NANOTECHNOLOGY: SMALL PARTS – GREAT FUTURE?

The still high expectations regarding nanotechnology are based on its potential of being able to generate material properties for completely new applications as well as to realize novel architectures and processes and to precisely adjust properties of macroscopic bodies by controlled assembly of these bodies from atomic and molecular components. For this reason, nanotechnology is expected to give new impetus for a wide range of socially relevant fields of application and innovations in almost all sectors of technology and industry. In information and communication technology (ICT), intensive work is being done on the development of new computer architectures which are intended to supersede conventional silicon electronics some day due to DNA and quantum computing. In power engineering, nanotechnology could give innovative impetus due to new materials. Novel nanoparticles could revolutionize chemical catalysis and production technologies. Finally, in medicine, nanobased therapeutics and carriers of active ingredients are being developed which can be positioned and dosed very precisely and which can escape immune defense or pass through the blood-brain barrier.

Due to its potential of fundamentally changing entire fields of technology (system innovation), nanotechnology is considered to be a key technology which might entail considerable economic, ecological and social consequences in the (near) future. Already more than one decade ago, the nanotechnology expert and Nobel laureate in Chemistry Richard E. Smalley described the consequences to be expected as follows (Smalley 1999): »The impact of nanotechnology on health, wealth, and the standard of living for people will be at least the equivalent of the combined influences of microelectronics, medical imaging, computer-aided engineering, and man-made polymers in this century.« Although this evaluation is rather speculative in part, it even then was based on the observation and analysis of tangible research and development activities.

VISIONS OF SALVATION AND HORROR

There are different visionary ideas which are significant particularly because they often dominate(d) the public awareness of nanotechnology and because they have been and still are discussed both in the feature pages and among experts. These visions are taking the next step. They are based on the idea that it will be possible in the future to manipulate matter at will and to assemble atom by atom and molecule by molecule according to one's own wishes. It is obvious that – depending on the personal point of view – this evokes either visions of salvation (»hope«) or visions of horror (»fear«). Though he often was considered to be a scientific outsider, it was first and foremost the American technology visionary K.E. Drexler with his »Foresight Institute« who initiated such discussions and who coined the term of »molecular nanotechnology« for his – predominantly optimistic – vision of the future regarding artificial, bacteria-like, self-replicating, intelligent nanomachines (»assemblers«) (Drexler 1986; Drexler/Peterson 1994). Moreover, his nanofuturistic visions prognosticated massive transformations of society and of the »conditio humana« due to nanotechnology. On the other hand, he – just like B. Joy (2000) – developed explicit horror scenarios regarding the extinction of all life e.g. due to self-replicating nanomachines which got out of control. In turn, this type of nanofuturism is part of a comprehensive and visionary ideology with regard to technology which mostly is referred to as »transhumanism« (Coenen 2010).

At the same time, these visions of Drexler, Joy and other futurists and technology visionaries are mainly based on assumptions concerning the future interactions of several new (or already known) technologies (for this, please also refer to A. Sauter's article on Synthetic Biology). Such visions of the convergence of different technologies are the drivers of hopes regarding extensive and far-reaching changes to the conditions of human existence. From this perspective, even on an administrative level, nanotechnology is considered to be an multidisciplinary element of interdisciplinary and transdisciplinary research and development and a convergence of nanotechnology with biotechnology, information technology, engineering sciences and further fields of technology is propagated under the name »Converging Technologies« (BMU 2010).

The enthusiasm which can be generated particularly by optimistic futuristic visions was used deliberately for example in the United States at the beginning of the 21st century in order to promote technology development. However, such a »hope and hype« strategy is always precarious. Besides the positive effects of this strategy (e.g. incentives for young scientists or arousing and sustaining political and commercial interest), there are also possible negative impacts: Thus, on the one hand, there is the danger that expectations of nanotechnology will be set too high, making disappointment inevitable. On the other hand, it might popularize the reverse of optimistic futurism – a pessimistic futurism involving apocalyptic fears and visions of horror. For this reason, a critical approach to these visions of horror, even if this initially makes them even more popular, would be an important contribution to a rational discussion which does justice to the problems of the potential – positive and negative – of nanotechnology (TAB 2008).

WHAT IS NANOTECHNOLOGY?

The American physicist and Nobel laureate Richard Feynman, who died in 1988, gave nanotechnology its name and therefore is considered to be its »founder«. In 1959 already, he prognosticated the technical opportunities of the nanoscale in a lecture (»There's plenty of room at the bottom«) and described the vision of assembling at the atomic level (»arrange the atoms one by one the way we want them«). Feynman (1959) assumed that there is no physical law excluding the possibility of moving individual atoms. According to that, it should be possible to manipulate matter at the atomic level. Thus, it should be possible e.g. to store the entire »Encyclopedia Britannica« on one grain of dust, if each atom would carry one bit. However, the atomic characters could be read only by means of a »super electron microscope«. This was presented 30 years later (1990) by D. Eigler and E. Schweizer of IBM Germany to the surprised press by means of an electron micrograph: 35 xenon atoms on a nickel substrate built the name »IBM« (Steinmüller 2006, p. 78).

The term »nanotechnology« itself was used for the first time in the 1970s by the Japanese researcher and engineer Norio Taniguchi. He described operating and manufacturing methods having a precision in the nanometer range. Precisely this fact – the technological control of the atomic and molecular dimension – is the actual new and particular thing about nanotechnology and offers the opportunity to optimize product properties in almost all sectors of the economy such as e.g. in power engineering, environmental engineering, information technology, in medical engineering as well as in the field of health and nutrition (VDI 2010, p. 19). Since the term »nanotechnology« was established, it has undergone changes again and again (Decker 2006). The term is mostly used for different scientific areas of research and technological lines of development which primarily have one thing in common: They are dealing with structures and processes on the nanometer scale.

