen). This facility of the former chemistry venture Krämer Chemie was seen to provide optimal conditions for further expansion.

That around 2000 “the climate for nanotech in Germany is very strong” was noted von Bubnoff [2007].

Requirements for tailored products became more and more complex so that new laboratories had to be built and many (cooperative) product developments started. The number of employees doubled to sixteen and *grants for research projects* contributed by fifty percent to operations of NANO-X [Hotfrog].

In 2002 in the sense of “continuous improvement” or innovative design-effects, respectively, a new designed product for concrete block surfaces entered the market. Fast-Food giant McDonald’s defined the colored paving stones with the NANO-X Clean Top surface as the new standard for the floors of their branches (in Germany).

New products entered the market, particularly hydrophilic layers for headlights and anti-fingerprint coatings for stainless steel sanitary components. The emphasis was on corrosion protection and coating systems for the consumer market. The number of employees increased to more than twenty and the scope of functionalities addressed by NANO-X increased as given in Figure 13.

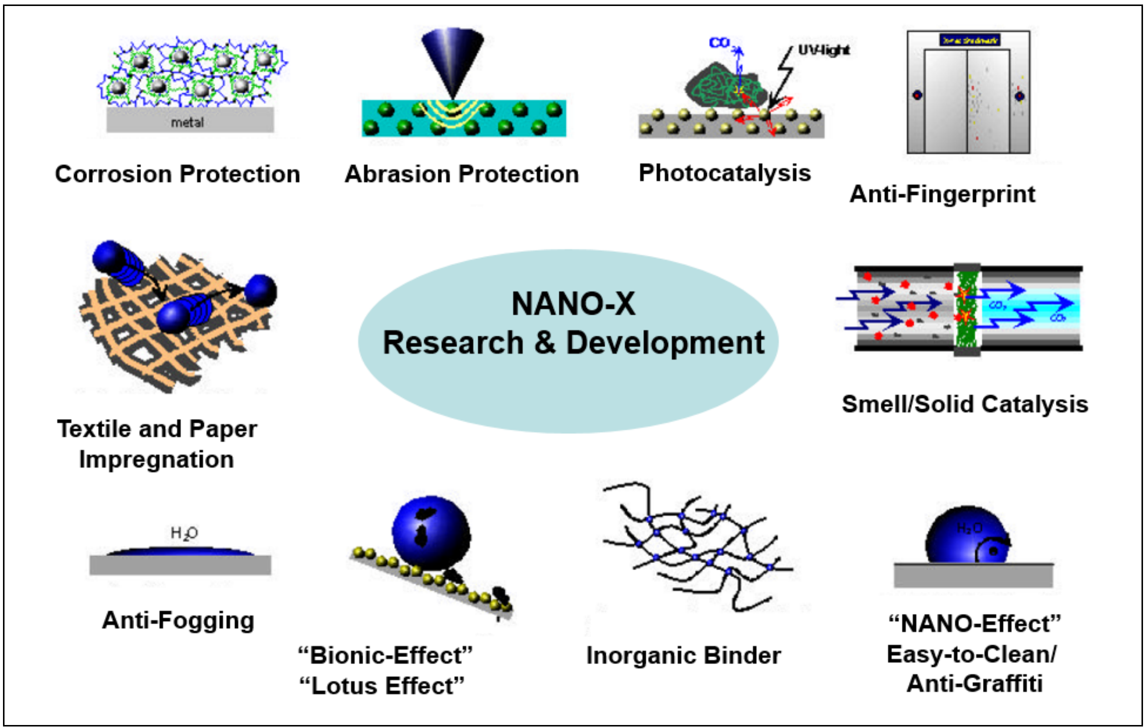


Figure 13: Functionalities pursued by NANO-X for products requested by industry [Sepeur 2003].

In 2003 almost 100 tons of coating materials were produced. For instance, the company Cofresco Frischhalteprodukte (GmbH & Co. KG), Europe’s leading brand manufacturer of home solutions for the fresh keeping and storage of food as well as household waste disposal offering powerful brands, launched Melitta’s “Toppits® Fix-Brat Alu” with NANO-X coating in the market (Figure 21).

With black coating of Toppits (x-coat® black) active uptake and rapid transport of the oven’s heat to fried food frying/cooking time is shorted compared with common aluminum foil which means energy saving.

And NANO-X grasped an order by Volkswagen (VW) for door rails with tribological surfaces. The number of employees was twenty-five [NANO-X].

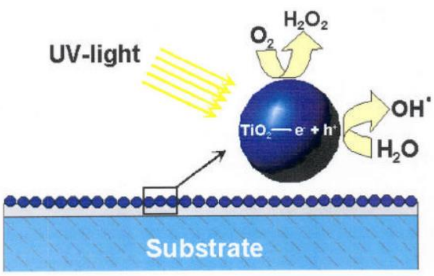
For development new paths were followed. The emphasis was on industrial customers. For *technical textiles* NANO-X delivered an impregnating material by barrels to the US. The consumer market was served via a cooperation with the new venture Nan4You GmbH (Bexbach, founded 2000) focused on market-driven development and commercialization of multi-functional materials and special materials based on chemical nanotechnology, particularly inorganic-organic nanocomposites.

Responses to customers’ requirements let emerge *product lines* with standard rather than customized features, such as [Sepeur 2003:8]:

- x-clean® (EC, PK, AF) – Easy-to-Clean, Lotus-Effect® (self-cleaning), photocatalysis (“Photokatalyse”) and anti-fingerprinting
- x-view® (PK) – anti-fogging
- x-tec® (CO) – corrosion protection.

For instance, anti-fogging (and also anti-bacterial) features can be based on photocatalysis, but is effective only in combination with UV-radiation, moisture and oxygen. It can be incorporated into the x-clean® line. It should be noted, however, that photocatalytic anti-fogging competes as a technique with the Lotus-Effect® [Sepeur 2003:17].

Each product line is characterized by specific advantages for application due to the physical properties of the coated surfaces.

Photocatalysis: • Nanoparticles containing, for instance, titanium dioxide, absorb UV-light [Kisch 2015], • Decompose water (H_2O) to generate OH● radicals and • Combine with oxygen from air to hydrogen peroxide (H_2O_2)	
Using x-clean® (PK) [Sepeur 2003]: The German WAREMA Renkhoff SE Group (presenting itself as TheSunlightManager, DerSonnenlichtManager) produces, for instance, sun shading systems for the home, external Venetian blinds and roller shutters.	 warema
FRANKE The German firm Franke Aquarotter GmbH furnishes sanitary rooms and its XINOX® nanocoated product line focuses on cleaning and avoiding fingerprints using **x-clean® (AF)** [Sepeur 2003].	   

By the end of 2003 the facilities of NANO-X comprised [Sepeur 2003]:

- A modern research lab with twelve workplaces
- Production facilities and a chemical storage with a capacity of producing more than 1,000 tons per year
- Application and hardening facilities for all common processes
- Testing workshops and systems.

In 2004 growth of NANO-X continued: production capacity had to be increased and the number of employees increased to thirty. Sales rose to €2.5 million and the firm was *profitable* [NANO-X].

There were further activities in the US market and scouting in Mexico, Japan and Korea. In Japan and Korea project partner were found [Sepeur 2009]. International fairs and exhibitions were attended. American Standard (Heating, Bathroom, Kitchen and Sanitary Brands) started to utilize Easy-to-Clean and anti-scaling nanocoating for all its products under the “EverClean” mark.

There was a direction towards nanocoatings for the automotive industry. And for the US firm Fresnel Optics NANO-X produced spin-coating capable scratch-resistant lacquers for displays in the interior of cars.

The order to coat several body parts of the (new) VW Passat model made NANO-X expand its company site. Adjacent buildings were bought and a new production hall and several offices were installed.

> With the end of 2004 NANO-X had not only survived the first three to four critical years of a new technical venture (the “startup thrust phase” [Runge:319,589,642,679]) but had also survived the Dot-Com Recession (2000/2001) and was on a track for further (organic) growth.

In 2005 the number of employees increased to forty and revenue reached €5 million. Activities were rather diverse [NANO-X]:

- Series production for Volkswagen (VW) started binding many capacities. Simultaneously NANO-X set up a company’s unit for application technology and quality assurance (QS – Qualitätssicherung) was integrated.
- A cooperation with the Japanese firm Kyowa Hakko Chemicals provided a necessary infrastructure to supply to the Asian region.
- The automotive markets signals more and more attention.
- Two BMBF-projects in the field of textile materials and photocatalytic effects were granted.
- Preparations were initiated concerning the expected REACH (Registration, Evaluation, Authorization and Restriction of Chemical Substances) *legislation* in the EU to become effective on Dec. 30, 2006.

Furthermore, as an offering NANO-X also provided nano-scale additives for conventional lacquers and paints to increase scratch resistance, UV stability or for adding self-cleaning features [VDI 2005]. It, hence, appeared in this regard as a supplier of “intermediates” for the paint and coatings industry.

In 2004/2005 the new production process at VW involved a coating based on nanotechnology to turn off the *scaling* during cold and hot forming (“Warmumformhärten” – hot forming curing/hot in-mold hardening at 950°C) [Goedicke 2005].

For structural body parts and safety parts of VW cars materials are used with highest strength. In particular for certain types of vehicles Volkswagen was producing more than ten components of manganese-boron steel (22MnB5). With this type of steel a strength of up to 1,650 MPa can be achieved by hot forming. Here heating up to 950°C in a nitrogen atmosphere occurs. In the conventional cold forming only values of up to 1,100 MPa were achieved. Apart from stability less weight by high strength at lower sheet thickness could be achieved.

A problem with this process was scaling (high-temperature oxidation) of the components that occurs when the heated component with 950 °C comes into contact with atmospheric oxygen. The parts have to be cleaned after each forming. Therefore righteous production volumes could not be achieved with it [Goedicke 2005].

There was a number of procedures that protect steel from scaling during hot forming. However, many components are so complex that the necessary degree of deformation can be achieved only in a two-step process, namely by cold forming followed by hot forming.

Previously, there was no protective layer which is suitable for both cold and for hot forging and could effectively protect steel against scaling. The contribution to resolve this problem brought about a breakthrough for NANO-X and visibility in the automotive industry.

The solution: The product x-tec® CO 4017 prevents scaling [Goedicke 2005]. NANO-X developed with the Department of Metal Forming Technology, University of Kassel, Volkswagen AG, ThyssenKrupp Stahl AG and DOC (Dortmunder Oberflächencentrum GmbH – Surface Center

GmbH) also belonging to the ThyssenKrupp Group a novel coating material which during the cure molding protects against scaling as outlined in Figure 14.

In the latest stage of development the protective coating exhibits additionally tribological properties in order to easily enable cold and hot forming. The paint was adapted to the requirements of coil coating that can be applied directly to the steel coil. This was happening at steel manufacturer ThyssenKrupp; NANO-X produced the paint. The coated steel coils were used in the Volkswagen Kassel site for a cold and hot forming in a series [Goedicke 2005]. In 2009 ca. 3,000 cars per day took advantage from the new treatment to suppress scaling [Anonymus 2009].

The steelmaker is actually the main customer of the NANO-X product. ThyssenKrupp delivers the coils (large steel coils) coated with the NANO-X product which prevent the formation of scale on the sheets to VW.

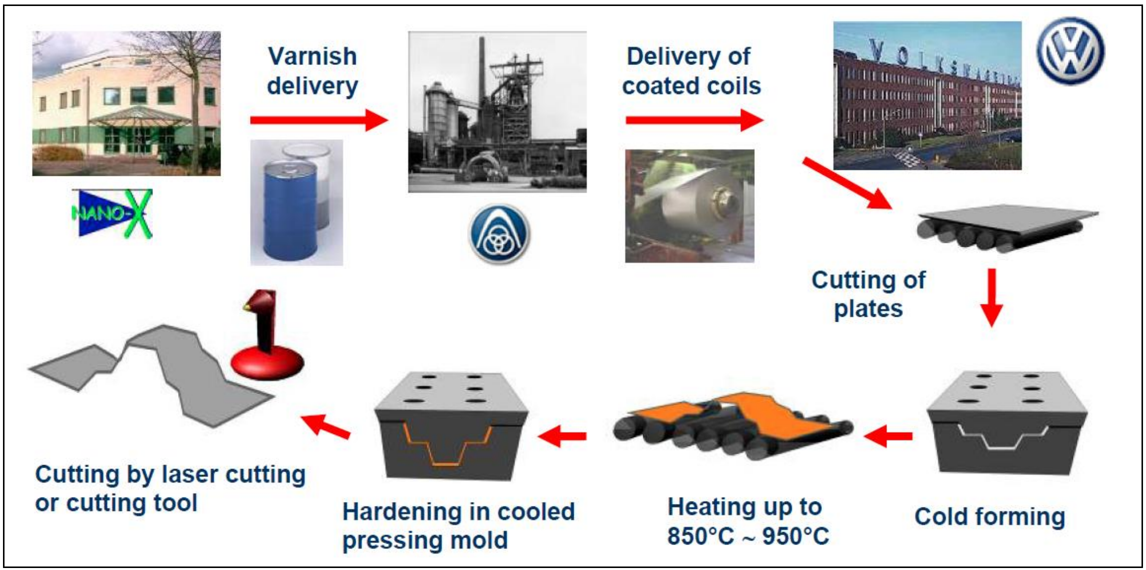


Figure 14: A NANO-X anti-scaling product (x-tec® CO 4017) introduced for a new process at VW for structural body parts and safety parts of VW cars [Sepeur 2006a].

The abstract representation following the “cooperative innovation cycle” of NANO-X in Figure 12 is filled with related players and activities in Figure 15 to characterize the “anti-scaling cooperative” innovation. Here also TKS Unternehmensberatung und Industrieplanung GmbH, a consulting and industry (project) planning firm, was included.

In 2006 this success was rewarded: NANO-X won the Steel Innovation Award in the category "Steel in Research and Development" (“Stahl-Innovationspreis in der Kategorie „Stahl in Forschung und Entwicklung") [NANO-X].

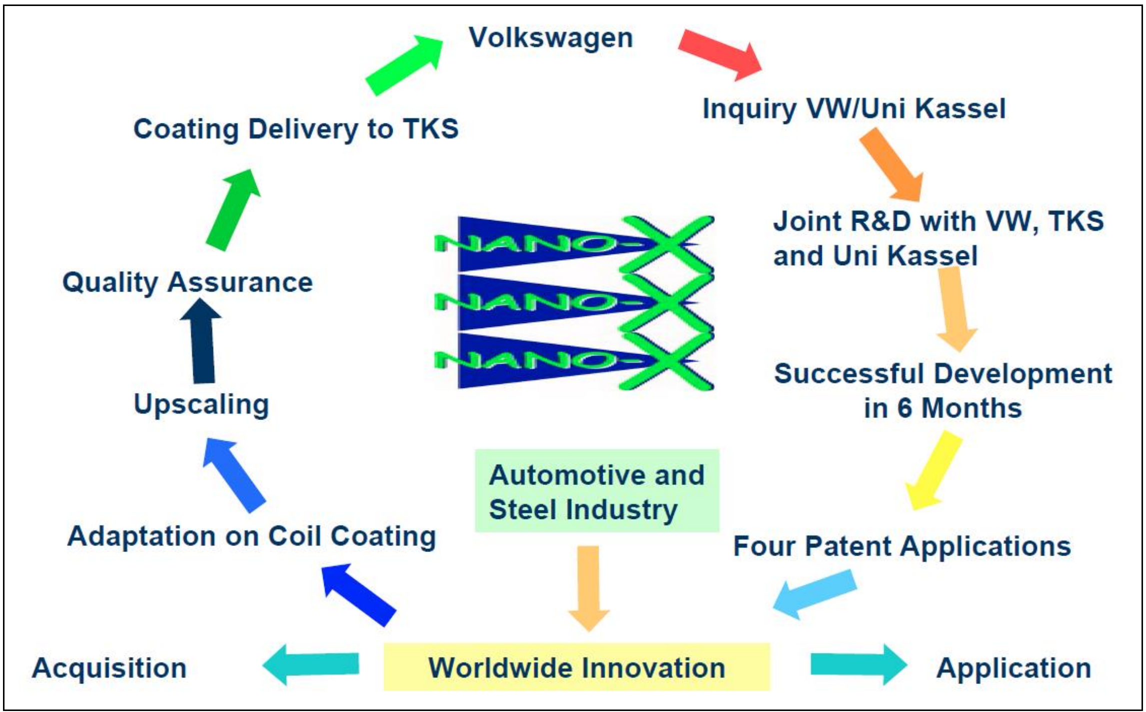


Figure 15: The way to market of NANO-X through participation in a cooperative innovation project in the automotive and steel industry [Sepeur 2006a].

Apart from x-tec® CO 4017 providing scaling protection with tribological properties Table 12 lists some further products which were developed in the x-tec® CO series.

Table 12: Selected products of the corrosion protection x-tec® CO and x-clean® AF lines [Sepeur 2006b].

Product Line	Application and Features
x-tec® CO 4004	As a primer for powder coatings: adhesion directly on the degreased aluminum, recoatable; free from chromate, replacement for chromating or phosphating of aluminum
x-tec® CO 4016	As a primer: water-based, transparent coating solution, spray or dip application, directly on the degreased steel, free from chromate
x-clean® AF 4037	Anti-fingerprint and corrosion protection for stainless steel or matt chromium (protection against oxidation by fingerprints), easy to clean, UV-resistant, used internally and externally

On behalf of Ideal Standard GmbH and American Standard Companies, Inc. NANO-X GmbH developed the EverClean™ coating for chrome surfaces based on nanotechnology, the patented system x-clean® AF 4032 [Innovations-Report 2006].

Anti-fogging (AF) is an issue of the hydrophilic properties of a surface. Generally, the hydrophilic – hydrophobic dichotomy reflects a relation between the free surface energy σ_S and the contact angle Θ (of water) in terms of the Young equation. This is exemplified together with the name creation of NANO-X product lines in Figure 16.

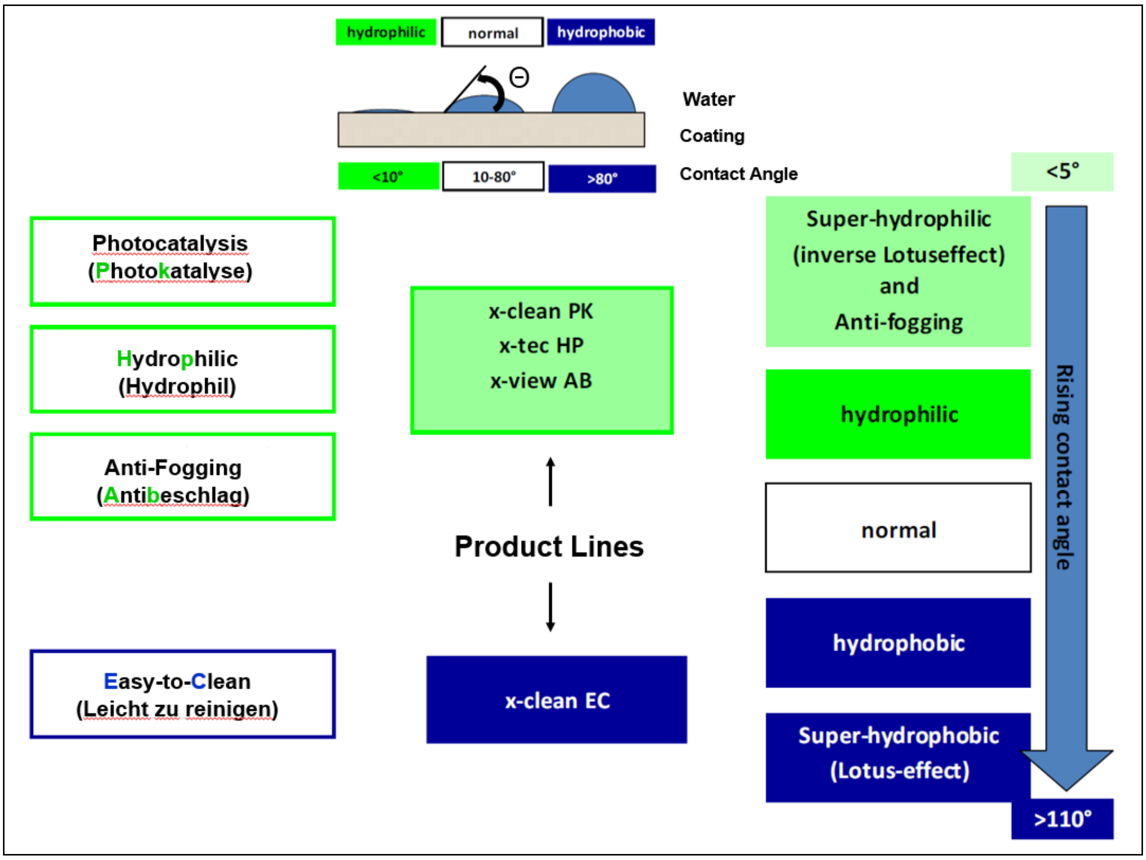


Figure 16: Characterization of surfaces concerning their hydrophil/hydrophonic properties and their relations to NANO-X product lines [Goedicke 2011].

The year 2006 activities involved a lot of developments and production of materials in the automotive industry and R&D projects with the automotive industry and demand for anti-scaling also from the steel industry. The NANO-X portfolio included more than 50 products for a large variety of applications.

Notably there were activities with x-tec® CA materials, for instance the CA 4000 series, which means coating with *catalytical* nanoparticles in an inert inorganic matrix and providing high chemical and thermo-corrosion resistance applied to filters and catalysts.

The German firm HJS Emission Technology GmbH & Co. KG, a specialist for exhaust after-treatment, started to work with related products on soot filters in Diesel exhaust gas systems for passenger cars, busses, trucks and machineries as well as soot regeneration on Diesel particulate filters in combination with excellent low back pressure performance [Sepeur 2006a; Sepeur 2006b]. And in 2006 HJS started series production of a retrofit catalyst for soot catalysis in Diesel engines [NANO-X].

For the automotive industry NANO-X provided tribological coatings and nanostructured hydrophilic surface coating (x-view® AB Materials – no fogging) [Sepeur 2006a, Sepeur 2006b]:

- Series for Volvo glass head lamps since June 2001
- On polycarbonate plastics since the end of 2003 (VW Phaeton)
- Impregnation on industrial fabrics/textiles (textiles in automotive).

Moreover, there was protection of plastic (scratch resistant coatings also polycarbonate foil; for instance, by x-protect® KR 3611, for Fresnel Optics, Inc. in the US) [Sepeur 2006b].

In 2006 NANO-X [NANO-X] discovered a technological gap and started to develop a new class of binders for coatings, the SiliXane® products, for high performance industrial coatings (Figure

24) [Sepeur 2009; Groß 2010]. And it opened itself to manufacturers of coating systems and offered for the first time a raw material and binder concept.

As a partner for distribution and sales of SiliXanes NANO-X worked with the firm Worlée Chemie GmbH (Hamburg), a raw materials and formulations supplier for diverse coatings – a globally operating and cooperating company offering among other products additives and binders and colors/pigments for the color and varnish industry (in 2012 revenue of €115 million with ca. 250 employees).

In 2007 the Federal State of the Saarland held the Empower Congress during which NANO-X was awarded as the most innovative enterprise of the Saarland.

During 2007 the emphasis was on large projects (see below sub-chapter). Basic research focused on developing new catalytic x-tec® CA materials showing that catalysis of soot without heavy metals is possible (x-glas® Technology). Also new models for scaling protection emerged.

Furthermore, the results of several small projects were implemented, such as coatings for (original) stones, anti-fingerprint for stove aperture and coatings of headlights. Hydrophilic coatings with anti-bacterial effects of heat exchangers were used in space in the Columbus laboratory. NANO-X conquered outer space! [NANO-X].

In the “NANO scene” at the Hannover Fair 2007, NANO-X presented the so-called "crab-effect" (Figure 17). The crab-effect® gives coatings and impregnation solutions extreme dirt resistance and excellent durability additionally to antiseptic properties. Researchers of NANO-X modified natural substances that serve as ingredients in shells of crustaceans that no germs occur in such a way that a fixed connection of these substances on various surfaces is possible. At the same time the antiseptic function is preserved. The new additives can be applied in coating materials for kitchens, bathrooms, textiles, medical areas or to impregnate wood, stone or ceramics [ZPT 2007].

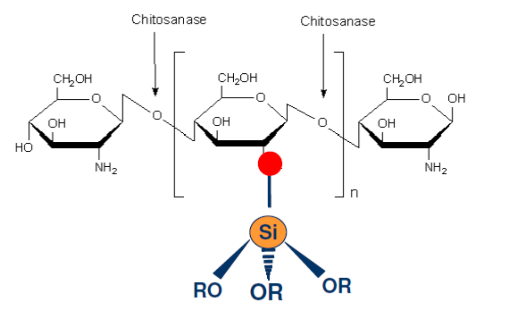


Figure 17: Linking the chitosan molecules to the organic matrix against viruses, bacteria, fungi and parasites.

In 2008 *internationalization* of NANO-X obtained more attention and efforts, particularly through support of the organization gwSaar Gesellschaft für Wirtschaftsförderung Saar mbH. gwSaar is an organization of the State Government of the Saarland targeting promotion and industrial development of the federal state (“Saarland Economic Promotion Cooperation”). NANO-X participated in fairs and exhibitions in Japan, Korea, the US, and South Africa. “Especially in the field of scale protection we meet worldwide interest.” [NANO-X]

The initiative “Saarland Empowering Nano” was set up by the Federal State Government of the Saarland to strengthen the position of the Saarland in the field of nanotechnology. “Saarland Empowering Nano” served as a common platform for promotions, actions, events, site advertising, location marketing and PR and was initiated essentially by the INM, NANO-X GmbH, sarastro GmbH, Nanogate AG and gwSaar, the latter leading this project. “Saarland Empowering Nano” should also improve the networking of Saarland nanotech companies [Saarland 2007a].

The Federal State Government of the Saarland is also active in financing startups, for instance, via the “Saarländische Wagnisfinanzierungsgesellschaft mbH” (SWG) which provides venture capital to preferentially technology ventures in the Saarland. In the context of an overall financing SWG may provide venture capital up to €1 million per firm.

Usually the SWG is involved as a silent partner. It cooperates with venture capital firms, angel investors and other partners. By close cooperation of the SWG with the Saarländische Investitionskreditbank AG (SIKB; Saarland Investment Bank) optimized financing concepts may be offered. NANO-X did not use SWG.

In order to resist the looming economic crisis NANO-X drove the commercialization of its products with all speed ahead [NANO-X]. However, making ca. fifty percent of its revenue with the automotive industry [Anonymus 2009; IHK 2009] did not bode well for the firm. When early in 2009 distribution of NANO-X products was about to be organized in Japan, the US and in China there were initial contacts [Anonymus 2009] the results of the recession emerged for NANO-X.

In development, NANO-X focused on coating materials, catalysts and new raw material concepts based on SiliXane® as binders (x-bond® product line for binders to formulate lacquers and coatings).

> In the following years further developments leading to marketable SiliXane® products led to important results for the further strategy of NANO-X.

At the end of 2008 the product lines and related brands of NANO-X (Figure 18) focused on properties and functions to improve coatings of a large variety of substrates and those reflecting a direction towards a paint company and raw material supplier of the paint and coatings industry (x-add®, x-bond® and x-coat®).

In 2008 Dr. Sepeur together with Nora Laryea, Stefan Goedicke und Frank Groß co-authored the book entitled “Nanotechnology”(“Nanotechnologie”), in English and German, which covers the state of the art regarding “Chemical Nanotechnology” [Sepeur et al. 2008].

At the end of 2008 transformations from niche and customized developments to serial production for the mass market could be achieved. Revenue reached almost €6 million [NANO-X].

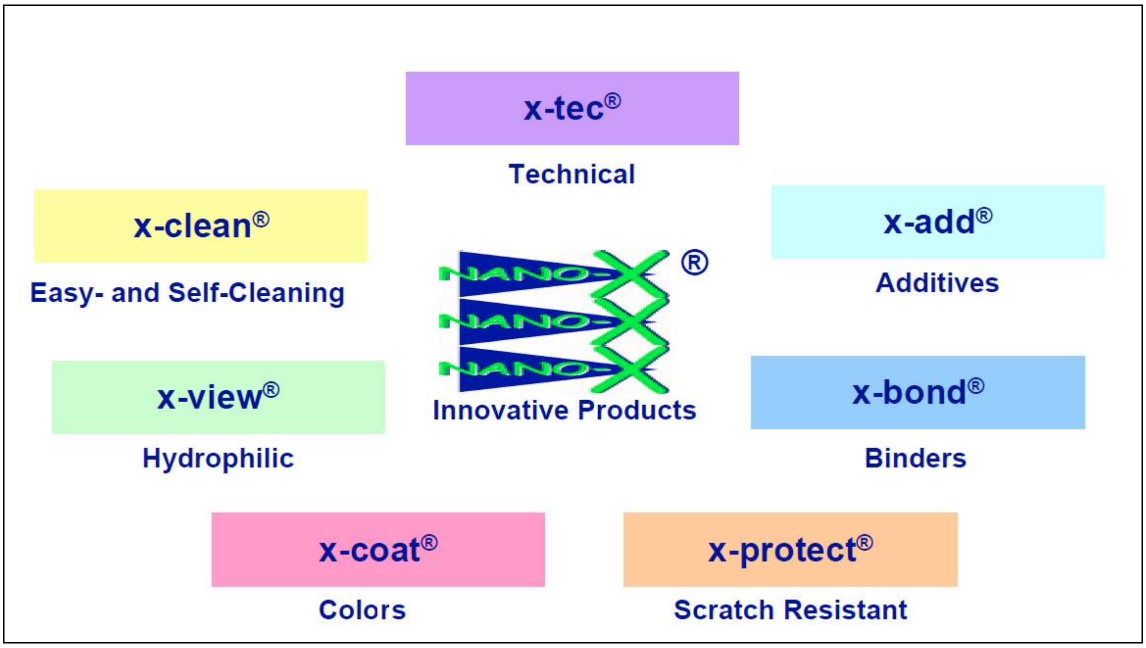


Figure 18: Product lines and brands of NANO-X® at the end of 2008 [Sepeur 2006a].

In 2008 NANO-X applied for a patent related to generation of energy. And in the medium term NANO-X planned to expand activities in the energy sector [NANO-X]. Furthermore, together with the German firm Felix Schoeller Jr. Foto- und Spezialpapiere GmbH & Co it set up a cooperation to develop paper-glass composites for insulations. The cooperation targeted combination of an insulation material which is compostable and water-resistant, but is lightweight and flexible, mechanically workable and not flammable. The solution was a waterborne glass-binder and pulp which is not flammable (x-form® Technology, Figure 19) [Sepeur 2009].

Also in 2008, through a collaboration with Professor Hempelmann, University of Saarbrücken, NANO-X developed nanoparticles which under irradiation with sunlight cleave water. Hydrogen gas bubbled and its generation remained stable! This result let NANO-X envision to expand in the medium term into the energy sector [NANO-X] meaning "CO2-neutral energy generation".

Research and technology orientation of NANO-X at the end of 2008, hence, is visualized in Figure 19.

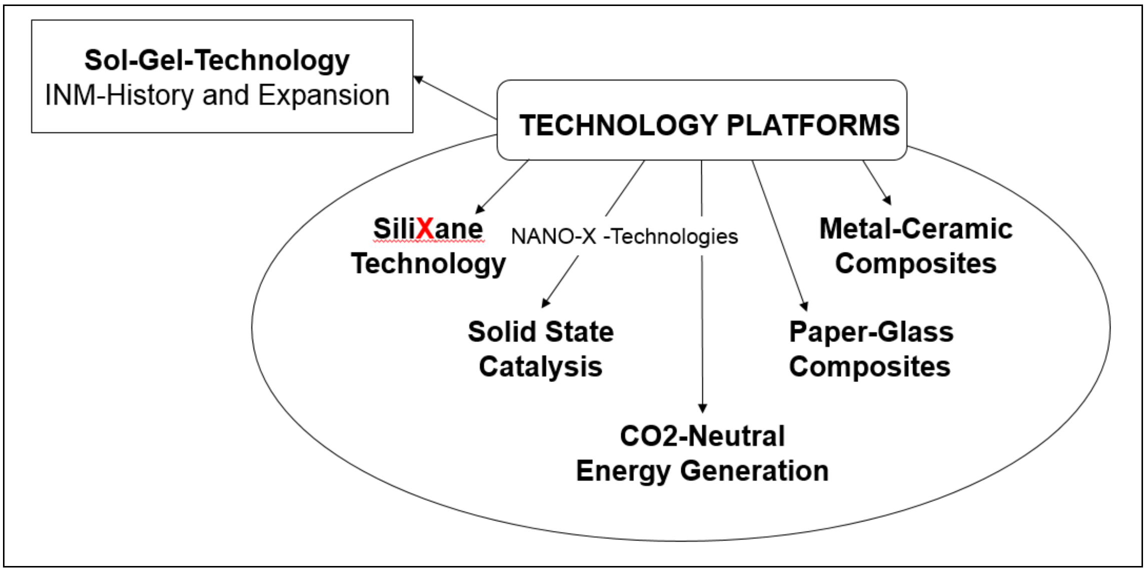


Figure 19: Research and technology strategy of NANO-X at the end of 2008.

Financing and Organization

Initial Financing

NANO-X GmbH was formally founded by Stefan Sepeur and Reimund Krechan based on only their own initial capital of DM50,000 (€25,000) on August 18, 1999 [NANO-X]. The firm's development was done without external capital. Generally, the co-founders of NANO-X wanted to keep their independence, whether it is technology or finances.

As described above very soon after foundation ownership of the limited liability company was extended to four partners, but keeping the majority ownership with Dr. Sepeur.

From the beginning development of NANO-X followed *organic growth* [Runge:681-683] based on *own financial resources*, essentially income from *selling products*. The profit generated was largely re-invested in new R&D projects or product developments (*investment and innovation persistence* [Runge:625,627,682]).

NANO-X had a national environment in which policy and national research associations funded R&D and entrepreneurship in nanotechnology tremendously. Correspondingly, due to his experience from INM and INM R&D projects funded by political and other public institutions and his focus on networking, Dr. Sepeur could utilize public funds and grants as an important basis of financing the startup's early development.

In 2000 when NANO-X had revenue of more than DM1 million (€500,000) with eight employees resulting from small and large production runs [Sepeur 2003] it could rely on publicly financed

R&D projects to contribute by approximately one half to the financial basis for its secure development [Hotfrog].

In 2008/2009 with five requested BMBF projects, of which four were promised in principle or granted, respectively, an EU project and many ongoing research collaborations, NANO-X could be convinced to have secured the base funding of its R&D research for the coming years [Hotfrog] – and also arranged to temper the effects of the Great Recession (December 2007 to June 2009).

"The fact that we are so widely placed and work on many research projects, has let us survive the crisis of 2009 without layoffs or short-time work," said authorized officer (in German Prokurist) Jörk Recktenwald [Anonymus 2011; NANO-X].

Fast early growth of NANO-X is reflected by changing the locations and increasing the site facilities:

- 1999: NANO-X Innovative Coating Service GmbH Völklingen 66333 (Gewerbe-Technologie-Zentrum, Rathausstraße 75--79).
- 2000: NANO-X Innovative Coating Service GmbH, Erzkaul (Industriegebiet Hasfeld 1, 66802 Überherrn)
- 2001 NANO-X, Theodor-Heuss-Straße 11A, 66130 Saarbrücken (borough Güdingen). This facility of the former chemistry venture Krämer Chemie was seen to provide optimal conditions for further expansion.

Public funds continued to provide contributions to the financial basis of NANO-X. For instance, in 2008 its revenue reached ca. €6 million, with publicly financed R&D projects contributing ca. €250,000 [Sepeur 2009]. The related statement (in German) indicates that funds from publicly financed R&D projects are treated as a stream of revenue.

Timelines of development of NANO-X in terms of revenue and number of employees is shown in Table 14. Financing and finances of NANO-X can be further illustrated looking into some details of the networking activities of the firm.

Organization

The research and production oriented organization of NANO-X is based matrix-like essentially on technology and products (*businesses*) and *functions* according to a common value chain.

This was reflected initially by the four partners of the GmbH (LLC) with two of them having joined NANO-X in 2000, one year after the foundation by Dr. Sepeur and Reimund Krechan and described above. In 2001 additionally Dr. Stefan Goedicke completed the quartet who later formed the leadership team.

Until 2005 NANO-X showed a tremendous growth in terms of revenues and numbers of employees (Table 14). For instance, the number of employees in 2003 were 25 and increased to more than 40 in 2005. According to the “10 – 25 – 150” rule of thumb [Runge:644,656] in a growing new firm a significantly increasing number of employees induces issues requiring reorganization in steps, essentially when the two ranges 8-12 or 20-30 employees are reached. Reorganization refers, for instance, to changes in leadership/management, specialization in terms of functions, and modes of communication, coordination and delegation.

In 2005 the lawyer Jörg Recktenwald joined NANO-X as a COO (Chief Operations Officer) and authorized officer (“Prokurist”) to then establishing the NANO-X management covering Dr. Sepeur, Reimund Krechan (Head of Production and Technology) and Jörg Recktenwald who also became an owner of NANO-X based on a “tiny” share.

According to the Firmenwissen database the shares of the now five owners were:

Dr. Stefan Sepeur	€12,750	51 percent
Reimund Krechan	€8,750	35 percent
Frank Groß	€2,000	8 percent
Nora Laryea	€1,250	5 percent
Jörg Recktenwald	€200	1 percent
SHARE CAPITAL	€24,950	

Parallel to the strong growth of the number of employees in NANO-X several different software programs and modules existed for operations in 2008. “We also had to contend with a high manual effort and numerous double entries," COO Recktenwald recalled. Financial accounting was outcontracted to a tax consultant. According to Recktenwald "We were looking for an integrated software that has all the key modules on board and can be flexibly adapted."

Ultimately, they implemented Microsoft’s enterprise resource planning (ERP) system Dynamics NAV. MS Dynamics NAV intended to assist with finance, manufacturing, customer relationship management, supply chains, analytics and electronic commerce for small and medium-sized enterprises [Microsoft 2008].

30 workplaces of 50 employees (some of them part-timers) were connected via MS Dynamics NAV having an interface to the DATEV-software of a tax advisor as well as the hazardous materials management system EPOS [Microsoft 2008]. The networked functions included [Microsoft 2008]:

- Administration and Accounting
- Materials Management and Procurement (“Warenwirtschaft”)
- Logistics
- Production
- Quality Management (Qualitätssicherung – QS).

In particular, for “Production and Technology” there is a unit “Application Technology” and “Quality Assurance” (QA).

Concerning quality management of operations and products in 2011 NANO-X achieved certifications according to the DIN ISO 9001 und DIN ISO 14001 certificates [Anonymus 2011; Sepeur 2012].

In 2008 [Sepeur 2009] the education of the employees or roles in NANO-X included seven graduated (Dipl.-Chem.) chemists (six of them with a doctoral degree) and twelve lab technicians (two of them still apprentices). And there were also four engineers and two persons with education in business administration and a lawyer (Jörg Recktenwald).

In 2012 the research and technology strategy of 2008 (Figure 19) mapped essentially the R&D-basis to related businesses and, hence, to the organization (Figure 20). The responsibilities of Dr. Groß, Dr. Laryea and Dr. Goedicke in R&D corresponded largely to those described above.

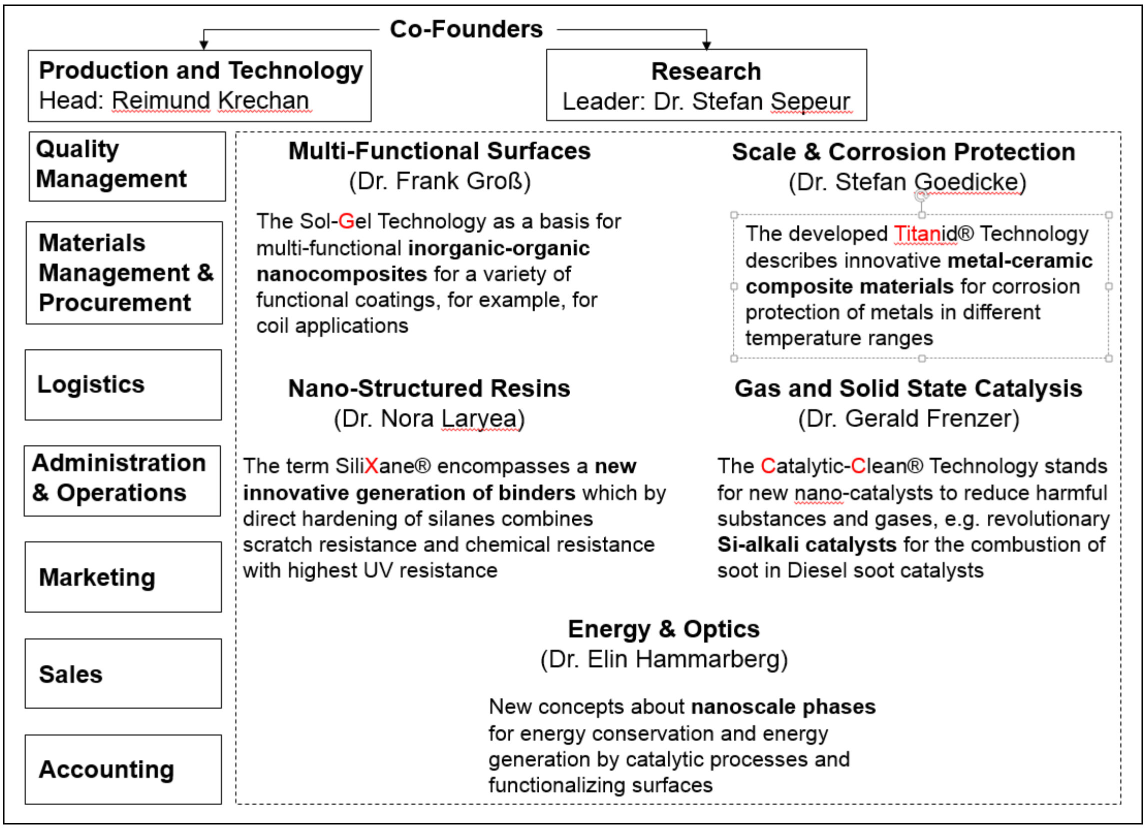


Figure 20: The essential organizational structure of NANO-X (Source: partially from [Sepeur 2012]).

Networking and Cooperation

For further developing and financing its R&D NANO-X itself or together with other organizations initiated various approaches to networking of which some selected ones shall be discussed. It seems obvious that NANO-X still kept its links with its “parent organization” INM and the Saarbrücken University. For instance, in 2009 for basic research it awarded doctoral theses [NANO-X]. But also diploma theses were performed with NANO-X.

As described above during the early phase of NANO-X there was the *Cooperation-X* (with new nanotech firms). Cooperation-X was established by Stefan Sepeur and several partners, essentially nanotech startups in the near environment of the INM in Saarbrücken. The members divided the broad requirements of nanotechnology among themselves. For smooth functioning Cooperation-X partitioned the market in such a way that overlap and entry into the field of other members was avoided [Georgescu and Vollborn 2002].

By resource pooling from research and development via cost- and time-optimized application and production and distribution the members wanted to take advantage from mutual know-how and business tips. The members which are active in different businesses informed each other about needs and wishes of customers and refered these to the appropriate partner [Georgescu and Vollborn 2002].

The concentration on leading professionals and innovative know-how in the fields of nanotechnology, sol-gel technology, chemical engineering, mechanical engineering and materials science of the consortium intended to guarantee a competent contact for every customer.

Also the initiative “Saarland Empowering Nano” served as a common platform for promotions, actionns, events, site advertising, location marketing and PR of nanotech firms of the Saarland. And *internationalization* of NANO-X was supported by the gwSaar Gesellschaft für Wirtschaftsförderung Saar mbH (gwSaar) organization.

gwSaar is an organization of the State Government of the Saarland targeting promotion and industrial development of the federal state (“Saarland Economic Promotion Cooperation”). NANO-X participated in fairs and exhibitions in Japan, Korea, the US and South Africa.

Together with the INM and other nanotech firms of the area NANO-X played an active role in the Competence Center – CC NanoChem (Chemical Nanotechnology for New Materials – Kompetenzzentrum Chemische Nanotechnologie für Neue Werkstoffe) (Figure 11).

Furthermore, NANO-X is a member of competence networks [Runge:176-177], such as NanoBioNet. With universities, public research institutes and companies active in the field as members cc-NanoBioNet e.V. is one of the largest German competence networks in nano-technology. It comprises also public organizations and agencies involved in innovation like the above mentioned gwSaar, SWG or ZPT Zentrale für Produktivität und Technologie Saar [NanoBioNet].

If funded by the BMBF ministry (Federal Ministry of Education and Research) or the Deutsche Bundesstiftung Umwelt (DBU; The German Federal Environmental Foundation) cooperative networks appear often as joint projects (Verbundprojekte, [Runge:180-181,1029,1216]). DBU is one of the largest foundations in Europe. It promotes and funds innovative and exemplary projects for environmental protection [Runge:1166].

Thinking of networking currently one should remember that Stefan Sepeur became an estab-lished expert for the German Federal Ministry of Education and Research whenever the future of nanotechnology is a concern [Leibniz Wissenschaftsgemeinschaft 2009].

Joint projects may cover universities, public research institutes and small/mid-sized or large firms. They are often initiated out of “competence networks” [Runge:1167]. On the other hand, there were individual cooperative projects of NANO-X with two or more partners from industry, but also universities and public research institutes.

As described above, after foundation the first project targeting “Easy-to-Clean” started with the firm Metten – Stein & Design, a German concrete block manufacturer (in North Rhine-Westphalia). And revenue was generated even in its year of foundation1999: DM100,000 (€50,000) [NANO-X; Sepeur 2009]. In 2000 first productions started with concrete block coatings and roof tile sealing (clay roof tiles) with Lotus-Effect®. For the roof tile project NANO-X partnered with Erlus AG [Sepeur 2003:12; Runge 2006:237-238].

NANO-X focused its cooperation essentially on the automotive industry and its suppliers of components.

Already in 2003 HJS won the German Environmental Award (Deutscher Umweltpreis) of the “Deutsche Bundesstiftung Umwelt” (DBU) for the development of a Diesel particulate filter in combination with excellent low back pressure performance based on sintered metal – the sintered metal filter (SMF®) – provided by the former President of Germany Johannes Rau [HJS 2003]. This award was related to a cooperation of HJS with NANO-X and using the x-tec® CA Materials (or x-coat® black) for coatings. High chemical and thermo-corrosion resistance was achieved [Sepeur 2006a].

So far, Diesel soot filters used catalytic effects of precious metals (Pt, Pd or Rh). Their disad-vantages are their extremely high price, de-activation by sulfur and negative effects on sintered layers.

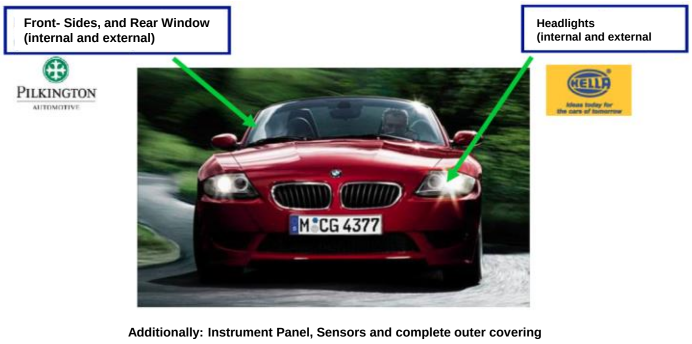
NANO-X did also projects that concerning subject did not match chemical nanotechnology directly.

For instance, starting in 2005, together with two engineering firms from Saarbrücken, NANO-X ran a DBU-project (6/1/2005-9/26/2007) [DBU 2005]. The goal was to develop a method for the separation of VOCs (volatile organic compounds) of low concentration out of large volumes of exhaust based on the electrically regenerated granular activated carbon adsorber (GAC adsorber) such that a comparison with thermal reactors provides significantly more favorable investment costs and the method has lower energy consumption by at least a factor of 2 and thus has corresponding lower emissions of CO_2. NANO-X was the grant recipient of €186,000. VOCs are a serious issue of the paint and coatings industry and are subject to continuously increasing strict legal regulations.

In the same year 2005 there started two BMBF-funded joint projects "Nan-On-Tex" and "NanoSafe" addressing the automotive industry. These BMBF-funded joint projects involving NANO-X are specifies in Table 13.

Table 13: Joint projects of NANO-X and its received grants [ptj 2006].

Project Name **(Duration)**	**Total Cost** **(Granted) (€)**	**(Number of Partners)** **Partners**
Nano-On-Tex (07/01/2005-06/30/2008)	2,008,544 (1,096,508) To NANO-X: 216,290	(5) Nano-X GmbH (Saarbrücken), Johann Borgers GmbH & Co. KG (Bocholt), Isringhausen GmbH & Co. KG (Lemgo), DITF (Denkendorf), NANOKRAFT (Engen)
Title/Subject: Nanoparticle-based processing and functionalization of textile surfaces to improve the indoor climate and hygiene in motor vehicles		
NanoSafe (08 /01/2005-07/31/2008)	5,616,660 (3,080,591) To NANO-X: 245,574	(14) BMW AG (München), DaimlerChrysler AG (Ulm), Siemens AG (Erlangen), Sachtleben Chemie GmbH (Duisburg), Degussa (now Evonik) AG (Hanau), PILKINGTON Automotive Deutschland GmbH (Witten), Hella KG GaA (Lippstadt), Universität Hannover (ITC), Fraunhofer ISC (Würzburg), Fraunhofer IST (Braunschweig), Genthe-X-Coatings GmbH (Goslar), NANO-X-GmbH (Saarbrücken), Hermsdorfer Institut für Technische Keramik (HITK) e.V. (Hermsdorf), FHR Anlagenbau GmbH (Ottendorf-Okrilla)
Title/Subject: Increasing the active and passive safety of vehicles by novel and multi-functional nano-coatings. The joint project "Nanosafe" targeted multi-functional nanocoatings for interior and exterior use.		



Source: [Groß 2010].

The complex project of 14 partners represented fully the value system from research institutes, material manufacturers, coaters, automotive suppliers and OEMs.
The project had four sub-projects "glass", "lights", "sensor quality", “painted outer layer" and "instrument panel" which was led accountably by the automotive suppliers.

Research results from 2007 showed that catalysis of soot without precious and heavy metals is possible for the firm HJS, a specialist for exhaust aftertreatment, which could start using related coating products on soot filters in Diesel exhaust gas systems. These led to a very important extension in 2008 by serendipity [Anonymus 2012].

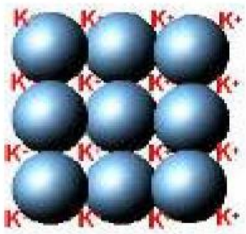
NANO-X developed a coating that can burn environmentally friendly Diesel soot ("Diesel particulate matter consisting of soot mixed with anything from volatile organic compounds to sulfur). However, for Dr. Sepeur the chemical Why is still a mystery. In 2008 they wanted to develop a new non-stick coating for oven plates. Someday during an experiment a lab technician had forgotten to turn the furnace off before leaving for lunch.

In this furnace sugar was heated at 270°C on a glass plate. On one half, which consisted only of glass, the sugar – as might be expected – was caramelized, so became a brown mass. On the other half you had the *glass which was melt together with alkali salts in nano size*. "There, the sugar was completely burned, leaving only some ashes left," Sepeur recalled.

Nano-X continued to pursue this serendipitous discovery and found that this nano-surface, with a certain ratio of glass and salt in the layer, was capable to fully convert soot to carbon dioxide already at a temperature of 250°C and more.

NANO-X then developed coating by which Diesel exhaust can be burned environmentally friendly. This was the basis for the CleanCoat® application technology, NANO-X then jointly drove forward with the German automotive supplier ElringKlinger AG to a product [Sepeur 2009] – involving probably also VW, BMW and/or Daimler. NANO-X marketed the development together with ElringKlinger [Anonymus 2012].

> The basically so-called x-glas® technology stands for revolutionary *siliciumoxide-alkaline catalysts* for the decomposition of soot or other organic compounds, which can be applied in a Diesel soot engine for example.



x-glas® coating means a water-based coating material with the chemical composition of an alkalisilicate. It provides a nanostructured glass matrix with a permanent integration of porosity.

The nano-porosity leads to an extremely large active surface [Sepeur 2009].

x-glas® technology exhibits a very good soot catalysis and is free from precious and heavy metals.

The material was first licensed worldwide and exclusively to ElringKlinger and then further developed on the engine test benches for use as a coating material in the Diesel particulate filter body and optimized [NANO-X] (on Facebook Oct. 21, 2014).

Until 2008 NANO-X developed from a research and production oriented NTBF to an essentially applied research oriented NTBF. The proportion of personnel in the lab was 40 percent [Anonymus 2009; IHK 2009].

Whereas in materials science and biotechnology, for instance, for R&D lab results in terms of a proof-of-concept represents a key for further development, in the application-oriented R&D of NANO-X a *proof-of-suitability* by close-to-production application and processing conditions is a "stepping stone" [Goedicke 2011].

Production capacity and inventory available for production of more than 1,000 tons [Sepeur 2003] and later even 2,000 tons [Groß 2008] was not utilized. But, production volume plateaued at ca. 350 tons (cf. Metrics).

Innovation Persistence, Expansion and Diversification

In 2009 the economic crisis, the Great Recession (December 2007 to June 2009), caught also NANO-X which achieved ten years of existence in August of this year.

In the same year 2009 NANO-X received the award as "Place of Ideas" ("Ort der Ideen") [Anonymus 2009; IHK 2009; NANO-X].

As observed with many firms targeting industrial customers the year 2009 was associated with a decrease of revenue (and profit). NANO-X, however, due to austerity and with short-time work, succeeded to end this critical year with a profit [NANO-X; Anonymus 2011]. It seems that utilizing public R&D projects also contributed to overcoming this critical period.

In 2009 NANO-X participated in a BMBF joint project "Increasing efficiency of the production of chlorine" (May 1, 2009-Oct. 31, 2012) which was led by Bayer MaterialScience (since September 2015 a commercially and legally independent unit of Bayer called Covestro) and involved overall eight partners, Bayer MaterialScience, Nano-X GmbH, MPI-Fritz-Haber Institut (Berlin), Justus-Liebig-Universität Gießen, Ruhr-Universität Bochum, Technische Universität Berlin, Universität Erlangen-Nürnber and Universität des Saarlandes [BMBF 2009b].

The goal to increase efficiency of chlorine production resulted from the following factors [Sawaryn 2011]:

- Chlorine is a key element in the chemical industry
- Approximately 65 percent of all chemical products are manufactured directly or indirectly with chlorine
- The production of chlorine is highly energy intensive
- For the production of chlorine precious metal-based catalysts are required.

Overall, the project should make sure competitiveness of chlorine production vis-à-vis increasing prices for power and precious metals. For the three years contribution to the sub-process "Coating Processes" [BMFB 2009c] NANO-X received €300,000 [Sepeur 2009].

NANO-X was engaged essentially in the following activities [BMBF 2009b]:

- Decrease use of precious metal (ruthenium) by coating the electrodes of the electrolysis
- Decrease the dependency on the monopolistic catalyst coating market
- Investigate alternatives to ruthenium-based catalyst.

For catching project grants it was often helpful for NANO-X to refer to examples to transfer its technology successfully into practical applications. For instance, there was a NANO-X project within the context of the BMBF program “nanoEfficiency” [Gehrke et al. 2013] for which NANO-X could refer to photocatalytic TiO_2 initiating the efficient decomposition of fouling layers that was successfully applied in this capacity on more than one million tiles (ERLUS Lotus® with the company ERLUS AG as described above).

Correspondingly, referring to photocatalytic TiO_2 for functional coatings, NANO-X participated in the BMBF program “nanoEfficiency” (May 1, 2009-Jun. 30, 2012) [Gehrke et al. 2013] involving development of a novel coating method to produce layers, which

- Have antifouling properties,
- Are anti-corrosive,
- Permanently adhere,
- Are not consumed and
- Not thicker than one micrometer.

And all these criteria were met by using nanoscale photocatalytic TiO_2 layers in combination with a light source.

The project had five partners [Gehrke et al. 2013]: Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik UMSICHT, NANO-X GmbH, CUT Membrane Technology GmbH & Co. KG, EVERS e.K. Wassertechnik und Anthrazitveredelung and Bartels Mikrotechnik GmbH.

FhG UMSICHT had developed high-flux micro-sieves to clean wastewater and convert water into drinking water quality and developed a new micro-filter which removes particles and bacteria from water and wastewater. However, the filtration performance decreased exponentially as soon as particle load media to be filtered. Through the project the new coated micro-sieve modules or membranes or membrane pumps, respectively, should prove conclusively their practicability in a decentralized drinking water treatment plant. This would open innovative filter opportunities for applications in the chemical Industry, the food industry, pharmacy and power plant technology’

In 2009 activities continued as “continuous improvements or extensions” of products and marketing efforts to increase visibility.

In 2009 also small and large productions found their way into the market, for example, a textile impregnation for apparel applications, scratch-resistant surfaces of furniture films or durable sealings for concrete blocks [Pressebox 2009].

The "European Coatings Show" appeared as a success. Together with its partner Worlée-Chemie NANO-X presented SiliXane® and a highly scratch-resistant clearcoat developed from these [NANO-X; Adebahr 2009]. The Hamburg-based Worlée-Chemie is the co-developer and exclusive distributor which sells the SiliXane® Europe-wide [Sepeur and Laryea 2008].

SiliXan® (SiliXane®), organic-inorganic polymers, represent a new class of binders for high performance industrial coatings (Figure 24). The presented product WorléeProtect, a novel hybrid-polymer sol-gel system, is the base for a variety of thin functional coatings with high scratch- and abrasion resistance, easy-to clean and anti-graffiti properties. WorléeProtect can be cured at room temperature. Worlée presented a variety of innovative specialities for the *formulators of high performance and functional coatings* [Adebahr 2009].

The following example will provide an impression of the complexity of formulations. For instance, the formulator will find out how sol-gel materials (WorléeProtect), SiliXan®-binders (NANO-X), water/solvent based nano-colloidal silica sols (CWK, Silco International), silane/silicone additives (WorléeAdd), Silica Aerogels (Nanogel®, Cabot), ultrafine TiO_2 (Ishihara) or colorshift pigments (Flex JDSU) help to realize related products.

In May 2009 NANO-X used the "Automotive Engineering Exposition" in Yokohama and gave two presentations on "Asia Steel" held in Korea. It presented its latest developments regarding scale protection for steel and corrosion protection [NANO-X].

There were activities on a nano-based insulating protection for residential buildings, which will include paper and glass (energy conservation – Figure 20). The environmental aspect of technology is critical to the future, said Sepeur [Anonymus 2009; Sepeur 2009].

Many new research activities/projects were suggested to NANO-X. Particularly the area of catalysts became a firm footing for NANO-X.

In 2010 NANO-X reached the 2008 turnover and completed one of its best years [NANO-X].

NANO-X started the first half of 2010 with a large production demand and publicly funded projects were approved [NANO-X]. For instance, with the firm HJS Emission Technology GmbH & Co. KG as a leader and partner of the project and NANO-X, NanoScape and the KIT (Karlsruhe Institute of Technology, Institut für Technische Chemie und Polymerchemie – ITCP) a joint project "Nano-SCR" (May 1, 2010-Apr. 30, 2013) was started to help reduce Diesel engine emissions [BMBF 2010].

As part of the project nano-SCR (Selective Catalytic Reduction) [3] particulate filters should be developed for Diesel engines that are equipped with *nanoscale catalysts for the reduction of nitrogen oxide emissions*. In addition to the requirement to produce as small as possible catalysts, there was a special emphasis on the aging resistance of the systems and the new generation of filter catalyst systems should also be space and weight saving. A simplified installation for the exhaust aftertreatment for vehicles and systems with Diesel engines, respectively, should be enabled.

A special nano-based coating for catalytic soot burn-off in ceramic Diesel particulate filters (DPFs) was developed: CleanCoat™. According to Anonymus [2012] NANO-X marketed the development together with the German automotive supplier ElringKlinger. In 2012, the company produced 30 tons of this nano liquid.

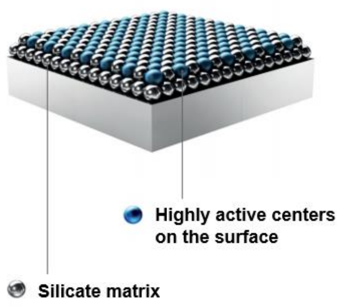
Concerning this special nano-based coating in ceramic Diesel particulate filters (DPFs) in June 2011 the first initially installed catalysts were tested successfully for building machines in series operation, because their engines run with less high speeds [Anonymus 2011]. In 2012 the catalytic converter was already being used in trucks, buses, construction machinery and locomotives. Other potential fields of application include ships and stationary motors as well as power plants.

In recognition of outstanding innovation in the efficient use of raw materials, the Federal Ministry of Economics and Technology (BMWi) awarded the German Materials Efficiency Prize in 2012 to ElringKlinger and NANO-X for the jointly developed heavy- and precious-metal-free CleanCoat™ soot catalyst [ElringKlinger 2012; Anonymus 2012].

Early in 2012 ElringKlinger subsidiary Hug Engineering's mobiclean R™ filter system, comprising oxidation catalyst and DPF with CleanCoat™ coating, received the coveted certification for on-road vehicles from the California Air Resources Board (CARB). Emission guidelines in the state of California stipulate that buses and trucks with a gross vehicle weight rating of more than 6.34 metric tons have to be retrofitted with DPFs [ElringKlinger 2012].

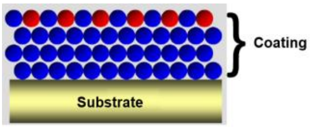
Coatings of other motor components by this technology were envisioned [Sepeur 2012].

The structure of the CleanCoat™ is shown below [ElringKlinger 2014].



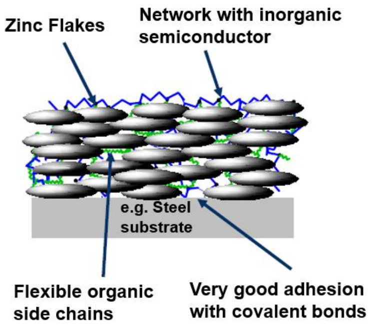
[ElringKlinger 2012]

The above mentioned cooperation with automotive supplier ElringKlinger AG and Hug Engineering AG (belonging to ElringKlinger) entered final straight inducing preparations for first sales in 2011 [NANO-X; ElringKlinger 2012]. ElringKlinger had bought Hug to enter a new business "exhaust aftertreatment" and used the cooperation with NANO-X for related innovation activities.



[Sepeur 2012]

At the end of 2009 a product MULTI ZINC for corrosion protection by a new technology was ready to be launched by the German Würth Group [Runge 2006:241,256-258; Runge:633,764-765] which appeared in 2010 on international markets with a new product name PROMAX [NANO-X; Goedicke 2011].

	It is active cathodic protection Zinc flakes are coated with nano-TiO_2 The semiconducting TiO_2 is simultaneously a binder and contact agent between the Zn-pigments High conductivity is kept May be applied via rolling, dipping or spraying Welding is possible

PROMAX resulted from cooperation of NANO-X with Kerona GmbH, a subsidiary of the Würth Group, targeting corrosion protection essentially by zinc. PROMAX is a room temperature (RT) curing micro-structured zinc aerosol spray with cathodic corrosion protection. Kerona specializes in functional cleaning and coating products utilizing the various possibilities of nanotechnology. The product is designed for the requirements and use in crafts – tuned for metal and steel construction as well as air conditioning and ventilation. The related technology named TITANID® is a registered mark of KERONA® [Kerona].

In only Germany industry and craftsmen consume every year 44,000 tons of coatings for corrosion protection. An example are repairs that were previously performed by craftsmen for corrosion protection of cut edges, drill holes and welds using zinc dust primers. It is claimed that with TITANID® material (Figure 20) savings can be achieved by up to 75 percent [Kerona].

One year later (2011) Kerona GmbH received the "German Raw Material Efficiency Award ("Deutscher Rohstoffeffizienz Preis") of the German Ministry for Economics (BMWi) for the zinc serving approach to corrosion protection developed together with NANO-X [Kerona]. Each prize is worth €10,000.

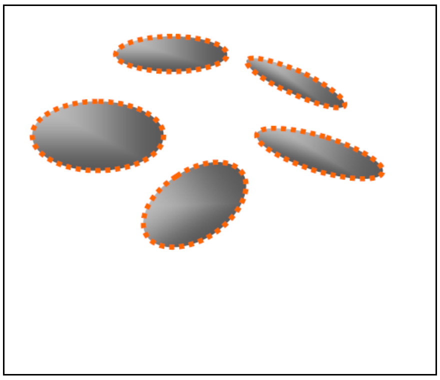
According to Thomas Isleib, Managing Director Kerona GmbH for Kerona and Nano-X the zinc coating was only the prelude to further cooperative projects. And he said [Kerona], "that from our idea for a new zinc coating within a very short time an entirely new product could be developed, we owe to the good cooperation with researchers at NANO-X. I am sure that we will work together to address many a project in the future."

PROMAX was a prototype of a generalized technology for "NANO-X Active Corrosion Protection" (NXACP) called Titanid® [NANO-X; Goedicke 2011; Goedicke et al. 2011].

Titanid stands for innovative metal-ceramic compound materials for corrosion protection applications at different temperatures (RT-1,300°C) and is the basis for the NANO-X NXACP business.

The Titanid® principle means [Goedicke et al. 2011; Goedicke 2011]:

- Nano TiOx coating on the pigment
- Passivation of discrete metal pigments without loss of electric conductivity
- Combination of aluminum, magnesium or zinc (Al, Mg, Zn) pigments are possible – which are the main pigments for NXACP and belong to the “x-tec® protect Technology” line.
- Cathodic corrosion protection for steel (for instance, 22MnB5 used by VW, Figure 14) and significant reduction of white rust formation.



NXACP –principle [Goedicke 2011]:

Metal particles with Nano-TiOx passivation

Further developments of NXAPC envisioned included

- Active corrosion protection for coil coating
- Corrosion protection for assembly groups
- Corrosion protection for press hardened and single automotive parts.

NANO-X became active in coating application for OEM or component supplier factories. For instance, PROMAX is also suitable as a repair system for brake disk coating. But, for OEM brake disk coating a water based system is necessary [Goedicke et al. 2011]. And in 2010 with a water-based zinc paint that even cures at room temperature, NANO-X developed a new energy-efficient material that is used for example in brake disc coating.

On the fair and exhibition Euro Plate (Euroblech 2010) NANO-X showed for the first time functional layers of nanotechnology for coil applications. Dr. Sepeur explained, “To expand our market presence, we need to reduce costs of components. This is achieved by applying the coating already cost efficiently during the manufacture of steel or aluminum strips.” "The crux in the development was that there are completely new demands for the material.” [Pressebox 2010]

Scratch-resistant coatings must be flexible and many times extensible. Corrosion protection layers must withstand extremely heavy pressing during forming. At the same time subsequent process steps, such as welding and painting, must not be affected.

By developing a new generation of binders, the SiliXanes, this hitherto regarded as unsolvable combination of properties suddenly became possible. "We see a huge market in front of us, and for the coming years we anticipate a further expansion of our production facility,” said Dr. Sepeur [Pressebox 2010].

NANO-X started the new development creating full awareness of the current architecture of brake discs, distinction between aspects of functional areas and other areas (brake disk being a visible design element, *protective and decorative functions*) as well as *friction surface* and the *currently used coating process* with high energy consumption. These insights in state-of-the art were translated into a set of requirements and specifications and tasks for new development, for instance [Goedicke et al. 2011]:

- Water based coating material, cathodic corrosion protection
- Curing temperature as low as possible
- One-component system with pot life of several months
- Compliance with related DIN-ISO standards and specific test settings
- Repair system for (paint) workshops necessary.

Sol-gel technology was used to tailor *water-based binders* with links to inorganic or metallic substrates, fillers or functional particles, for instance, metals; co-condensation relied on hetero-metal ions, such as aluminum, titanium, etc. On the next level, *formulation* of coating materials consisted of a water-based binder, zinc and aluminum pigments and additives to optimize according to required properties. In a further step *Proof-of-Suitability* (PoS) was performed by close-to-production application and curing conditions in a *pilot plant* [Goedicke et al. 2011].

Additionally, NANO-X developed an environmentally friendly "x-tec® eco" technology for brake discs, free from chromium and energy-saving by curing at 100°C with promising first test runs in an OEM production plant [Goedicke et al. 2011].

"No rust!" was the answer of Dr. Sepeur to the question of the function of the x-tec technology. "Under the brand x-tec we sell mature products utilizing the latest binder technologies from the future research that have not previously known properties or differ by process or manufacturing benefits significantly from the prior art in corrosion protection!," said Dr. Sepeur [Innovations-Report 2012; Pressebox 2013a].

During the International Trade Fair for Surfaces and Layers 2012 (Die internationale Fachmesse für Oberflächen & Schichten – O&S 12.06. - 14.06.2012, Stuttgart, Germany) NANO-X announced the product "x-tec® eco … with highest performance in corrosion protection with an energetically favorable coating and maximum resistance." "As a water-based coating material with selected environmentally sound raw materials the 'eco' in the product name is for resource efficiency and sustainability," explained Dr. Sepeur [Innovations-Report 2012]. The x-tec® technology was recognized in 2006 with the Steel Innovation Award and the German Raw Material Efficiency Prize in 2011.

Especially in the area of the brake disc coating the Saarbrücken researchers saw an interesting initial market for the universal technology. This would include brake discs for automobiles, but also for motor cycles and bicycles. For the potential of this innovative technology NANO-X also envisioned the coating of fasteners, attachments or brake parts for trains and trucks. [Pressebox 2013a].

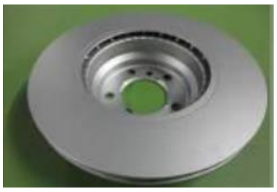
The demand of the automotive industry for a suitable water-based coating for the entire disc including the functional surfaces with excellent anti-corrosion property and very high resistance to highly aggressive wheel cleaners in conjunction with low curing temperature is satisfied with the product "x-tec eco". Using selected pigments also coloring is possible [Innovations-Report 2012].

Goedicke et al. [2011] presented already "Anthracite anti-corrosion coating for brake discs – x-tec® eco black" in 2011 as a "product under development" at the European Coatings Conference (ECC) in the context of automotive coatings.

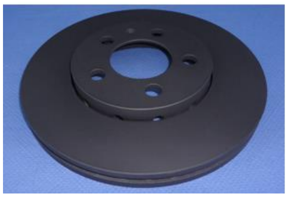
Most common brake disks are made of cast iron and thus susceptible to rust.

Light metal rims are widely used.

The brake disk has become a *visible design element* [Goedicke et al. 2011]



Cast iron brake disc coated with x-tec® eco (VP CO 4973)



Anthracite anti corrosion coating for brake discs – x-tec® eco black

x-tec eco black was a highlight on the ECS 2013 (European Coatings Show). And the absolute novelty for the market was: Curing at room temperature is possible! Under this name NANO-X provided the aqueous black coatings with active corrosion protection, for instance, also for the *protection of pipelines*.

“x-tec® eco black” is a lucid example for further product development in terms of products’ generation entering new applications or providing additional or new features [Sepeur 2009, Goedicke 2011; Goedicke et al. 2011]: x-clean® → x-tec® black → x-tec® eco black

In the early development phase a related product technical highlight was the product “Quick Alu” winning the Alufoil Trophy 2005 of the European Aluminium Association (EAA) presented together by the firms Hueck Folien and Cofresco [Alu-web.de; Groß 2008; Sepeur 2009]. Hueck Folien GmbH is a part of Hueck Industrie Holding KG, a specialist for eye-catching, functional coatings and high security features (Figure 21).

Figure 21: Black coated grill dishes and household foil (top) and food packaging (bottom) in 2005.

By black coating active uptake and rapid transport of oven heat to fried food is achieved.

In the current classification the original product “x-coat® Black 4002” would show up currently as x-tec® Energy (heat/IR-absorbing coatings) – with food approval

By 2011 the spectrum of developments for corrosion protection and scale prevention by NANO-X according to process temperatures are shown in Figure 22.

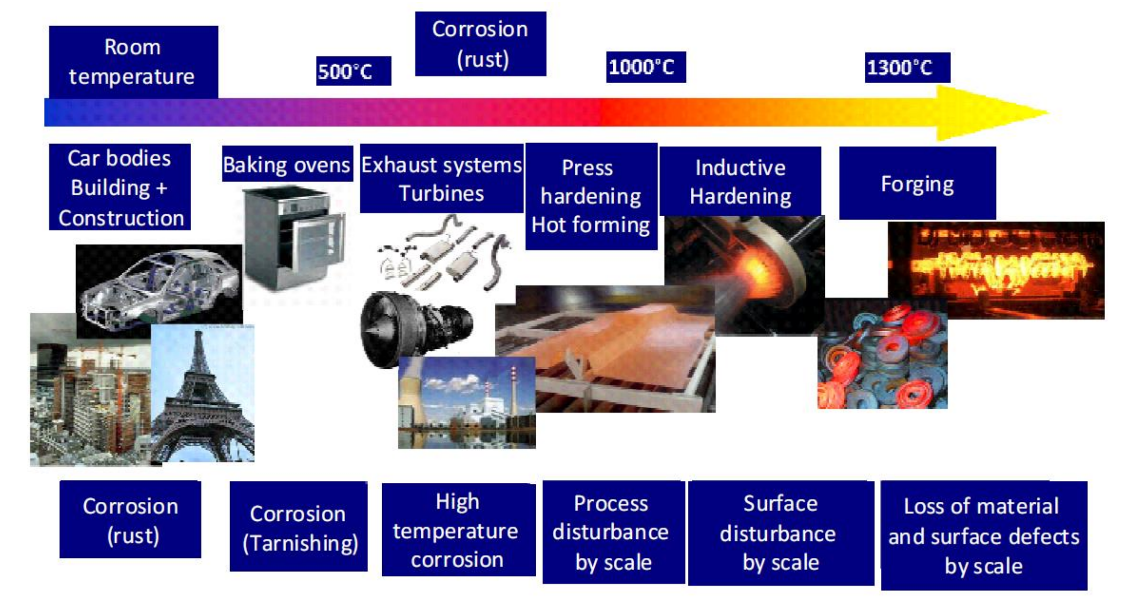


Figure 22: Different types of corrosion with respect to application/use and initiation temperature of related processes [Goedicke et al. 2011].

At the end of 2010 the level of production increased considerable; the volume of production kept this level in 2011 [NANO-X]. During the European Coatings Show more than two hundred professional requests occurred. And binders were distributed globally [NANO-X].

In 2011 NANO-X did re-orient back the *strategic focus stronger on its “non automotive” customers* and focused on new implementations. Projects for solar applications and functional layers for coil application approached implementation [NANO-X].

Since January 2012 (till December 2014, but then extended till June 30, 2015) and supported by €566,388.97 NANO-X participates in a bi-national project, RFB-Solar – consortium. Prof. Dr. Rolf Hempelmann, Chair of Physical Chemistry at the University of the Saarland coordinates the EU (INTERREG IV A Greater Region Program) project RFB Solar "Redox flow batteries as solar energy intermediate storage for electric mobility" [RFB Solar].

The RFB solar consortium consists of two scientific project partners and three strategic partners from Germany and France [RFB Solar]. Scientists at the University of the Saarland (Prof. Rolf Hempelmann) and the Transfer Center for Nanoelectrochemistry at the University of the Saarland will be researching together with French colleagues from the University of Lorraine (Université de Lorraine and CNRS) a future generation of redox flow batteries as solar energy intermediate storage for electric mobility.

In addition to theoretical foundations, such as the optimization of the electrodes, it is also about developing appropriate software for CAD manufacturing of battery stacks consisting of twelve or more individual cells. Strategic partners are the membrane manufacturer FuMA-Tech GmbH from St. Ingbert, NANO-X, Saarbrücken, and the Institute for Future Energy Systems (IZES), also in Saarbrücken.

As mentioned above, in recognition of outstanding innovation in the efficient use of raw materials, the Federal Ministry of Economics and Technology (BMWi) awards the German Materials Efficiency Prize. In 2012 the accolade went to a research institute and four companies, including ElringKlinger as a consortium partner to NANO-X GmbH, for the jointly developed heavy- and precious-metal-free soot catalyst CleanCoat™ [ElringKlinger 2012; Anonymus 2012]. NANO-X marketed the development together with the German automotive supplier ElringKlinger [Anonymus 2012].

<table>
<tr>
<td>In 2011/2012 (combined with WorléeProtect) the NANO-X “x-protect® EC” (clearcoat) formulations with an added “Easy-to-Clean” function of removing insects and graffiti in automotive and transportation applications and a new nanocoating system for cooling systems of trains found use by “Deutsche Bundesbahn (DB, German Rail) and by the company Voith GmbH [Sepeur 2009; Voith 2012].</td>
<td>

(External and internal application)</td>
</tr>
<tr>
<td colspan="2">According to its Web site Voith is a globally active engineering company. With its broad portfolio covering plants, products and industrial services, Voith supplies essential markets: energy, oil & gas, paper, raw materials and transport & automotive. The holding company is Voith GmbH based in Heidenheim/Brenz (Germany). Voith GmbH is 100 percent family-owned. The operative business is pooled in four Group Divisions, Voith Hydro, Voith Industrial Services, Voith Paper and Voith Turbo, steered by a legally independent holding company. Founded in 1867, Voith employs over 39,000 people today at locations in over 50 countries of the world and has ca. €6 billion in revenue.</td>
</tr>
</table>

A continuous issue of using stainless steel surfaces for various applications is the distinct perceptibility of fingerprints and greasy residues.

In 2013 Nano-X GmbH launched a new anti-fingerprint coating to the market, which is applied directly by the coil-coating process to the metal substrate. As a result, a variety of new applications opened for that material that was previously put on by spraying [Krüger 2013].

Refrigerators, ovens and other household appliances in stainless steel look are currently all the rage. But even in the living area more and more furniture with stainless steel elements collection emerge. In addition, architects and planners like using the metal with its attractive appearance, which is mechanically and chemically very robust, for facades. In principle, stainless steel is very easy to clean – if it were not the problem with the run-up tracks from fingerprints (Figure 23).

Figure 23: Examples of household appliances and outdoor lamps in stainless steel providing anti-fingerprint effects [Goedicke 2011].

In recent years NANO-X developed a variety of anti-fingerprint coatings that are applied to finished components by spraying. "Many of our customers do not have access to spray painting or cannot integrate spray coating of components economically into their production process," explained Dr. Groß of NANO-X. Therefore, NANO-X developed an anti-fingerprint coating for a cost-saving coating of stainless steel bands by the coil process. As a result, the coated stainless steel is available for widespread use." [Krüger 2013]

Compared to spray application, additional requirements are imposed on a coil coating. This is why for further processing the composite of stainless steel and coating is cut, folded, deep drawn, stamped, etc. "For this reason, a compromise in the development of coating had to be found between hardness and flexibility," said Groß. Moreover, high demands were placed on the look and haptics of coated stainless steel by the *customers and product designers* [Krüger 2013].

In collaboration with a renowned manufacturer of stainless steel via optimization of the coating process the researchers from NANO-X were able to develop a coating technology that requires no special primers for the stainless steel.

After four years of development in 2014 with the product SILVERICE X NANO-X had a new implementation for anti-fingerprint stainless steel in the manufacture of kitchen, household appliances, etc. for the Italian firm *Acciai Speciali Terni SpA* [VIVINOX 2014].

The product VIVINOX® of Acciai Speciali Terni combines the typical characteristics of stainless steel substrates with the advantages of organic coating. But, through a special coatings, VIVINOX® can optimize the surface finish of stainless steel improving anti-fingerprint properties (SILVER ICE®). VIVINOX® is supplied with one or more layers of special organic coatings applied on a properly prepared surface by a coil coating process.

Acciai Speciali Terni is one of the world's leading manufacturers of stainless steel flat products whose most important application fields are: food preservation, household electrical appliances, constructions, kitchenware, energy production and distribution as well as the base, mechanical and steelmaking industries. It also has a subsidiary in Germany (Acciai Speciali Terni Deutschland GmbH in Düsseldorf).

In this context it is notable that Dr. Frank Groß of NANO-X received the *Award of the Saarland State for Design* 2009 (Saarländischer Staatspreis für Design 2009) concerning multi-functional anti-fingerprint coating "x-clean AF" for stainless steel surfaces in 2009.

During the International Trade Fair for Surfaces and Layers 2014 (Die internationale Fachmesse für Oberflächen & Schichten – O&S 24.06. - 26.06.2014, Stuttgart, Germany) NANO-X presented new waterborne environmentally friendly products to remove rust associated with durable protective coatings. Applications can be found in industrial processes, but also around the house and the car [Pressebox 2014].

An emphasis was coatings directly on the coil for industrial series production and anti-fingerprint coatings for stainless steel. "The anti-fingerprint effect is the slightest problem. Combining scratch resistance, chemical resistance, UV resistance and ductility in a very thin layer was the challenge," said Sepeur [Pressebox 2014].

Furthermore, for powder coating processes NANO-X developed an aqueous zinc primer which can be applied without great technical expenditure to powders and concerning performance can compete with a fully galvanizing (zinc-based) approach. According to research, it is a world first one, which combines environmental benefits with a drastic cost reduction [Pressebox 2014].

In December 2014 NANO-X opened a *retail shop* "Dr. Nano Konsumerprodukte" for selected consumer products with the shop having the address of the NANO-X site. It also opened the "Dr. Nano Shop online" offering many of its products (market-ready coating materials) to all interested persons, to consumers and also to craft operations or distribution partners.

Since the end of 2011 NANO-X focused essentially on four basic R&D and technology areas (cf. also Figure 20) [Goedicke 2011; Goedicke et al. 2011].

- Sol-Gel Technology
- Titanid® Technology
- x-glas® Technology
- SiliXane® Technology.

In 2011 NANO-X introduced a clearcoat developed together with a German automobile manufacturer of the premium class calling the related model approach "X-protect® cc" [Industrie Anzeiger 2011].

CEO Dr. Sepeur assumed the development to be for so groundbreaking that he spoke of a billion potential: "We have not only developed a clearcoat, but an entire technology. The last time that this occurred successfully is 70 years ago with the development of polyurethanes or silicones. Finally, we see a market of several billion euros over the next 15 years."

"X-protect® cc" is based on SiliXanes. And these organic resins (binders) are combined structurally at the atomic level with high-strength ceramics. The result is a paint uniting gloss, flexibility, UV resistance, easy processing and ceramic hardness.

"In spite of the great successes we are only at the beginning of development," noted Dr. Sepeur. "The acceptance in the coatings industry will not occur with a short-term process. The higher it will be for the future expected potential." The *new technology* is actually expressed in terms of *binders (resins) and additives* [Industrie Anzeiger 2011] – entering the formulation level.

NANO-X was working on further projects in paints for plastics, colored paints, powder coatings and metal coatings apart from the clearcoat development.

Goedicke et al. [2013] provide an overview of selected recent products offered by NANO-X focusing on corrosion protection for stainless steel, aluminum, zinc galvanized steel, protection of zinc and zinc-nickel galvanized steel and cast iron parts, Titanid Active Corrosion Protection and anti-fingerprint and anti-tarnish coatings. And their overview finally presents an example of cast iron tubes positioning x-tec® eco black against state-of-the art:

State of the art anticorrosion coatings for pipelines: • 2K polyurethane coating, 2-3 mm thickness • Epoxy coating 300..500 µm thickness two or three layer systems (2K: Two components)	versus	No black water based active corrosion protection available before x-tec® eco black

This means NANO-X positioned itself against *the* incumbent of the global polyurethane coatings market, Bayer AG (Bayer MaterialScience) [Bayer AG].

In 2013 the technical significance of SiliXanes and anticipations (and hopes) associated with their market potential led to a spin-off from NANO-X to focus on development and commercialization of SiliXanes, SiliXan GmbH, which would operate as a supplier of raw materials for the paint and coatings industry. Its focus would be on binders, curing catalysts and additives that make possible formulation of coatings with multi-functional properties.

SiliXane® and SiliXan GmbH

Nanobusiness is about business, yes; but it's also about possibilities [Lovy 2009].

Specifically, SiliXane® compounds emerged already in 2006 as a technological gap for a new kind of binders for coatings (and adhesives). And as a supplier of related raw materials and binders for the paint and coatings industry a distribution alliance with Worlée-Chemie was established by NANO-X [NANO-X].

There were considerable promotion activities for SiliXane® in terms of presentations in 2008 and 2009 [Groß 2008; Goedicke 2008; Sepeur and Laryea 2008; Sepeur 2009] and participation in exhibitions and conferences like the American Coatings Show Daily 2008 [ACS 2008] and European Coatings Show [Adebahr 2009] together with Worlée-Chemie.

Accordingly, SiliXane® represent a new class of *binders to produce multi-functional coating* materials. There is a combination of silane chemistry with the principles of conventional paint technology and the curing mechanisms of silicone chemistry. The novel binders were synthesized on the basis of high-molecular silanes.

The properties of the compound class are related above all to the specific structure, which is characterized in that the organo-functional groups of the binder are already completely crosslinked, while the inorganic network is only formed during a curing process. A model of the SiliXane® structure, its scope of variability and binder properties are shown in Figure 24.

The chain length of the methylene bridges (x, y subscripts) and the functionality F will vary depending on the implementation of the low molecular weight silanes with organic molecules in the form of monomers, oligomers or polymers. Apart from the catalyst used for crosslinking these will determine the property profile of the binder class.

The chemical bonding to metal, plastics or painted surfaces by chemical crosslinking is achieved via the silyl moiety or the functionality F of the chain, for instance, via hydrogen bonds. The average molecular weights of SiliXane® are >1,000 g/mol, so that the individual binder molecules cannot evaporate during the curing process between 80°C and 200°C [Goedicke 2008; Sepeur and Laryea 2008; Sepeur 2009].

The inorganic crosslinking does not take place, as common with silanes, after addition of water or mineral acids catalytically via the sol-gel process, but there is a direct linkage of the silyl units by special catalysts (e.g. by metal complexes).

SiliXane® are distinguished from the sol-gel technology mainly by the fact that with a solid part of up to 80 percent they exhibit also storability and can be diluted as desired with organic solvents [Sepeur and Laryea 2008]. SiliXane® combine the positive properties of silicones and sol-gel materials.

Water-free direct inorganic crosslinking of silanes to siloxanes according to the respective application is possible with special catalysts [Sepeur 2009]:

- Lewis acids ($Al(OH)_3$, $Zr(OH)_2$ …) and activation temperature of 80°C
- Acetic acid, phosphoric acid and activation temperature >120°C
- Sulfuric acid, alkalis and activation temperature is room temperature (RT).

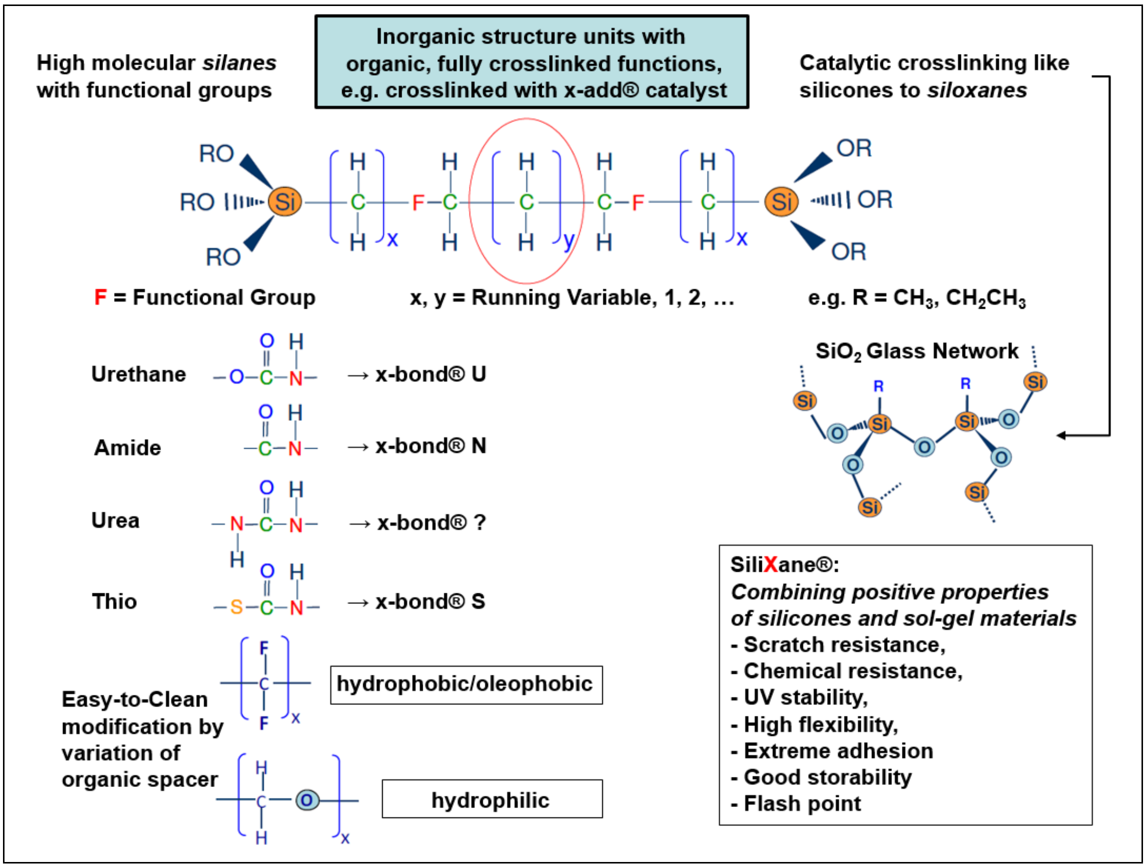


Figure 24: A basic model of the SiliXane® structure, its scope of variability and key properties [Goedicke 2008; Sepeur and Laryea 2008; Sepeur 2009].

The various types of SiliXanes exhibit different characteristics, also typically with regard to substrates, for instance [Goedicke 2008]:

Urethane SiliXane – x-bond® U:

Coating properties:

- Good adhesion to metals and plastics
- High mechanical and chemical (stable against attack of acids and alkali) resistance
- High UV stability

Thio SiliXane – x-bond® S:

Main coating properties:

- Very good adhesion to precious metals like gold, silver or copper
- Scratch resistant: high mechanical and chemical stability
- Chemical resistance: stable against attack of acids and alkali

According to the Firmenwissen Database SiliXan GmbH was officially registered on February 2, 2013 as a limited liability company (LLC) with Dr. Frank Groß as the Managing Director ("Geschäftsführer") being the single employee of the firm located at the same address as NANO-X and NANO-X being the single owner contributing €25,000 as the share capital.

As according to the Firmenwissen Database the number of employees of NANO-X in 2014 was thirty five one would assume that in 2014 ca. ten employees of NANO-X were formally attributed to SiliXan (cf. Table 14 and text below).

The new company sees itself as an innovation engine for the paint industry. *Multi-functional binder concepts* shall revolutionize the paint and coatings industry. "What is special with nano-structured resins and binders: We are the only ones with such high-tech products in the paint area!" said Managing Director Dr. Frank Groß [Pressebox 2013b].

The company SiliXan sees its *market mainly to be the national and international small and medium-sized enterprises (SMEs*). "There is a variety of small and medium-sized paint manufacturers which can get a big boost to innovation through SiliXan," he explained. It will focus on *binders,* complementary *curing catalysts and additives* that make possible the formulation of coatings with multi-functional properties.

"In contrast to the binders known so far which usually tend to cover only one of the characteristics *decoration, protection or function* those paints that are made with SiliXane technology are capable to combine all these aspects," said Dr. Groß [Pressebox 2013b]. Achieving new material combinations in surface technology are entirely due to the *multi-functional character already of the raw materials*.

"Green Nanotechnology" is the slogan under which SiliXan will sell its products. According to Dr. Groß [Pressebox 2013b] this is to be understood as a clear *environmental orientation*. "From raw materials used to the finished product high environmental criteria will be applied." The whole process of production and the application of one or more coating layer hence are optimized in terms of resource and energy efficiency.

During the ECS 2013 SiliXan GmbH presented starting formulations to create highly scratch-resistant automotive coatings. In addition products, for instance, for the formulation of chrome-free corrosion protection coatings or efficient UV curing coatings, were shown.

The preparation of curable molding compounds and novel adhesives and sealants is also possible on the basis of SiliXanes.

The following potential *target markets* for SiliXan GmbH were envisioned:

- Manufacturers of paints, coatings and lacquers, especially industrial coatings
- Automotive series and lacquers, as well as airplane coatings, wood and furniture coatings and architectural coatings
- Anti-corrosive paints, primers and ship coatings
- Manufacturers of industrial adhesives and sealants and curable molding compounds (dental, medical)
- Manufacturers of lubricants, lubricating varnish and release agents.

With regard to the relevance of the automotive industry for NANO-X (and Silixan) it is generally assumed [SpecialChem 2015a]:

The automotive coating of the future: energy-saving coating of a mix of materials. “The need to reduce fuel consumption and CO2 emissions is spurring the development of lightweight motor vehicles made from a mix of different materials. For automakers, *the cost- and energy-efficiency of the coating process plays a crucial role*. Also very important is the *appearance of a coating* – from the purchase of a car to resale.

Customers are increasingly demanding products based on renewable raw materials. Environmental compatibility is becoming a market requirement. At the European Coatings Show, Bayer MaterialScience was showcasing a milestone in this field: Pentamethylene diisocyanate (PDI) is a new isocyanate 70 percent of whose carbon content comes from biomass, an *eco-friendly hardener* component [SpecialChem 2015a].

It should be noted that Bayer had a cooperation (and common patents) with INM and should be aware of what is going on there and with NANO-X.

The basic approach for innovation and new product development (NPD) is to incorporate partners along the supply chain and their know-how into the firm’s development efforts as early as possible to ensure that customers are successful in the market. Furthermore, customer-orientation and material solutions resulted often from development partnerships. But for the paint and coatings industry obviously also another aspect emerges.

The *value system of coatings* (Figure 25) has to incorporate the “decorative” aspects in terms of design – for instance, expressed by the above described interactions of the coating firm and customers and designers emphasized by Dr. Groß who also received a Design Award for brake discs as a *visible design element.*

And that is also expressed by company names of customers of NANO-X, such as Metten – stein + design (Source of below figure: [NANO-X]), Birkenmeier – Stein+ Design [Sepeur 2004] or the US firm UniLock – DESIGNED TO CONNECT which in 1996 became the only North American member to join the prestigious European Stein+Design innovation and manufacturing group and explicitly differentiates Designer’s Choice and Craftmen’s Choice.

METTEN stein+design

This situation is similar to OLED-producers who also co-work with designers for lighting arrangements [Runge 2014d].

The relevance of the “design” components for the paint and coatings industry was explicitly emphasized by Lowry [2007]:

> "Reaching out to designers in the early stages of the product development cycle will be important for coatings manufacturers in the years ahead."

"The paint and coatings industry has focused on the technical specifier and viewed them as customer: Detailed specifications and designs of a product being readied for production occur after the conceptual design of the product has been fixed. Specification of a coating is a minor thought process in the product design even when it can have a major effect on the performance and perception of the product in question them as the customer." [Lowry 2007]

This value of the coating design is emphasized, for instance, by BASF [SpecialChem 2015b].

MasterProtect® C 350 hydrophobic coating of the MasterProtect line of protective coatings, provides a finish which resists dirt pick-up, and requires only rainfall or rinsing with water to remove any dirt which does accumulate, helping reduce exterior maintenance costs. And, "*designers and owners* have expressed a need for a durable, protective coating which is attractive and easy to clean," said Brian Denys, Vice President of BASF North America.

The design part of the supply chain is a unique participant and an industry in itself, for instance, represented by *independent design consulting firms* or *Design Departments of large firms*. Correspondingly the value system ("supply chain") of the paint and coatings industry has emerged as shown in Figure 25.

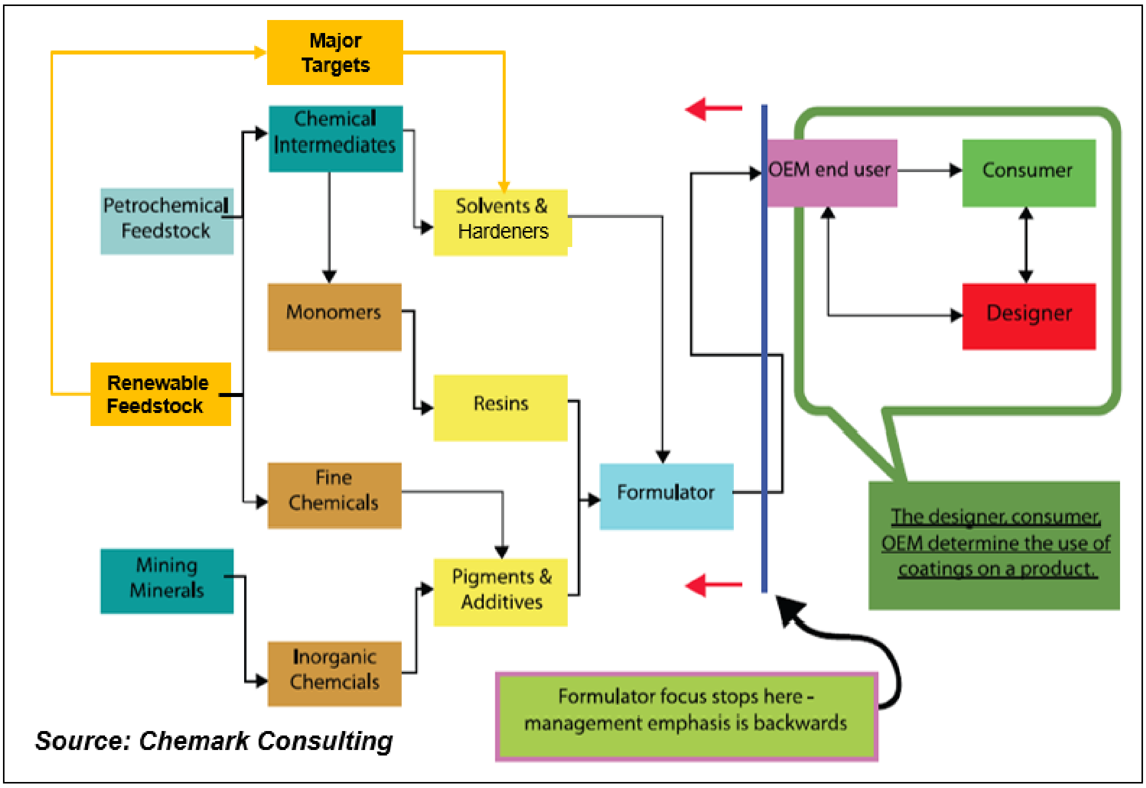


Figure 25: The "real" supply chain in the coatings industry [Lowry 2007] modified by adding "Renewable Feedstock".

Current practical use of renewable feedstock for coatings can already refer to "green" hardeners (crosslinkers) as described above and "*green solvents*" [Runge:1114-1115].

Even if almost no solvent is present in the final dried paint film due to evaporation, their role is essential in coating formulation. Solvents control the viscosity for the application and can have an important effect on film quality, which is strongly dependent on the solvent evaporation rate during drying. As a result of this they can affect properties such as film appearance, adhesion, or even corrosion.

But currently also for the resin/binder part of coatings there are first examples of “green” polyurethane (PU) coatings.

For instance [BioAmber 2013], in 2013 at the European Forum for Industrial Biotechnology (EFIB) BioAmber [Runge:1115-1117] together with Synthesia and Stahl Holdings presented a practical example of an emerging supply chain for *eco-wood coatings* based on succinate polyols from Synthesia, made by BioAmber bio-succinic acid [Runge:1114-1118,1121-1124]. Synthesia manufactures polyester polyols for the polyurethane industry while Stahl Holdings presented the performance of solvent-free Polyurethane Wood Coatings made with BioAmber bio-succinic acid compared to adipic acid in PU coatings. This illustrates that polyurethanes based on polyols made from renewable resources and bio-succinic acid can be used to make high performance eco-wood coatings with significantly higher renewable content and equal performance versus non-bio based coatings.

The structure of the global paint and coatings industry can be described taking that of Germany as a representative sufficient also for other countries and the global situation and for the position of SiliXan GmbH.

There are about 250 companies operating in the German paint and coatings industry (the by far strongest in Europe) generating about €7 billion. The vast majority belongs to the class of small and medium-sized enterprises (SMEs). More than 53 percent of them have revenues less than €5 million, 12 percent have revenues in the range €5-€10 million, and almost 25 percent have revenues of €10-€50 million. Only eleven firms generated sales of more than €100 million [Gagro 2012]. In the last group the known German big names show up, such as BASF, Bayer (MaterialScience) and Evonik Industries (Degussa), but also other non-German large firms are active in the German paint and coatings market, for instance, AkzoNobel from the Netherlands, and from the US DuPont, Dow Chemical, and the Pittsburgh Plate Glass Company (PPG Industries).

Looking at their roles vis-à-vis NANO-X and SiliXan, for instance, in 2003 PPG introduced two-component clearcoat called Ceramiclear addressing scratch resistance for production painting as well as a repair paint. The technology combined polyol siloxane and silica nanoparticles (silica nanoparticles embedded in the organic binder) and can be used in a number of coating technologies, such as 1K, 2K, radiation curing (UV) and dual cure systems. And there was the claim that this was “the breakthrough into a new clearcoat generation." The technology was started as a joint development project between DaimlerChrysler and PPG Industries lasting four years and was first used in the plants in Sindelfingen and Bremen [Editorial 2004a].

As described above Dr. Sepeur assumed the development of SiliXanes to be so groundbreaking that he spoke of a billion potential and, finally, to see a market of several billion euros over the next 15 years. And he continued, "In spite of the great successes we are only at the beginning of development". “The acceptance in the coatings industry will not occur with a short-term process.”

The foundation of SiliXan GmbH looks like an approach to focus the product portfolio of NANO-X and to concentrate much efforts on successfully exploiting the envisioned market potential referring to national and international small and medium-sized enterprises (SMEs) and a perceived superiority of the SiliXane technology.

But there is a caveat. For the case of electronic chemicals Runge [2006:146] describes how realities of the market and economies of scale, not technological merit, often dictate who wins and who loses in the manufacturing marketplace. He further shows that innovation has to tackle to issue of long-term planning and financial commitment with regard to research, but may also have a longer-term commitment issue to the innovation’s commercialization phase, which means the innovation adoption.

Key Metrics

For the development of NANO-X one can differentiate two periods separated by the Great Recession (December 2007 to June 2009) and evident by the related negative impact seen in the revenue dip in 2009 (Table 14).

NANO-X developed from a research and production oriented NTBF to an essentially *research oriented NTBF*. The proportion of personnel working in R&D is ca. 40 percent [Anonymus 2009; IHK 2009] with production level having become constant (Table 14).

The number of chemists with a doctoral degree were given as seven [Lüers 2008] or six (plus one chemist with a diploma degee) [Sepeur 2009] and correspondingly for lab technicians the numbers were eight [Lüers 2008] or twelve (including two trainees) [Sepeur 2009]. Furthermore, there also worked four engineers. The total number of employees at that time were fifty employees. However, there were also some part-timers [Sepeur 2009].

Time for developments of NANO-X products ranged from half a year year (Figure 15) to four years (ca. twenty man-years) for the market ready product SILVER ICE® in case of the cooperation with Acciai Speciali Terni. Four years of development for an industrial coating solution was also reported by PPG for its coating cooperation with DaimlerChrysler. Often development periods are 1-2 years.

Around 2008 fifty percent of revenue was achieved by selling to the automotive industry [Anonymus 2009; IHK 2009]. But in 2011 NANO-X did re-orient back the strategic focus stronger on its “non automotive” customers and focused on new implementations.

NANO-X GmbH kept its organizational and financial independence generating its growth essentially by cash flow from income and to a minor degree by grants resulting from cooperation in public projects. Development occurred essentially without external finances.

NANO-X obviously seems to be *strongly oriented towards its home markets in Germany*. The Firmenwissen Database reports a tiny export rate of only four percent which, even if it were ten percent, is very surprisingly low for a German NTBF. In the preceding text some few sales in the US and cooperation in Japan are mentioned and also intentions to go abroad. But, for instance, the intention to go to the US probably did not materialize due to the Great Recession.

For the quantitative development of new ventures revenues and numbers of employees (and related productivities, revenue per employee) were used as indicators of growth [Runge:638-640]. These are given in Table 14 together with some more indicators.

The tremendous jump in revenues and number of employees in 2004/2005 related to the success with scale protection applied by the firms VW and ThyssenKrupp (Figure 14, Figure 15) is further discussed by Runge [735-736,779-780]. This event represented the breakthrough for NANO-X for its development.

In 2004 NANO-X became profitable [NANO-X].

Disregarding the special situation of the data for 2004/2005 Table 14 provides the impression that the development of NANO-X during the first eleven years of existence exhibits the characteristics of almost plateauing [Runge:558-559].

However, it is unknown (to the author) whether the founders, owners or leadership team of NANO-X actually want their firm to grow distinctly [Runge:557-558].

Table 14: Selected indicators of development of NANO-X, particularly revenues and numbers of employees.

Year	Revenue (€, million) 1)	Number of Employees 1)	No. of Patent Families	Production Level (tons)	References, Remarks
1999	0.05	5			
2000	0.5	8			
2001	1.0	16			
2002		20, 22			[Sepeur 2003]
2003		25	>10	Almost 100	[Sepeur 2003]
2004	2.5	30			
2005	5.0	43 (>40); 37	>20		[Sepeur 2006a]
2006	5.2				[Saarland 2007b]
2007	5.4	46			Estimated
2008	Almost 6	50	37	300	[Groß 2008], [Sepeur 2009]
2009	5.3				Estimated; comment in [NANO-X], cf. Table 15
2010	6				
2011		45	>40, 43	350	[Sepeur 2012]; [Anonymus 2009]
2012					

1) If not given otherwise data are from [NANO-X] and sometimes added or complemented from other sources.

The productivities (revenues per number of employees) of NANO-x were €116.000 in 2005 and the following years.

According to definition [Runge:19] NANO-X is a small enterprise (headcount < 50, turnover ≤ €10 million).

In Table 15 the equity of NANO-X around the 2009 dip in revenues from the Elektronischer Bundesanzeiger [EB] (Electronic Federal Announcements) is given. Here the effect of the Great Recession is reflected by a considerably reduced growth rate of equity in 2009. The current *equity ratio* according to the Firmenwissen Database is 80 percent (in 2013).

Table 15: Equity of NANO-X for selected years [EB].

Year	2007	2008	2009	2010
Equity (€)	2,352,154	2,778,842	2,940,285	3.602.067

NANO-X operates a site of 7,000 square meters with an area of 1,500 square meters occupied by buildings (for offices, labs and production) [Sepeur 2009].

Concerning production in 2003 the production plant and chemical warehouse provided an annual production capacity of more than 1,000 metric tons [Sepeur 2003] which was increased to an annual production capacity of about 2,000 tons [Sepeur 2006a] – after the “scale protection success”.

In relation to these capacities the actual production levels of produced material given in Table 14 appear modest. Moreover, in the current FactSheet of NANO-X (Web site of 2014/2015) a production quantity of 150 tons is cited (as well as 45 patent families).

Considering the foundation of SiliXan GmbH in 2013 one is tempted to speculate that the 350 tons of 2011 are separated attributing ca. 200 tons to SiliXan. In a similar way, one is confronted with the number of employees of NANO-X to be 35 in 2014 according to the Firmenwissen Database. Referring to the 2011 number of employees probably ten of them have been attributed (formally) to SiliXan.

After more than twelve years of existence NANO-X ceased to be regarded as an NTBF [Runge:16] and has entered the class of existing SMEs belonging in Germany to those twelve percent of paint and coatings firms having revenues in the range €5-€10 million.

Intellectual Properties

The text already has shown that NANO-X focusses strongly on trade names (TM) and registered trademarks (®). In 2009 it owned ca. twenty marks [Anonymus 2009].

On the other hand, indicated in Table 14 there is a very strong orientation on intellectual property in terms of patents. The goal was building and having one's own line of patents and patent applications [Sepeur 2003].

As mentioned above in 2014/2015 NANO-X relies on forty-five patent families. In the appendix forty-five patent families in terms of corresponding representatives are listed together with three patents (actually two families) having Dr. Sepeur as a co-inventor and Bayer AG as the only patent assignee applied for in 1998 – prior to foundation of NANO-X (Table 20).

Figure 12 and Figure 15 reveal that the approach of NANO-X to the market is essentially via cooperative developments and generation of patents together with the cooperation partner. It is not known (to the author) how commercial exploitation of the common patents is shared between the partners.

With regard to patents it is not obvious whether common patents result from a contractual joint research alliance (JRA) or joint development alliance (JDA) or whether NANO-X operated like a contract research organization (CRO) gaining certain rights to exploit the patents commercially.

Usually, if a critical component of JRA or JDA is to retain intellectual property rights, the CRO must contribute to the overall cost of the project. The goal of private research contracts then is, at a minimum, to cover all out of pocket costs and contribute to the overall overhead.

A list of patent co-assignees of NANO-X is given in Table 16. Including also the three patents of Bayer (Bayer MaterialScience) with Stefan Sepeur as a co-inventor (1-3 in Table 20) it turns out that Bayer and Volkswagen were important partners in patenting NANO-X technologies.

Table 16: List of co-assignees of NANO-X patents (given in Table 20).

Number	Company as Co-Assignee	Remarks
6, 8, 15, 26	Volkswagen AG	
10	Genthe-X-Coatings GmbH	Partner in Cooperation-X, founded in 2000; now named GXC Coatings,
11	Alfred Kärcher GmbH & Co	
12	n-tec GmbH	Partner in Cooperation-X
13	Cofresco Frischhalteprodukte GmbH & Co KG	Figure 21

14	Profine GmbH	
16	HJS Fahrzeugtechnik GmbH & Co	Ch. Awards and Publicity
17	American Standard International Inc.	
28	Institut für Textil- und Verfahrens-technik der Deutschen Institute für Textil- und Faserforschung, Isringhausen GmbH & Co KG, Johann Borgers GmbH & Co KG, NanoCraft GbR	
29	ItN Nanovation AG	Partner in Cooperation-X; INM spin-off [Jung 2001], founded in 2000 in Saarbrücken; focuses on innovative nano-ceramic filters and coatings for large industrial customers (“CleanTech”); The ItN Nanovation group generated overall revenues of €3.4 mil. in 2013 (€3.0 mil.in 2012); operating results of 2013 (loss) were -€3.9 mil.(- €6.4 mil. in 2012)
32	Felix Schoeller jr. Foto- und Spezialpapiere GmbH & Co. KG	X-form® Technology [Sepeur 2009]
35	Kyowa Hakko Chemical Co Ltd. (Japan)	
37	Kerona GmbH	Ch. Awards and Publicity
40	Bilstein GmbH & Co KG	Bilstein: one of the world's largest supplier of cold-rolled products of cold rolling mill; has JV ThyssenKrupp Bilstein
47, 48	Bayer MaterialScience AG	Plus three patents (1-3) with Dr. Sepeur as a co-inventor

Though patenting activities of NANO-X were on average four patents/applications per year the actual time line of activities shows a different pattern. In Figure 26 the numbers of patent applications per year are presented (Table 20).

The very early period after foundation was associated with a boost of patent applications awaiting utilizing the inventions commercially. But this was probably hindered by the Dot-Com Recession and its effects covering 2002 and 2003. The following almost continuously increasing number of patent applications reflects the impacts of the Great Recession in terms of a significant dip in 2010. The following period 2011-2013 shows again rather regular patent applications but on a lower level than in the 2004-2009 period.

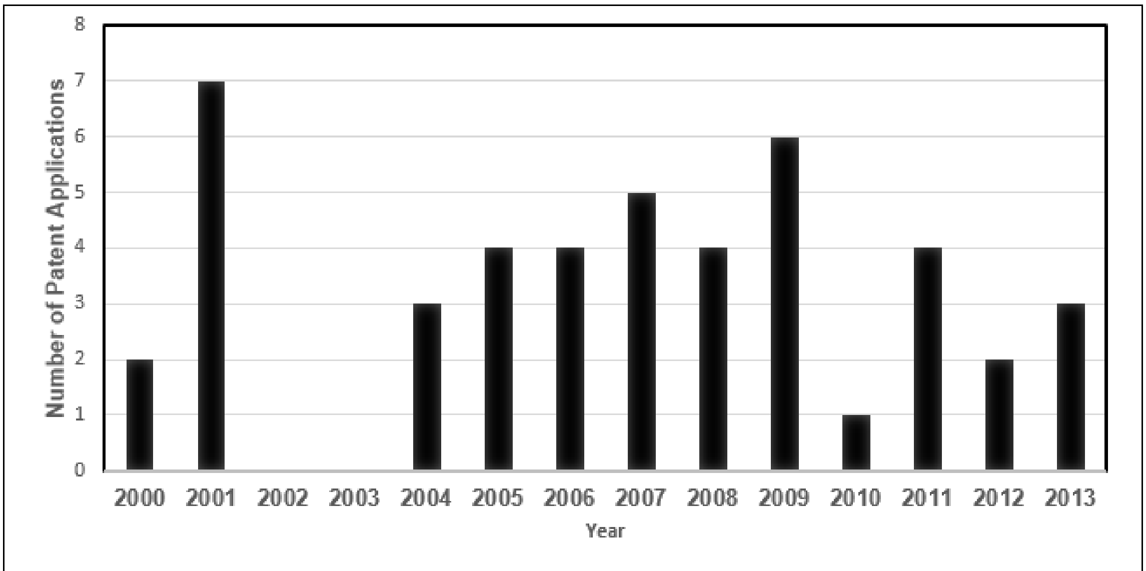


Figure 26: NANO-X patent activities – number of patent application by application year.

Addressing the variety of countries appearing in the applications of the patent families of NANO-X reflects usually a commercial orientation of firms concerning internationalization and export intentions. Apart from Germany and Europe with major designated states covering the EU countries AT (Austria), France (FR), Great Britain (GB), Italy (IT), the Netherlands (NL) and Sweden (SE) as well as Switzerland (CH) and Russia (RU) the Asian countries China (CN), Japan (JP), Korea (KR) as well as the North American countries Canada (CA) and the US (Figure 27) appear as a surprise considering the low export rate of NANO-X.

Disregarding WO-patents of the World Intellectual Property Organization (WIPO) the US as a patent country shows up with eighteen counts after Germany and EP, though currently the US seems to be a minor market, with the exception of one or the other named customer.

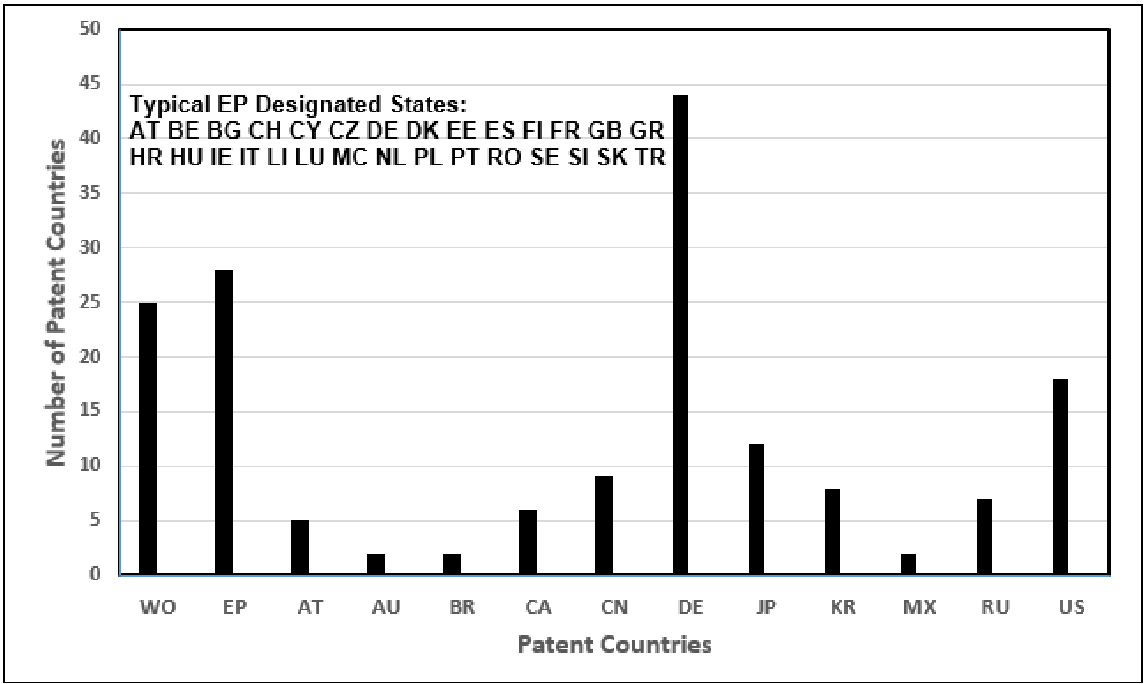


Figure 27: Distribution of countries for patent applications of NANO-X patent families.

Relative importance of patents for a firm refers usually to the number of application countries in the patent families. For NANO-X we consider two qualitative measures for indicators of relative importance.

- **Very important inventions:** different application countries > 7
- <u>Important inventions:</u> different countries = 6-7.

Indicators of relevant importance of patents (in Table 20) are expressed by presenting the related numbers of different countries in patent families in bold face font or by an underline as defined above. EP patents are counted as one country.

Out of the forty-five patent families (Table 20) five of them are regarded as very important and six as important. The overall eleven outstanding patent families account for twenty-five percent of the whole set which actually means an expected “80:20” rule is almost met.

Accordingly, the two most important patent families comprise the family No. 15 with eleven countries, which includes a granted US patent (7,645,404, January 12, 2010) together with Volkswagen AG and ThyssenKrupp Steel AG related to the composition for producing a protective layer against scaling on the surface (Figure 12, Figure 15). Note that ThyssenKrupp Steel AG does not occur in the related German basic patent. The SiliXane technology (No. 22) with ten different patent countries in the related family is next.

Indicative for the very broad technological scope and claims of the SiliXane technology patent family (Figure 24) is that it contains also four US patent applications from 2009, 2010, 2011 and 2012.

One often observes that it is rather difficult and/or time-consuming for non-US companies to enter the US market with a new particular technology or application. The key for progress would be to find a competent, well known and committed distributor or generating the perception to be a US firm via a subsidiary, say NANO-X Inc. or SiliXan Inc. Well known in this situation means well known to the (nano)coatings market/industry. This could be supported by regular attendance of related exhibitions, fairs, conferences or meetings in the US and efforts to increase networking referring to already existing reference customers in the US.

Location of a subsidiary in the US could be Chattanooga (Tennessee) where Volkswagen Group of America inaugurated its Chattanooga Assembly Plan. The $1 billion plant, opened in May 2011, serves as the group's North American manufacturing headquarters. And also BASF has production capabilities at Chattanooga.

Irrespectively of the how, entering the US market would require considerable efforts and financial investments.

Furthermore, in a technical field US authors often disregard (intentionally or unintentionally) contributions from abroad. An example is a recent “review and perspective” concerning “*Organosilane Technology in Coating Applications”* presented by three authors of the Dow Corning company [Materne et al. 2012].

“Dow Corning pioneered the development of organosilane technology more than 50 years ago to provide new classes of materials with specific physical and chemical properties: silicones and silanes.” [Materne et al. 2012]. “Sol-gel material architecture” is shown as a graphic to introduce a sub-chapter. “A segment of the coatings industry in which silanes provide crucial functionality is primer systems, in which silanes are used either to pretreat a substrate or are added into a coating formulation as an adhesion promoter.”

More descriptions report the following. For paints and coatings siloxane-alkyd, siloxane-epoxy and siloxane-acrylic chemistries can be used to improve industrial, architectural and marine antifouling coatings. By combining silanes with organic resins and through careful manipulation of the hydrolysis/condensation balance, it is possible to create coatings with superior properties, such as low viscosity, high solids content and low VOC; adhesion to metals, cements and quartz-like surfaces; low combustibility; and improved heat and UV resistance, which results in improved gloss retention. Some special considerations target

- Impregnation
- Abrasion-Resistant Coatings
- Metal Corrosion Protection.
- Chromium Replacement.

Without any citations there is the conclusion: “Some self-cleaning, easy-to-clean and scratch resistant coating applications are already using sol-gel technology.” There are forty-one references in the overview including eight US patents. No reference refers to NANO-X and none of the US patent applications or granted patents of NANO-X are taken care of.

Moreover, in 2006 the German firm Nanogate AG (viewed as “an ideal technology leader for Dow Corning”) and Dow Corning Corp., Midland, Michigan (USA), signed a long-term cooperation agreement to jointly develop and manufacture special hybrid materials systems for a wide range of applications and industries to offer additional innovative products and materials targeting markets such as protective coatings for buildings and textiles. Entering into meaningful business relationships is an important part of the corporate strategy at Nanogate as well as Dow Corning [Nanogate 2006].

Nanogate, founded in 1998, one year prior to NANO-X, to commercialize chemical nanotechnology is also a spin-out of the Institute of New Materials (INM) [Runge:683,741-742; Runge 2006:550] [4]

Therefore, one may speculate that Dow Corning has no interest to invite other US firms to seek cooperation with (or even acquisition of) another German firm leading in chemical nanotechnology.

Vision/Mission, Business Model and Risks

The founders of NANO-X presented their story [NANO-X] by a timeline embedded into an entry and an exit statement emphasizing a *vision* of “products of the future” based on research and production:

> “Once upon a time ... there were a chemist, and electrical engineer. They had an idea: We develop the products of the future!”
> “... And if they are not doing research they are about to produce still today!”

Specifically related to an approach “from rust removal to permanent protection” NANO-X said “Our vision is a cleaner world.” [Pressebox 2014]. Moreover, (chemical) nanotechnology can appear as a “green technology”, for instance, if precious raw materials can be utilized more efficiently or if nanotechnology provides a direct contribution to environmental protection.

In this sense Dr. Sepeur was honored by the German Association of Nanotechnology (Deutscher Verband Nanotechnologie e.V. – DV Nano) with the Environmental Award "Green Dwarf" [Pressebox 2013c].

The *mission* extracted from its way of operation can be expressed essentially as follows;

> NANO-X GmbH develops and produces coating materials in the field of chemical nanotechnology providing special or even multi-functional properties to objects and substrates following a path from niche and customized developments to serial production for the mass market. This comprises standard market-ready coating materials as well as well-engineered coating solutions.

There is a difference between a company that happens to use nanotechnology for one application, say scratch resistant coatings of metals and glass, and a so-called nano-platform company that is applying the science and technology broadly to a variety of products. Accordingly NANO-X is a *nano-platform company*.

Since its inception NANO-X followed “sales through production, not development!” and “innovation as a basis for market (competitive) advantage and higher added value.” Product innovation plays a key role as the fragmented nature of the market results in many companies developing new products to gain competitive advantage.

Having strong IP is important for companies building a base in nanotechnology. Furthermore, announcing relatively early new product developments and anticipated applications is important.

For its operations and innovations NANO-X exhibits *investment and innovation persistence* [Runge:625,627,682]. Novel technology and products and also innovative design effects for nanocoatings are often generated by cooperative R&D. Incremental innovation proceeds by continuous improvement of existing products.

Regarding the business model of NANO-X we shall focus roughly on the years after foundation till around 2011 which accidentally represents the twelfth year of existence. By definition [Runge:16], at the end of this year NANO-X has ceased to be an NTBF. Except for the Great

Recession this was a time of a rather stable or slowly changing way of running its business (Figure 12).

After 2011 NANO-X started with changing strategy and showed business model innovation.

- In 2011 NANO-X did re-orient the *strategic focus stronger on its “non automotive” customers* and focused on new implementations [NANO-X].
- There was much more emphasis on SiliXanes and medium-sized companies of the paint and coatings and chemical industries.
- Finally, NANO-X entered direct sales of standard products to professional (commercial) customers like craft operations and consumers by an online shop and a real retail shop.

Dr. Sepeur views NANO-X as a “paint manufacturer” (”Lackhersteller”) [Kappler 2009] supplying the paint and coatings industry with new kinds of SiliXane binders and related additives and developing and selling Silixane-related products by a specifically founded, formally separated company, SiliXan GmbH.

Key orientations for SiliXane, new-to-the-world-products (disruptive innovation), for developing customers would require essentially two steps: Create them and bind them [Runge:623].

Referring to publicly existing information NANO-X is currently almost entirely focused on its home market in Germany. To the knowledge of the author, no explicit strategy for internationalization, specifically entering the US market, has emerged (publicly). Entering the US market would require considerable financial and marketing efforts.

Efforts so far (in Germany) targeting *marketing and customer relationships* comprise:

Gaining visibility:

- The Web (home page, YouTube contributions)
- Public attention exclusively in the business world is achieved by participating in related industry’s fairs, exhibitions and conferences
- Attention among researchers from public research organizations and industry may be gained by participation in competence networks and related events of the network
- Reviews in scientific and technical journals; an article for instance, in the journal Magazin für Oberflächentechnik (MO 10/2014; Magazine for Surface Technology) entitled "Protecting stainless steel optimally" appeared.
- Winning various awards and prizes alone or with cooperation partners.

Customer Contacts:

- Sales and after-sales services by highly qualified scientific/technical personnel
- Customer visits
- Customization of products
- Test measurements
- Common projects.

In the sense of typical steps of customer development – Find them, Attract them, Bind them [Runge:623] – NANO-X succeeded in several cases to convert one-time customers into customers coming back to NANO-X, such as Metten, HJS, ElringKlinger or Bayer MaterialScience and Volkswagen AG (VW).

Finding customers does not only mean responding to a demand, a product or a problem-solution, but also promoting (chemical) nanotechnology to firms looking for a means of rekindling their growth.

At the end of 2014 NANO-X had a rather broad offering portfolio, ten areas of business for which continuous improvement of products occur and one channel (Dr. Nano) for direct sales to end-users (Table 17).

Table 17: NANO-X offerings portfolio by the end of 2014 [NANO-X].

Product Line	**Expressions of Products or Offerings**
x-tec® corrosion protection	Chromate-free metal pigment-containing products to protect metals from corrosion Zinc-containing products for active corrosion protection of steel Overpaintable zinc primer for paints and powder coatings Scale protection for hardening and forming of steel
x-tec® Passivierung (Passivation)	Transparent or colored scratch-resistant passivation of metals Scratch resistant corrosion protection of galvanized surfaces Scratch resistant corrosion protection of aluminum and magnesium High-temperature tarnish protection for stainless steel
x-tec® catalysis	Nanostructured highly efficient catalyst technology: • Silicate-based soot catalysis • Nanostructured electrocatalysis • Heavy metal-free oxidation catalysis
x-tec® Energie (Energy)	Nanostructured energy absorption or reflection: • Ablative coatings • IR reflective coatings
x-protect® Kratzfest (Scratch Resistant)	Highly scratch resistant protective coatings for polymer, paint and plastics: • Car paints • Temperature curable scratch resistant coatings • UV-curable scratch-resistant coatings
x-clean® Reinigungseffizienz (Cleaning Efficiency)	Easy-to-cleant or self-cleaning surfaces: • Water-repellent surfaces • Self-cleaning, photocatalysis • Nanostructured super-hydrophilic silicate layers
x-clean® Anti-Fingerprint	Anti-fingerprint with ultra-thin layers highly resistant glass layers: • Anti-fingerprint of stainless steel or Physical Vapor Deposition (PVD) surfaces (coating parts) • Anti-fingerprint for coil application
x-tec® Imprägnierungen (Impregnation)	Efficient protection against soiling: • Stone and concrete impregnation • Textile and leather impregnation
x-view® Antibeschlag (Anti-Fogging)	Anti-fog by super-hydrophilicity for glass and plastic: • A clear view through anti-fog effect
SiliXan (SiliXanes)	Raw material for the paint industry
Dr. Nano	End-user products (with direct sales via an online and a real shop)

Concerning distribution and sales operations NANO-X focus strongly on *ex-company sales* – materials/items sold directly by the company. *In-market/ex-distributor sales* – materials/items sold by the company's network of independent distributors – seems to play a minor role.

Concerning business execution for such a broad offering portfolio two immediate issues emerge:

- Can produce versus can sell (in sufficient quantity)
- Which offerings do generate a steady significant business income ("cash cows")? Which are the twenty percent of offerings that provide eighty percent of revenue?

An explicit representation of the NANO-X business model using Osterwalder’s Business Model Canvas is given in Table 18.

Table 18: Business Model Canvas (according to Alexander Osterwalder) of NANO-X and Business Model Innovation (*Later* means in 2011-2014, enlarged by Table 21).

Key Partners	Key Activities	Value Proposition(s)	Customer Relationship	Customer Segments
Partners in JRAs and JDAs and joint projects Research cooperation with various German universities	Research and development Production (relatively small scale; ca. 350 metric tons – low volume, high value) Act as a nano-platform company that is applying the science broadly to a variety of products Presence and active role in various networks Build long-term (repetitive) relationships with customers for continuously have cooperative projects	Provide *standard* products and materials for *innovative value-adding nanocoatings* of various substrates, such as metals, plastics, stones and concrete, glass, with *targeted functionality or multi-functionalities* by own production Provide *cooperative research and development* with selected partners to generate customized innovative mono- or multi-functional coatings to be used according to given specifications and required designs. Protect the underlying technology by *common patents* or act in the sense of a contract research organization to *transfer IPRs* to the project partner. Set up marketing and sales agreements or non-compete covenants, if applicable. Focus on *“green” products* or products showing direct effects of environmental protection.	Customer as the innovator: 1:1 cooperative projects – development, production, IP Build relationships with potential customers as a partner in joint projects Services for customers ranging from innovation consultancy to the development and production of high-tech coating materials by competent and top-level members of staff	Industrial customers: Automotive including component suppliers, steel, building & construction; OEM customers Professional customers: Crafts operations Kitchen, bath and sanitary appliances Often cooperation with customers target consumer markets Later: Focus on SiliXanes adding medium-sized firms of the paint & coatings and chemical industries as customers Also consumers directly served by NANO-X (market-ready and DIY coating materials)
	Key Resources		**Channels**	
	Own profits and cash from sales Partners in JRAs and JDAs and joint projects Extensive networking involving competence networks, governmental (ministries (BMFB) and non-governmental organizations (DBU) Reputation as an excellent cooperative R&D partner		Direct distribution of materials by trucks (and/or railway) Other modes of distribution? Later: Online shop and direct retail shop for professional customers like craft operations and consumers	

Cost Structure	Revenue Streams
Expenses for personnel, 50+ percent owing to very high proportion of researchers and engineers in R&D and production Keeping R&D and production facilities operational (including depreciation, raw material inventory and power) and distribution of products Cost for power ca. 10 percent	Sales of products and services (from innovation consultancy to target-oriented adjustment developments to production and support in the application of the desired coating solutions) Public research and development funds and grants Licenses

The revenue stream from the online shop and direct retail shop contribute only little to the overall revenues (“Channels”). But their value may result from promotional effects.

Concerning risks NANO-X shows a strong dependence on customer of the automotive industry including components suppliers which will induce cyclicality (customer demand following the ups (booms) and downs (recessions) of the national economic developments). The same is true for the paint and coatings industry as well as the building and construction fields.

Focusing on environmentally friendly products can mitigate negative effects only to a certain degree.

From a regulation point of view, despite their numerous uses in such domains as cosmetics, personal care and medicine, nanomaterials always remain at the center of debate regarding the risk they could represent in everyday life. It is true that nowadays a strong psychological block remains due to a lack of regulations and risk studies.

Further risks include the following aspects:

- The Company is exposed to liability risks, particularly to product liability (as are other nanomaterials firms).
- Due to the masses and complexity of intellectual property rights (IPRs) of patents, there is a risk of infringing IP rights of third parties. There is also a risk that third parties violate IP rights of NANO-X.
- Competitors (from the US, Russia, China and India) may develop superior coatings technology or cheaper technology.
- NANO-X currently has few customers by which the company’s turnover is determined.
- The partner concept of NANO-X is associated with risks, particularly if long-term commitment of cooperation partner is needed.

- If NANO-X targets distinct growth, also as a security net for further existing as a founder controlled firm, the company needs additional liquidity for their growth.
- The company's competitors may have greater resources than NANO-X.
- A growth of the company carries risks particularly if it will utilize its resources overproportionately to grow the SiliXane area.

Competition and Business Strategies

For nanocoatings product development and innovation currently takes mostly the form of small-to-medium enterprises (SMEs) developing their own in-house products and selling directly or via distributors, cooperation and/or licensing agreements between SMEs and multi-national large firms, or ultimately technology buy-outs by multi-nationals.

To put issues of competition in nanocoatings into a context it seems worthwhile to look into the favorable economic situations for nanotechnology firms in the periods after the Dot-Com Recession and the recent Great Recession.

Looking at the situation in 2007 when key nanotech startups were 6-8 years old and a certain stabilization of the startup scene has occurred Pekarskaya [2007] noted that

- Virtually every large manufacturer has some form of nanotechnology initiative [Pekarskaya 2007:5]. Not developing a nano strategy is ultimately a big risk. A premise of the nano revolution is that today's established companies will not be able to survive without a nano strategy [Teresko 2005].
- In 2007 the US, Japan, Germany and South Korea were the dominant players in nanotech activities and technology development strength [Pekarskaya 2007:17].
- Companies need to exploit international nanotech development to successfully address commercialization challenges.

Furthermore, by 2006/2007 it was generally assumed that most of the nanotech companies founded seven-to eight years ago will never reach profitability configured as they are. As the common strategies were not working at the end of 2007, a new business strategy to make nanotech companies profitable and nanotechnology an investible field was proposed [Shalleck 2007].

> The sell what you have and the "go-it-alone" strategies were rejected.

For the US (and also for Germany) the following questions where posed [Shalleck 2007]. "Why are small to medium size nanotechnology companies not growing rapidly in sales and why are they not profitable seven years after the first NNI?" (NNI = US National Nanotechnology Initiative). The following answers were provided.

First, most of the nanotech "product" offerings were *too low on the value system* to contribute attractive gross margins making sales volume the vital ingredient for profitable operations. The company focus has been on primary materials phenomena and incremental improvements to existing markets. Those foci led to low supply chain nano-products.

Realizing high sales volume from low value system offerings is arduous, dependent in most instances on the marketing efforts of other companies who may have different priorities. The higher on the nanotech supply chain a company's offerings are, the more gross margin/unit and the less the dependency for sales volume on other companies.

> Hence, nanocoatings companies are advised their offering to follow a way up the (nano)coatings supply chain (Figure 25) to gain more gross margin!

Second. A lack of "critical product mass" exists in most nanotechnology companies. There are many small nanotech companies essentially doing the same thing and addressing the same need with minor differences in approach or results – low value system sub-products.

For the next few year at least a product line that creates a completely new industry or new dominant application changing technology in an existing market was not seen at the horizon by Shalleck [2007].

He suggested that nano-companies should look around them for complementary products and/or companies, view them not as competitive but as opportunities, and merge with those companies to offer ever broader and more complete nanotech product lines (or up the supply chain lines).

> Nanocoatings companies strongly pursuing a goal-oriented new merge-to-win or acquire-to-win strategy will have the best chance for sustainable growth.

In early 2012, Scott Rickert, co-founder of Nanofilm LLC (see below; Table 19) tackled again the *issue of commercialization and production* in the nanotech area referring to a new public-private consortium in the US charged with investing more than $500 million in nanotechnology and other emerging technologies called the Advanced Manufacturing Partnership (AMP) [Rickert 2012]. AMP includes large (US) firms and well-known universities, joining with the National Economic Council, Office of Science and Technology Policy and the President's Council of Advisors on Science and Technology.

A group of the US top engineering schools will collaborate to *accelerate the lab-to-factory time-table* with AMP connecting them to manufacturers.

AMP is backed up with investments including [Rickert 2012]

- $300 million in domestic manufacturing in critical national security industries. That includes high-efficiency batteries and advanced composites – where nanotech leads.
- $100 million for the research, training and infrastructure to develop and commercialize advanced materials at twice the speed and a greatly reduced price.
- $12 million from the Commerce Department for an advanced manufacturing technology consortium charged with streamlining new product commercialization.
- $24 million from the Defense Department for advances in weaponry and programs to reduce development timetables that enable entrepreneurs get into the game.
- $12 million for consortia to tackle common technological barriers to new product development – the way earlier partnerships approached nanoelectronics.

But Rickert expressed a “deep concern that we can easily become addicted to it and start building business models to earn grants, not profits.”

Anticipated competition for NANO-X are either large (and giant) firms or startups and NTBFs targeting the same applications and products and/or markets. But, as NANO-X exhibits a rather low export rate competition is largely restricted to Germany.

First of all, there seems to be little competition with the NTBFs which participated in the $_{\text{Cooperation}}$-X. This is seen, for instance, by the fact that some related NTBFs show up together with NANO-X as patent assignees, such n-tec GmbH, GXC Coatings GmbH and ItN Nanovation AG (Table 16). Generally, after almost fifteen years of existence these NTBFs compete with NANO-X on a very low level and generate revenue of €2-€4 million per year, far less than NANO-X.

More potential competitors from recent nanotechnology collections or company lists [BMBF 2014b; Nano in Germany] are ETC Products GmbH (Deggendorf) and Heiche Group (Heiche Oberflächentechnik GmbH, Schwaigern) which both use sol-gel technology for coatings and are operational for more than twelve years in nanocoatings [BMBF 2014b:90,126].

Whereas ETC Products provides only a very small number of nanocoating products Heiche Group is a fifty years old German company group centered around Heiche Oberflächentechnik GmbH, (Schwaigern) with sites in Leisnig and Hundersdorf (Germany), Stanowice (Poland), Sátoraljaújhely (Hungary) and since 2013 in Spartanburg (SC, USA) – Heiche US Surface Technology LP – close to the BMW-Factory in Spartanburg [Heiche 2013].

Heiche provides a variety of surface treatments based on sol-gel technology (since 2000) mainly for the automotive industry, mechanical engineering, electronic industry and medical engineering. Its core competencies cover processing of components of light metals, steel and zinc die cast [BMBF 2014b:126]. Properties or functions addressed include (cf. also Table 17):

- Adhesion on metals (especially on light metals)
- Corrosion protection
- Hydrophoby (Easy-to-clean)
- Oleophoby (oil repellent)
- Electrical isolation
- Resistance against organic solvents
- Temperature resistance.

Coating thickness is 3-5 μm (transparent) or 10-15 μm (pigmented).

In 2006 the Heiche Group had revenue of €13.7 million with approximately 160 employees [Kompetenznetz Mittelstand 2006] and ca. €30 million with ca. 400 employees in 2014 [Heiche 2014].

On entering the US the above shortly introduced Nanofilm LLC focusing on thin films would appear as a potential competitor of NANO-X and in Germany Nanopool GmbH focusing also on thin films [Runge 2010] may emerge as a competitor.

As described above around 2000 some viewed Scott Rickert from the US as a role model entrepreneur for (chemical) nanotechnology. But, "for starters, his company's history is measured in decades, not months, and his company makes a profit on real products." [Teresko 2005]. Rickert's company was founded in 1983 as Flexicrystal to become Nanofilm LLC in 1985. It obtained an investment in 2000 by Carl Zeiss Vision, Inc., the US subsidiary of the German high-performance optics company [Runge 2006:236,554,562; Runge:8,45,191,265,308]. [2]

Nanofilm's move into the automotive products arena was rather difficult. It is dominated by big branding that requires serious marketing dollars to succeed. For Nanofilm to try and overcome this by themselves would be extremely difficult and costly. There would be the need to expand its plant, buy new equipment, and beef up its sales and marketing within the next few years. And forming a strategic alliance with a company that already has the complementary assets required to succeed in the automotive products field would be attractive.

Over its life-time Nanofilm encountered several periods of fighting for survival but also showing growth as can be seen in Table 19.

Table 19: Selected key development events of Nanofilm.

Year	Situation, Events	Indicators: Revenues, Number of employees
	Dr. Scott Rickert, was already researching self-assembling thin films (nanometers to microns, 2-2,000 nm) as part of his work as a professor at Case Western Reserve University (from 1980 to 1987).	
1985	Emergence of Nanofilm Ltd. as a spin-out of Rickert's research; co-foundation with businessman (former business executive) Don McClusky in 1985 to develop and commercialize ultra-thin films,	

	called nanofilms, to enhance the durability, clarity, ease of use and performance of transparent materials.	
1988	Dr. Rickert and McClusky managed to raise $1 million from friends, family and other individual investors by 1988 [Feder 2004; Business Week 2005].	
1989	Nanofilm was in the middle of a four-year slog to make a thin, see-through substance as tough and nonstick as Teflon and sell it to someone -- anyone. And in four years he had not made a dollar of revenue. Nanofilm was almost bankrupt. The eyeglass industry was switching from glass lenses to plastic ones, and lensmakers needed something to make them more durable [Feder 2004; Business Week 2005]. Dr. Rickert succeeded to persuade the firm LensCrafters in 1989 to pay Nanofilm to build two 1.5-ton robots to put its high-strength, protective nanocoating on premium eyeglasses. LensCrafters also agreed to pay a $4 royalty for every pair of glasses sold. Nanofilm became *profitable* the following year [Feder 2004; Business Week 2005].	Employees 17
1991	The reliance on one key customer, LensCrafters, backfired in 1991 when LensCrafters during the recession decided to shut its manufacturing in favor of outsourcing its production. Nanofilm went nearly bankrupt and shrank from 17 employees to 5. Dr. Rickert eliminated his salary and the others were cut to 65 percent [Feder 2004].	Employees 17 in 1990, then to 5
1992-1999	Almost no publicly available information for this period; probably a period of struggling for survival and slow growth	
2000	Corporate investment by Carl Zeiss Vision, Inc., the US subsidiary of the German high-performance optics company; “including a significant minority equity interest in that company.” [PTB Industry 2000]. Part of the equity arrangement: Carl Zeiss would establish a research facility at Nanofilm's headquarters in Valley View, Ohio, near Cleveland. Nanofilm in turn will establish a laboratory at the Zeiss facility in Aalen, Germany. Nanofilm became one of the few *profitable* nanotech startups [Feder 2004; Editorial 2004b; PTB Industry 2000].	Employees in 1999/2000 ca. 35
2001	It has been profitable since 2001. It took his company a good 15 years to get off [Feder 2004; Business Week 2005].	
2004/ 2005	Nanofilm distributes its first consumer product for the auto market – an antistreaking windshield coating that mimics the nanoscale structures on the surface of lotus leaves that repel dirt; it founds a small sales and distribution outpost in the Netherlands. Innovations kept Nanofilm growing and, since 2001, it is steadily profitable. “Revenues topped $15 million last year, Dr. Rickert said.” "We're the quiet company," said Dr. Rickert [Feder 2004] Nanofilm continues to pursue joint development agreements with major customers	Revenue $15 million in 2003 (or 2004?) In 2004 Dr. “Rickert said his goals included increasing revenues to $30 million to $50 million over the next five years [Feder 2004].
2006	Nanofilm was selling lens-cleaner products to opticians under the Clarity brand name and producing an anti-fogging coating for eyeglasses, sports goggles and safety glasses called Fog Eliminator. The company also made Clarity Defender Auto Glass Treatment, an ultra-thin coating that protects windshields by repelling rain, dirt, bird droppings, snow and ice. Nanofilm launched products including a dual-purpose cleaning/ conditioning optical coating and an easier-to-apply version of Defender. Nanofilm has landed a handful of new corporate clients [The Plain Dealer 2006].	

2008	Ferro Glass Systems and two other businesses in the company's Inorganic Specialties Group will market Nanofilm's nanocoatings to the global glass and ceramic industries to keep architectural and automotive glass clean and protective coatings for technical display glass, appliance glass, solar glass, glass cookware and other containers. Ferro Corp: 2008 sales of $2.2 bil. with 5,600 employees. This relationship combines Ferro's extensive sales network and leading performance materials supplier position in the glass and ceramic industries with Nanofilm's technology platforms and experience in formulating thin films for a wide range of substrates and surfaces [GlassWorld 2008].	
2011		Employees 50 [NanoBusiness 2011]
2012		Rev. $7.5 mil., Emp. 65 [Plunkett Research 2013]
2013		Rev. $8.0 mil., Emp. 65 [Plunkett Research 2013]
2014	Merger of Nanofilm and Applied Nanotech Holdings, Inc. to a new company PEN Inc. (Products Enabled by Nanotechnology) [Businesspress24 2013; Yahoo 2015]	

When looking at Nanopool GmbH [Runge 2010; BMBF 2014b:228] which is also active in *ultra-thin layers* the firm claims its technology to be "suitable for the functionalization of nearly all surfaces." Nanopool is located also in the Federal State of the Saarland, rather near to NANO-X.

Nanopool uses a technology called "liquid glass" marketed as NP® Technology. It operates in the clandestine concerning revenues, numbers of employees or profitability, but claims "NP® technology is known in more than 150 countries through specialist journals and TV reports." Furthermore, "the NP® product specifications are successfully established nationally as well as internationally in different niche markets." [BMBF 2014b:229].

Founded in 2001 Nanopool's number of employees at its headquarters in Germany was twenty in 2008 [Runge 2010] and fourteen in 2010 [Tressel 2010] and currently there may exist some few additional employees in Nanopool sales offices or other facilities.

Admittedly, there is much confusion concerning the notions of ultra-thin layerings, nanoparticles and nanocoatings which entered discussions about liquid glass in the public. It seems that Nanopool is still heavily about to generate awareness and trust in its *"Liquid Glass"* technology and related products – despite having won some awards in the UK and recognition in Germany.

Nanopool is strongly focused on the UK concerning commercialization of its products [Runge 2010] [5, 6] But whether via blogs or individual contributions on the Web discussions express doubts about the technology/products – sometimes on the level "too good to be true". [6 ,7]

Concerning technology or innovation adoption skepticism is often expressed by characterizing an innovative offering as "too good to be true" meaning the view that something so seemingly fine must have something wrong with it, is too positive to be real or believable.

Considering all this it appears that Nanopool does not represent a significant competitor of NANO-X.

On the other hand, NANO-X as well as the German firm Nanogate AG founded in 1998 and also as a spin-out of the INM [Runge:683,741-742; Runge 2006:550] [4] are ones of the very few existing small firms operating profitably in the chemical nanotechnology area, specifically nano-coatings. Nanogate started with the name "Neue Materialien und Technologien mbH" (NMT) [Farbe&Lack 1999].

Nanogate was cited as one of the representatives in Germany, perceived from the US point of view as “the country supports innovators in interesting ways.” [von Bubnoff 2007]

Nanogate differs fundamentally from NANO-X as it resulted from a project of the INM with Bayer AG and after a short time of existing like a private-public-partnership (PPP) firm [Runge:1141-1143] it became a *venture capital financed* firm with Ralf Zastrau having been established as the CEO. Furthermore, Nanogate’s remarkable growth was associated with *non-organic growth* [Runge:681-682,740] – via acquisitions of other firms.

And at the end of 2006 Nanogate went public (at the German Stock Exchange) capturing ca. €15 million for further expansions. [4]

Concerning its cooperation with Dow Corning for Nanogate ”it is increasingly important for us to cooperate with global players in order to tap into high-volume markets effectively.”

“Our emphasis is to work on a license model within the framework of a strong, long-term relationship,” said CEO Ralf Zastrau. Nanogate would enhance materials provided by Dow Corning using chemical nanotechnology processes in order to add new properties, particularly using sol-gel processes [Nanogate 2006].

In 1999, since then operating with the name Nanogate, it had the goals to achieve revenue of DM50 (€25) million in five years at the latest and to have an Initial Public Offering (IPO) at the stock exchange [Farbe&Lack 1999]. But revenue of €25 million were finally achieved between 2010 (€15.4 mil.) and 2011 (€33.2 mil.) [Nanogate 2014].

Currently Nanogate shows revenues of €38.2 million (2012) and €53.0 million (2013) and productivity of ca. €150,000 per employee with the number of employees being 243 (2012) and 357 (2013) [Nanogate 2014:2]. According to the definition of micro, small and medium-sized enterprises (SMEs) in Europe Nanogate is a medium-sized firm just about to leave this class with revenue of more than €50 million [Runge:19].

Nanogate AG is the parent company of a holding:

Companies belonging to the Group as per 31 December 2013:	**Share of capital (%)**	**Consolidation**
Nanogate Industrial Solutions GmbH, Quierschied-Göttelborn	100	full
GfO Gesellschaft für Oberflächentechnik AG, Schwäbisch Gmünd	75	full
Eurogard B.V., Geldrop, Netherlands	100	full
Nanogate Textile & Care Systems GmbH, Quierschied-Göttelborn	100	full
Plastic Design GmbH, Bad Salzuflen	76	full
Nanogate Glazing Systems B.V., Geldrop, Netherlands	100	full
sarastro GmbH, Quierschied-Göttelborn	100	

In 2012 Lux Research Inc. assessed tomorrow’s winners in the protective coatings field addressing friction, corrosion and fouling that can juggle “extreme cost sensitivities and increasing environmental and regulatory considerations,” and Nanogate was one of them. The others – the US firms Modumetal and MesoCoat – have technologies and businesses that do not compete with those of Nanogate – and NANO-X [PaintSquare 2012].

Nanogate was assessed to follow strictly customer orientation addressing its business operations based on the following principle:

“Users must strike the right balance between performance concerns along with industry factors, including cost tolerance, regulatory drivers, throughput, volume and qualification timelines.”

Furthemore, the Nanogate Group commencing operations in 1999 has been a trailblazer in nanotechnology with first-class customer references. Nanogate also entered into strategic co-operation with international companies rather early [PaintSquare 2012].

Nanogate had started a joint venture with the US firm Air Products and Chemicals Inc., Allentown (PA), a company with ca. $7.4 billion in revenues, in 2005. Air Products and Nanogate Technologies GmbH announced the JV formation in May 2004. The Nanogate Advanced Materials JV (NAM) focused its ongoing work on advanced display technologies as well as security applications.

One focus of Air Products was nanoscale oxides and metals and was focusing many of its efforts here. The joint venture NAM, based in Saarbrücken, was developing tiny powder that can be mixed into paints and coatings to make them rock hard, fireproof or electrically conductive. It targeted market opportunities in functional films, coatings and electronic displays.

Air Products’ initial nanoparticle dispersion offerings included zinc oxide, silver, and indium and antimony tin oxides in a variety of organic, aqueous and 100 percent solids systems. Finally, Air Products purchased NAM’s nanoparticle dispersion production, and related dispersion technologies and assets located in Saarbrucken. In 2008 Nanogate Advanced Materials GmbH was fully acquired by Nanogate [Runge 2006:550; Runge:741; Teresko 2005].

According to Air Products the keys to successful nano-projects of large firms are alliances and partnerships in the spirit of open innovation. Nano was deemed essential to growing existing markets as well as entering entirely new areas.”Properties of nano-material can greatly enhance our product performance platform." [Teresko 2005]

For the entry into nanotech Air Products first formally examined the potential of nano in 2000, following a variety of nano projects and experiments. The company spent six months analyzing underlying technologies, market opportunities and timelines to nano commercialization before initiating a corporate nano strategy.

"What we think is robust about our strategy is first, our understanding of the exciting opportunities nanotechnology represents, plus our understanding that it will take five to seven years, maybe longer, to reach the marketplace." "To address these opportunities, we need to build the capabilities. To build those capabilities, we developed technology and applications for existing markets and customer channels to later springboard to adjacent markets." The trick in exploiting the nano-dimension was seen to be: Recognizing and accepting that gaining any product and business edge will require organizational rethinking [Teresko 2005].

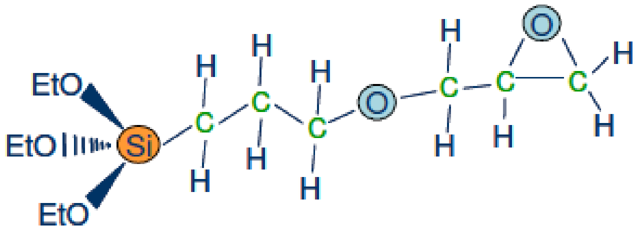
In terms of Open Innovation of Henry Chesbrough (published by Harvard Business School Publishing in 2003) "rather than restricting innovations to a single path to market, open innovation inspires companies to *find the most appropriate business model* to commercialize *a new offering* -- whether that model exists within the firm or must be sought through external licensing, partnering or venturing." (Emphasis added)

A particular strength of NANO-X is the strong links in various kinds of networks and its reputation as a very good cooperation partner (mostly in Germany). Partnering can accelerate product development enough to be first to market.

Concerning its SiliXane technology NANO-X has a technologically unique position. But operating as a “paint company” in a global, highly fragmented industry with players well established for a long time and having stable customer relationships for a long time NANO-X/SiliXan will be plagued with the typical situation of a disruptive innovation (with respect to resins/binders and additives and formulations).

An option could be to initially commercialize at a lower risk via a substitution application, for instance, replacing a resin which is in a phase-out period due to health concerns like currently the phthalates- based plasticizers in infants' toys. In the coatings area bisphenol A based epoxy resins for can coatings is such a field.

NANO-X uses an epoxy structure in Figure 7 derived from glycidyloxypropyltriethoxysilan (GPTES) which, however, does not contain aromatic sub-structures as, for instance, bisphenol A does. But there exist BPA-free epoxies claimed to replace BPA in food can coatings.



GPTES

In the past decade, consumers and health experts have raised concerns about the use of bisphenol A (BPA) in food packaging, particularly using BPA-based epoxy resins for can coatings. The chemical industry and makers of metal food packaging contend that BPA is safe. But most food companies are eager to move away from packaging based on BPA. Irrespective of the various pros and cons people (in the US) want to avoid the chemical [Bomgardner 2013].

Paint firms including Valspar, PPG Industries and AkzoNobel and chemical firms such as Eastman Chemical, Cytec Industries, and Dow Chemical are about to develop substances to replace the ubiquitous epoxies [Bomgardner 2013].

"The winning recipe or recipes need to meet high-performance requirements, because can coatings do double duty under difficult conditions. They protect the integrity of the can from effects of the food and protect the food from the steel or aluminum of the can." Coatings must maintain an airtight seal, even under the high heat and pressure built up during sterilization.

They must have minimal cost and avoid health and environmental impacts. The coating should not alter the taste or odor of the food. The most difficult hurdle for a can coating is working across *different types of food* and *as a drop-in material in high-speed manufacturing* lines.

The challenge the industry is facing: "The lowest-price, best-performing solution today is epoxy." It is assumed that no one formulation in the initial group of alternatives will work across all food and beverage types. Instead, a variety of new technologies will be required.

None of the many envisioned alternatives gets high marks in all categories of performance and safety. Many are based on acrylics and polyester resins as discussed and shown quantitatively in a table by Bomgardner [2013]. Moreover, chemical and coating companies know that any substitute they propose will be carefully scrutinized by watchdog groups.

Final issue for successfully solving all these problems would be to get FDA-approval (in the US) and approval of food-contact materials by EU Food Contact Regulation for use in can coating.

In the preceding text it was mentioned (for the case of electronic chemicals [Runge 2006:146]) how realities of the market and economies of scale, not technological merit, often dictate who wins and who loses in the manufacturing marketplace.

Similar effects may occur for SiliXane products, for instance, referring to polyurethane (PU) surface coatings. For PU coating the big name chemical firms, like Bayer MaterialScience or PPG and also some smaller ones, appear. SiliXanes emerge as a generic technology; they address the same endand the same applications (Table 17), as the well established PU manufacturers which have very long existing, stable relationships with the potential industrial customers NANO-X/SiliXane GmbH wants to attract.

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Notes

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3. *Selective Catalytic Reduction (SCR)* – Diesel Technology Forum: Selective Catalytic Reduction (SCR) is an advanced active emissions control technology system used in

Diesel engines. (http://www.dieselforum.org/about-clean-diesel/what-is-scr-last access 2/3/2015).
SCR technology is one of the most cost-effective and fuel-efficient technologies available to help reduce Diesel engine emissions. For instance, in the US all heavy-duty Diesel truck engines produced after January 1, 2010 must meet the EPA standards, among the most stringent in the world, reducing particulate matter (PM) and nitrogen oxides (NOx) to near zero levels.

4. Runge, W.: *Nanogate AG*. Technology Entrepreneurship Scripts: Handout Lectures 3.7 (p. 37), 7.8 (p. 34), 10.18 (p. 9), 10.28 (p. 14), 10.33 (p. 17). http://ce.ioc.kit.edu/55.php.

5. *Liquid Glass Canada* – A Division of Classic Glass Auto Products. We are a Canadian Distributor – Wholesale & Retail – Liquid Glass Products.
http://www.liquidglasscanada.com/ (last access 3/31/2015);
LIG PROTEC LTD. PROTEC TECHNOLOGY OF THE FUTURE (English/German language Web; Contact us: German phone number). What makes us different and why our products are so unique and special? We are a licensed and approved distribution partner for Germany, Austria and Switzerland. Liquidglass-Protec is based on a molecular compound with a SiO_2 + TiO_2 formula. Unbelievable and unique Lotus-effect. http://liquidglass-protec.com/?lang=en (last access 3/31/2015);
Liquid Glass Shield Ltd. – the home of multi-surface protective nano-technology. Covers an online shop. “As you can see from the video, the level of protection that Liquid Glass Shield provides is incredibly impressive.” “Over the last 12 months the team has grown to cover the UK, Germany, Portugal, Spain, United States and India which has given the company far reaching access to existing and new markets in most parts of the globe.” http://www.liquidglassshield.com/ (last access 1/25/2015);
Liquid Glass Nanotech: We manufacture a range of Liquid Glass coatings that offer different characteristics and benefits for each industry (UK phone number). If you have any questions or encounter a problem whilst browsing through Liquid Glass Nanotech.com please contact the Crystalusion Limited team on info@crystalusion.com or via the contact form – “Crystalusion - Liquid Glass Protection is on Facebook (last access 3/30/2015). WHAT IS LIQUID GLASS? Apart from a select group of professionals, very few people globally are even aware of this incredible “ultra thin layering” technology. https://www.liquidglassnanotech.com/liquid-glass/ (last access 3/30/2015).
Professor Nanostein: Liquid Glass explained by Professor Nanostein. Uses YouTube and interviews. “Professor Nanostein is the inventor and creator of Crystalusion Limited’s Liquid Glass coatings. He is a German scientist who currently lives in the United Kingdom working incessantly to help bring to light the benefits and characteristics of Liquid Glass. https://www.liquidglassnanotech.com/category/liquid-glass/liquid-glass-explained-in-interview-with-professor-nanostein/ (last access 3/30/2015).

6. “These treatments have been created in order to satisfy the demand for self cleaning and easy clean surfaces which possess background bacterio-static effects. It may sound as though it is too good to be true but extensive independent testing confirms the exceptional characteristics of the products.” (Reference 9 in [Runge 2010]).
A collection of press releases, mainly from the UK in 2010, was used by Nanopool to increase awareness about the potential of its liquid glass technology and drive out doubts in the technology. Relatedly the first article by Steve Connor [Nanopool 2014] which appreared in The Independent of February 1, 2010 just started with a related entry: “Liquid glas sounds like the stuff of sci-fi, but it patent holders claim it will protect us from disease, help grow crops, and keep wine delicious. But can it really live up to the hype?” And he continued: “It sounds too good to be true.”

7. The Sceptics' Guide to the Universe. *Author Topic: New "spray on liquid glass"; woo or not?* http://sguforums.com/index.php?topic=25810.0 (last access 2/21/2015).

Appendix

Table 20: Some data of the representatives of patent or patent application families of NANO-X until 2013 as obtained from the German DEPATISnet patent database [1)] including three patents of Bayer AG with Stefan Sepeur as a co-inventor.

Number [2)] – Patent Publication Number	Application Date	Inventor	Patent Assignee/Owner	Title
1 CN000001162488C	1998 08 17	Bier Peter, DE Krug Herbert, US Sepeur Stefan, DE	Bayer AG, DE	[EN] Coating compounds based on silanes contg. epoxide groups
2 BR000009812024A	1998 08 17	Bier Peter, DE Krug Herbert, US Sepeur Stefan, DE Stein Sabine	Bayer AG, DE	[PT] Composições de revestimento à base de silanos contendo grupos epóxido
3 DE000019858998A1	1998 12 21	Bier, Peter, Dipl.-Chem. Dr., 47800 Krefeld, DE Capellen, Peter, 47803 Krefeld, DE Krug, Herbert, Dipl.-Chem. Dr., Harrison, Pa., US Sepeur, Stefan, Dipl.-Chem., 66787 Wadgassen, DE Stein, Sabine, Dipl.-Chem. Dr., Schaan, LI	Bayer AG, 51373 Leverkusen, DE	[DE] Cerdioxid enthaltende Beschichtungszusammensetzungen
4 DE000010051182A1	2000 10 16		Nano-X GmbH, 66130 Saarbrücken, DE	[DE] Nanopartikel mit hydrophoben und oleophoben Eigenschaften, deren Verarbeitung und Verwendung [EN] Nanoparticle useful for coating substrate surfaces to impart hydrophobicity and oleophobicity, has ...
5 DE000010063519A1	2000 12 20		Nano-X GmbH, 66130 Saarbrücken, DE	[DE] Lösungsmittelarme Sol-Gel-Systeme
6 DE000010128869A1	2001 06 15	Gloger, Jürgen, 38518 Gifhorn, DE Sepeur, Stefan, 66802 Überherrn, DE	Volkswagen AG, 38440 Wolfsburg, DE	[DE] Sensor zur Erfassung eines Verbrennungsparameters [EN] Sensor used for determining parameters in combustion process of combustion engine has coating with structures having parameters in nanometer ...
7 DE000010135684A1	2001 07 21		Nano-X GmbH, 66130 Saarbrücken, DE	[DE] Material zur Herstellung abriebfester, hydrophober und/oder oloephober Beschichtungen [EN] Material used for making abrasion-resistant, hydrophobic and/or oleophobic coatings comprises an alkoxysilane ...
8 DE000010148129A1	2001 09 28	Haldenwanger, Hans-Günther, 85055 Ingolstadt, DE Langenfeld, Stefan, 38547 Calberlah, DE Sepeur, Stefan, 66802 Überherrn, DE	Volkswagen AG, 38440 Wolfsburg, DE	[DE] Verbrennungskraftmaschine und Verfahren zur Verbrennung eines Luft-Kraftstoff-Gemisches [EN] Combustion engine, especially self-igniting combustion engine, has surface of component of combustion ...

9 DE000010158433B4	2001 11 29	Dräger, Nicole, 66646 Marpingen, DE Goedicke, Stefan, Dr.-Ing., 66540 Neunkirchen, DE Groß, Frank, Dr.-Ing., 66386 St. Ingbert, DE Kihm, Michael, 66346 Püttlingen, DE Schirra, Hermann, 66111 Saarbrücken, DE Sepeur, Stefan, Dr., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Beschichtung
10 DE000010158437A1	2001 11 29	Dräger, Nicole, 66646 Marpingen, DE Goedicke, Stefan, Dr.-Ing., 66540 Neunkirchen, DE Sepeur, Stefan, Dr., 66787 Wadgassen, DE Thurn, Carolin, 66787 Wadgassen, DE	Genthe-X-Coatings GmbH, 38642 Goslar, DE NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Beschichtung zur dauerhaften Hydrophilierung von Oberflächen und deren Verwendung
11 DE000010158865A1	2001 11 30	Sepeur, Stefan, 66787 Wadgassen, DE	Alfred Kärcher GmbH & Co., 71364 Winnenden, DE	[DE] Verfahren zur Beschichtung von Oberflächen
12 DE000010159288A1	2001 12 04	Groß, Frank, Dr.-Ing., 66386 St. Ingbert, DE Interwies, Jan, 84034 Landshut, DE Sepeur, Stefan, Dr., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE n-tec GmbH, 93049 Regensburg, DE	[DE] Beschichtung zum Aufbringen auf ein Substrat [EN] Coating used for impregnating textiles and paper and for antibacterial surfaces comprises an inorganic or inorganic-organic matrix with fluorinated ...
13 EP000001484372B1	2004 06 04	Arning Hans-Juergen Dr, DE Gross Frank Dr Ing, DE Sepeur Stefan Dr rer nat, DE	Cofresco Frischhalteprodukte Gmbh & Co KG, DE NANO-X GmbH, DE	[DE] Beschichtete Aluminiumfolie und Verfahren zu deren Herstellung [EN] Coated aluminium foil and process of producing same [FR] Feuille d'aluminium revêtue et procédé pour sa fabrication
<u>14</u> WO002005007286A1	2004 07 15	Frings Wolfgang, DE Gross Frank, DE Krechan Reimund, DE Sepeur Stefan, DE Weyer Christoph, DE	Frings Wolfgang, DE Gross Frank, DE Krechan Reimund, DE Profine GmbH, DE Sepeur Stefan, DE Weyer Christoph, DE	[DE] Photokatalytisch aktive Beschichtung eines Substrats [EN] Photocatalytically active coating of a substrate [FR] Revetement photocatalytiquement actif pour un substrat
15 DE102004049413A1	2004 08 10	Goedicke, Stefan, 66540 Neunkirchen, DE Paar, Uwe, 34128 Kassel, DE Sepeur, Stefan, 66787 Wadgassen, DE Steinhoff, Kurt, 47533 Kleve, DE	NANO-X GmbH, 66130 Saarbrücken, DE Volkswagen AG, 38440 Wolfsburg, DE	[DE] Verfahren zur Beschichtung von metallischen Oberflächen
16 DE102005021658A1	2005 05 06	Gros Frank, DE Steigert Simon, DE Zirkwa Ingo, DE	HJS Fahrzeugtechnik GmbH & Co, DE NANO X GmbH, DE	[DE] Träger [EN] Automotive catalyst comprises sintered metal filter substrate covered by intermediate layer of aluminum oxide and silicone dioxide nano-particles
<u>17</u> DE102005027789A1	2005 0615	Groß, Frank, Dr.-Ing., 66386 St. Ingbert, DE Schlick, Gerd, Dr.rer.nat., Freyming-Merlebach, FR Sepeur, Stefan, Dr.rer.nat., 66787 Wadgassen, DE	American Standard International Inc., New York, N.Y., US NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Alkalistabile Sol-Gel-Beschichtung

18 DE102005059613A1	2005 12 12	Goedicke, Stefan, Dr., 66540 Neunkirchen, DE Reuter, Nicole, Sarreguemines, FR Sepeur, Stefan, Dr., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Beschichtungsmaterial für Substrate [EN] Coating material, useful for substrates e.g. steel and leather, comprises lubricant, binder, pigment or filler material, a solid substrate that bounds to ...
19 DE102005059614A1	2005 12 12	Goedicke, Stefan, Dr., 66540 Neunkirchen, DE Reuter, Nicole, Sarreguemines, FR Sepeur, Stefan, Dr., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Beschichtungsmaterial zum Schutz von Metallen, insbesondere Stahl, vor Korrosion und/oder Verzunderung, Verfahren zum Beschichten von Metallen und Metallelement [EN] Anti-corrosion and/or anti-scaling ...
20 DE102006023375A1	2006 05 17	Goedicke, Stefan, Dr., 66540 Neunkirchen, DE Groß, Frank, Dr., 66740 Saarlouis, DE Sepeur, Stefan, Dr., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Beschichtungsmaterial
21 DE102006044310A1	2006 09 18	Laryea, Nora, Dr., 66113 Saarbrücken, DE Schlick, Gerd, Dr., Freyming-Merlebach, FR Sepeur, Stefan, Dr., 66787 Wadgassen, DE Thurn, Carolin, 66265 Heusweiler, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Silanbeschichtungsmaterial und Verfahren zur Herstellung eines Silanbeschichtungsmaterials
22 DE102006044312A1	2006 09 18	Groß, Frank, Dr., 66740 Saarlouis, DE Laryea, Nora, Dr., 66113 Saarbrücken, DE Mönkemeyer, Melanie, 66287 Quierschied, DE Sepeur, Stefan, Dr., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Verfahren zur Beschichtung von Oberflächen und Verwendung des Verfahrens
23 DE102006056427A1	2006 11 28	Goedicke, Stefan, Dr., 66540 Neunkirchen, DE Sepeur, Stefan, Dr., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Keramisches Beschichtungsmaterial
24 DE102007016946A1	2007 04 05	Frenzer, Gerald, Dr., 66130 Saarbrücken, DE Groß, Frank, Dr., 66740 Saarlouis, DE Sepeur, Stefan, Dr., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Beschichtungsmaterial mit einer katalytischen Aktivität und Verwendung des Beschichtungsmaterials [EN] Coating material for applying on substrate, i.e. glass and metal, and for manufacturing coatings ...
25 DE102007028391A1	2007 06 15	Frenzer, Gerald, Dr., 66130 Saarbrücken, DE Oliveira, Peter William, Dr., 66111 Saarbrücken, DE Sepeur, Stefan, Dr., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Partikel bzw. Beschichtung zur Spaltung von Wasser

26 DE102007038214A1	2007 08 13	Goedicke, Stefan, Dr., 66540 Neunkirchen, DE Paar, Uwe, 34128 Kassel, DE Sepeur, Stefan, Dr., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE Volkswagen AG, 38440 Wolfsburg, DE	[DE] Verfahren zum Korrosionsschutz von Karosserie-, Fahrwerks-, Motorbauteilen oder Abgasanlagen
27 DE102007038215A1	2007 08 13	Breyer, Christine, Dr., 66117 Saarbrücken, DE Goedicke, Stefan, Dr., 66540 Neunkirchen, DE Sepeur, Stefan, Dr., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Verfahren zur Herstellung einer aktiven Korrosionsschutzbeschichtung auf Bauteilen aus Stahl
28 DE102007017303A1	2007 11 04	Akari, Sabri, Dr., 78250 Tengen, DE Armin, Volkmar von, Dr., 73230 Kirchheim, DE Laryea, Nora, Dr., 66113 Saarbrücken, DE Mehmen, Knut, 47166 Duisburg, DE Sartor, Simon, 33813 Oerlinghausen, DE Scherrieble, Andreas, 72762 Reutlingen, DE Sepeur, Stefan, Dr., 66787 Wadgassen, DE Stegmaier, Thomas, Dr., 73277 Owen, DE	Institut für Textil- und Verfahrenstechnik der Deutschen Institute für Textil- und Faserforschung Denkendorf - Stiftung des öffentlichen Rec, 73770 Denkendorf, DE Isringhausen GmbH & Co KG, 32657 Lemgo, DE Johann Borgers GmbH & Co KG, 46397 Bocholt, DE NANO-X GmbH, 66130 Saarbrücken, DE NanoCraft GbR (vertretungsberchtigte Gesellschafter: Michael Korte,78247 Hilzingen, Harald Kühn, 78315 Liggeringen, Dr. Sabri Akari, 78520 Tengen), 78234 Engen, DE	[DE] Antibakteriell wirksames Mittel und dessen Verwendung
29 DE102008019785A1	2008 04 18	Frenzer, Gerald, Dr. rer. nat., 66130 Saarbrücken, DE Goedicke, Stefan, Dr.-Ing., 66540 Neunkirchen, DE Meyer, Frank, Dr., 66111 Saarbrücken, DE Nonninger, Ralph, Dr., 66119 Saarbrücken, DE Sepeur, Stefan, Dr. rer. nat., 66787 Wadgassen, DE	ItN Nanovation AG, 66117 Saarbrücken, DE NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Verfahren zum Herstellen einer korrosionsstabilen, gasdichten Beschichtung und Verwendung der Beschichtung [EN] Production of a corrosions-stable gas-tight coating used as an anti-adhesion coating ...
30 DE102008020216B4	2008 04 22	Breyer, Christine, Dr. rer.nat., 66117, Saarbrücken, DE Goedicke, Stefan, Dr.-Ing., 66540, Neunkirchen, DE Sepeur, Stefan, Dr. rer. nat., 66787, Wadgassen, DE	NANO-X GmbH, 66130, Saarbrücken, DE	[DE] Verfahren zum Schützen eines Metalls vor Korrosion und Verwendung des Verfahrens

31 DE102008051883A1	2008 10 16	Breyer, Christine, Dr. rer. nat., 66117 Saarbrücken, DE Goedecke, Stefan, Dr. Ing., 66540 Neunkirchen, DE Sepeur, Stefan, Dr. rer. nat., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Beschichtung zum kathodischen Korrosionsschutz von Metall, Verfahren zum Herstellen der Beschichtung und Verwendung der Beschichtung.
32 DE102008059770A1	2008 12 01	Kalthoff, Friederike, Dr., 33739 Bielefeld, DE Laryea, Nora, Dr., 66113 Saarbrücken, DE Sepeur, Stefan, Dr., 66787 Wadgassen, DE	Felix Schoeller jr. Foto- und Spezialpapiere GmbH & Co. KG, 49086 Osnabrück, DE NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Verbundwerkstoff, Verfahren zur Herstellung eines Formkörpers und Verwendung des Verbundwerkstoffs
33 DE102009005537A1	2009 01 20	Sepeur, Stefan, Dr. rer. nat., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Verfahren zum Modifizieren von Metallschmelzen
34 DE102009008144A1	2009 02 09	Frenzer, Gerald, Dr. rer. nat., 66130 Saarbrücken, DE Hüfner, Stefan, Prof. Dr., 66121 Saarbrücken, DE Müller, Frank, Dr., 66125 Saarbrücken, DE Sepeur, Stefan, Dr. rer. nat., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Verfahren zur Herstellung von Alkali- und Erdalkalilegierungen und Verwendung der Alkali- und Erdalkalilegierungen
35 JP002010242196A	2009 04 09	Fukuda Yukitoshi Kondo Takashi Kuze Yukinobu Ogura Kiyoyuki Sato Koji	Kyowa Hakko Chemical Co Ltd NANO X GmbH	[EN] Method for producing hot press steel sheet
36 DE102009021388A1	2009 05 14	Groß, Frank, Dr. Ing., 66740 Saarlouis, DE Sepeur, Stefan, Dr. rer. nat., 66787 Wadgassen, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Phenolatesterverbindungen
37 DE102009044043A1	2009 09 17	Groß, Frank, Dr., 66740 Saarlouis, DE Götz, Hans, Dr., 74635 Kupferzell, DE Isleib, Thomas, 74074 Heilbronn, DE Sepeur, Stefan, Dr., 66787 Wadgassen, DE	Kerona GmbH, 74653 Ingelfingen, DE NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Verwendung eines raumtemperaturhärtenden Beschichtungsmittels
38 DE102009044717A1	2009 12 01	Frenzer, Gerald, Dr.rer.nat., 66130 Saarbrücken, DE Groß, Frank, Dr.-Ing., 66663 Merzig, DE	NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Verfahren zum Erleichtern der Ein- und Entformung von Polymeren oder Naturstoffen [EN] Facilitating molding and demolding of polymer or natural substance, useful in producing e.g. tires for automobile, ...
39 DE202010008390U1	2010 08 27		NANO-X GmbH, 66130 Saarbrücken, DE	[DE] Reinigungsmittel für Metallteile
40 WO002011113575A1	2011 03 15	Goedicke Stefan, DE Krech Dieter, DE Sepeur Stefan, DE Zwickel Gerald, DE	Bilstein GmbH & Co KG, DE Goedicke Stefan, DE Krech Dieter, DE NANO X GmbH, DE Sepeur Stefan, DE Zwickel Gerald, DE	[DE] Verfahren zur Herstellung eines beschichteten Metallbandes [EN] Process for producing a coated metal strip [FR] Procédé de fabrication d'une bande métallique revêtue

41 DE102011114902A1	2011 10 05	Goedicke, Stefan, Dr., 66540, Neunkirchen, DE Groß, Frank, Dr., 66663, Merzig, DE Laryea, Nora, Dr., 66113, Saarbrücken, DE Sepeur, Stefan, Dr., 66787, Wadgassen, DE	NANO-X GmbH, 66130, Saarbrücken, DE	[DE] Alkydharz und dessen Verwendung in Beschichtungsmaterialien [EN] New alkyd resin comprising silane substituents useful e.g. as coating material, spackling paste, auxiliary, color lacquer, protective ...
42 DE102011054615A1	2011 10 19	Goedicke, Stefan, Dr., 66540, Neunkirchen, DE Groß, Frank, Dr. Ing., 66663, Merzig, DE Hammarberg, Elin, Dr., 66119, Saarbrücken, DE Laryea, Nora, Dr., 66113, Saarbrücken, DE Sepeur, Stefan, Dr., 66787, Wadgassen, DE	NANO-X GmbH, 66130, Saarbrücken, DE	[DE] Verfahren zum Herstellen von härtbaren Werkstoffen
43 DE102011118232A1	2011 11 10	Frenzer, Gerald, 66130, Saarbrücken, DE Hammarberg, Elin, 66119, Saarbrücken, DE Sepeur, Stefan, 66787, Wadgassen, DE	NANO-X GmbH, 66130, Saarbrücken, DE	[DE] Vorrichtung zum Reinigen von Gasen und Verfahren zu deren Herstellung [EN] Device, useful to purify exhaust gases e.g. hydrocarbons from e.g. ships, comprises selective catalytic reduction active ...
44 DE102012005806A1	2012 03 22	Goedicke, Stefan, 66540, Neunkirchen, DE Muth, Alexandra, 66539, Neunkirchen, DE Münnich, Martin, St. Avold, FR Sepeur, Stefan, 66787, Wadgassen, DE	NANO-X GmbH, 66130, Saarbrücken, DE	[DE] Verfahren zur Herstellung einer Korrosionsschutzbeschichtung
45 DE102012008959A1	2012 05 03	Laryea, Nora, 66113, Saarbrücken, DE Sepeur, Stefan, 66787, Wadgassen, DE Wottke, Alexandra, 66386, St. Ingbert, DE	NANO - X GmbH, 66130, Saarbrücken, DE	[DE] Bindemittelsystem
46 DE102013001498A1	2013 01 29	Goedicke, Stefan, 66540, Neunkirchen, DE Groß, Frank, 66663, Merzig, DE Laryea, Nora, 66113, Saarbrücken, DE Sepeur, Stefan, 66787, Wadgassen, DE	NANO - X GmbH, 66130, Saarbrücken, DE	[DE] Lackaufbau und dessen Verwendung als Fahrzeuglack, Schiffslack, Bautenschutz- oder Industrielack
47 DE102013202143A1	2013 08 02	Bulan, Andreas, 40764, Langenfeld, DE Frenzer, Gerald, Dr., 66130, Saarbrücken, DE Groß, Frank, Dr., 66663, Merzig, DE Hammarberg, Elin, Dr., 66119, Saarbrücken, DE Kintrup, Jürgen, Dr., 51373, Leverkusen, DE Sepeur, Stefan, Dr., 66787, Wadgassen, DE	Bayer MaterialScience AG, 51373, Leverkusen, DE NANO - X GmbH, 66130, Saarbrücken, DE	[DE] Katalysatorbeschichtung und Verfahren zu ihrer Herstellung

48 DE102013202144A1	2013 08 02	Bulan, Andreas, 40764, Langenfeld, DE Eiden, Stefanie, Dr., 51371, Leverkusen, DE Frenzer, Gerald, Dr., 66130, Saarbrücken, DE Groß, Frank, Dr., 66663, Merzig, DE Hammarberg, Elin, Dr., 66119, Saarbrücken, DE Kintrup, Jürgen, Dr., 51373, Leverkusen, DE Sepeur, Stefan, Dr., 66787, Wadgassen, DE	Bayer MaterialScience AG, 51373, Leverkusen, DE NANO - X GmbH, 66130, Saarbrücken, DE	[DE] Elektrokatalysator, Elektrodenbeschichtung und Elektrode zur Herstellung von Chlor

1) Expert search mode string “(IN=((Sepeur(w)Stefan)) OR PA=(nano(w)x)) NOT PA=((inst?(2w)neue(w)mat?))” provided 215 hits (by April 7, 2015); removal of patent family members reduced the set to 48 hits; 2) Numbers with bold face font indicate very important patents/applications of NANO-X based on diversity of patenting activities and number of family members larger than 7; underlining numbers indicate important inventions with 6-7 different application countries.

Table 21: Business Model Canvas (according to Alexander Osterwalder) of NANO-X and Business Model Innovation (Reduced as Table 18).

<table>
<tr>
<td colspan="2" rowspan="2">Key Partners
Partners in JRAs and JDAs and joint projects
Research cooperation with various German universities</td>
<td colspan="2">Key Activities
Research and development
Production (relatively small scale; ca. 350 metric tons – low volume, high value)
Act as a nano-platform company that is applying the science broadly to a variety of products
Presence and active role in various networks
Build long-term (repetitive) relationships with customers for continuously have cooperative projects</td>
<td colspan="2" rowspan="2">Value Proposition(s)
Provide standard products and materials for innovative value-adding nanocoatings of various substrates, such as metals, plastics, stones and concrete, glass, with targeted functionality or multi-functionalities by own production
Provide cooperative research and development with selected partners to generate customized innovative mono- or multi-functional coatings to be used according to given specifications and required designs.
Protect the underlying technology by common patents or act in the sense of a contract research organization to transfer IPRs to the project partner.
Set up marketing and sales agreements or non-compete covenants, if applicable.
Focus on “green” products or products showing direct effects of environmental protection.</td>
<td colspan="2">Customer Relationship
Customer as the innovator:
1:1 cooperative projects – development, production, IP
Build relationships with potential customers as a partner in joint projects
Services for customers ranging from innovation consultancy to the development and production of high-tech coating materials by competent and top-level members of staff</td>
<td colspan="2" rowspan="2">Customer Segments
Industrial customers:
Automotive including component suppliers, steel, building & construction;
OEM customers
Professional customers:
Crafts operations
Kitchen, bath and sanitary appliances
Often cooperation with customers target consumer markets
Later:
Focus on SiliXanes adding medium-sized firms of the paint & coatings and chemical industries as customers
Also consumers directly served by NANO-X (market-ready and DIY coating materials)</td>
</tr>
<tr>
<td colspan="2">Key Resources
Own profits and cash from sales
Partners in JRAs and JDAs and joint projects
Extensive networking involving competence networks, governmental (ministries, BMFB) and non-governmental organizations (DBU)
Reputation as an excellent cooperative R&D partner</td>
<td colspan="2">Channels
Direct distribution of materials by trucks (and/or railway)
Other modes of distribution?
Later:
Online shop and direct retail shop for professional customers like craft operations and consumers</td>
</tr>
<tr>
<td colspan="5">Cost Structure
Expenses for personnel, 50+ percent owing to very high proportion of researchers and engineers in R&D and production
Keeping R&D and production facilities operational (including depreciation, raw material inventory and power) and distribution of products
Cost for power ca. 10 percent</td>
<td colspan="5">Revenue Streams
Sales of products and services (from innovation consultancy to target-oriented adjustment developments to production and support in the application of the desired coating solutions)
Public research and development funds and grants
Licenses</td>
</tr>
</table>

Acknowledgement

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