First of all, »nano« – derived from the Greek word »nanos« meaning »dwarf« – refers to size. Nanotechnology deals with dimensions sized from approximately 1 to 100 nanometers (nm) with 1 nm being a billionth of a meter (1 nm = 10^{-9} m). To formulate it precisely: If a football would be shrunk to a sphere with a diameter of 1 nm, the degree of miniaturization would correspond to shrinking the globe to the size of a football. Thus, the dimension of nanotechnology ranges from the size of an atom approximately to the wavelength of visible light. Those are the dimensions in which basic biochemical and molecular-biological processes are taking place. Moreover, it marks a threshold where the behaviour of matter cannot be described only with the laws of classical physics anymore. Quantum effects occur increasingly: »Atoms stick to each other. Particles tunnel through potential barriers, which actually are impenetrable for them, and cannot be distinguished from each other anymore. Light turns around the corner and takes on a granular structure« (Steinmüller 2006, p. 77).

Thus, nanotechnology not only deals with tiny objects, but it also is characterized by using specific effects which (only) occur in these dimensions. Regardless of the reference to size, there is a tendency of subsuming a multitude of already established and new processes as a general term for a multitude of technologies dealing with structures and processes on the nanometer scale mentioned. This range will be achieved both by the use of new physical instruments and procedures via a further miniaturization of current microsystems and by the use of construction plans of animate and inanimate nature for the self-organizing assembly of matter.

RESEARCH POLICY ACTIVITIES – MUCH »HOPE«

Of course, research policy also focuses (and focused) on »nano«. A reference to the potentials of nanotechnologies is a »must« for every political statement regarding technologies of the future. Since the end of the 1980s already, research policy has increasingly adopted the term »nanotechnology«. Since that time, it was the basis of manifold research activities particularly in the United States resulting in a first climax in 1999 with the launch of the National Nanotechnology Initiative (NNI) which was announced and publicly promoted by the former President Clinton referring to Feynman's »vision« (Böl et al. 2010). Since the end of the 1990s, the development and establishment of nanotechnology as a key technology is promoted and funded by immense governmental funding programs in all high-tech regions worldwide. Every state that aims at boosting national cutting-edge research activities is intensively promoting this area of research.

In Germany, a comprehensive political program of action for nanotechnology has been formulated since the beginning of the 21st century by the government, but also by different initiatives of the German Bundestag. Among other things, this program has generated different frameworks for action and initiatives, manifold discourses, dialogs and communication platforms under participation of science, industry, government, associations and the public. Moreover, it has advanced the promotion of various projects regarding security research and provided for continuous status quo reports (TAB 2009). In order to further develop the potentials

On the international level, it has not been possible yet to find a concluding concretization of the rather diffuse »definition« of nanotechnology. Among other things, there are different opinions regarding criteria of demarcation such as e.g. the size of nano-objects and functional properties which have been modified by the miniaturization of structures, layers and objects. Germany is involved continuously in international discussions aiming at the development of a definition (EU commission, CEN, OECD, ISO) which is homogeneously manageable worldwide (German Federal Government 2010). As »interim solution«, mostly the definitions laid down by the Technical Committee 229 of the International Organization for Standardization (ISO) are quoted (BMU 2010):

- *Nano-objects*: Materials with one, two or three external dimensions in the nanoscale (approx. 1 to 100 nm). Nano-objects typically include nanoparticles, nanoplates and nanofibres, the latter comprising electrically conducting fibres (nanowires), nanotubes and solid nanorods.
- *Nanostructured materials*: These materials have an internal structure in the nanoscale and generally occur as compound systems of nano-objects (e.g. aggregates and agglomerates). In this case, however, they are not limited in their physical size or shape (according to ISO).

of nanotechnology for Germany in a strategically comprehensive way and to adapt them for use in tangible applications, the »Action Plan 2010« was implemented in the middle of the decade and it was followed by the »Action Plan Nanotechnology 2015« at the end of the decade. This Action Plan is intended to serve as a »common platform for a successful and sustainable use of nanotechnology in all its aspects« (BMBF 2010). In view of research promotion, regulation and health care, the European Union also intends to adopt a new action plan in 2011 which shall define strategies until 2015. Within the EU's 7th Framework Programme for Research alone which will be running until 2013, subsidies of much more than 1 billion Euros have been spent on nanotechnology up to now (BMBF 2010).

In Germany, nanotechnologies are funded by the public authorities with approximately 500 million Euros per year. The largest part of funds is contributed by the BMBF (Federal Ministry of Education and Research) which supports a large network of centers of excellence, e.g. for nanoanalysis, nanomaterials, nanoelectronics, nanooptics, nanobiotechnology, nanochemistry, ultrathin layers as well as molecular architectures and many others more. With a research quota of 14 % (R&D expenditure in relation to total sales), the sector of nanotechnologies currently is one of the most researchintensive technology areas in Germany. At the international level, there are signs of a neck-and-neck competition. The European Union, the United States and Japan are investing public funds of approximately 1 billion Euros each year in nanotechnologies. Adding expenditure of industry and of other important states (France, the United Kingdom, Korea, China, Russia), the total amount worldwide is likely to be considerably higher than 5 billion Euros per year (BMBF 2010; German Federal Government 2010; VDI 2010).

MARKET OPPORTUNITIES AND HOPES – MUCH »HYPE«

On the world markets, nanotechnology opens up (hopes for) new opportunities due to smaller, faster, more efficient and more intelligent system components for new products with novel or improved functionalities. There are several evaluations by market research institutes which try to quantify the »leverage effect« of nanotechnology by taking into consideration global market potentials of nano-optimized products. Due to the international interdependence of the markets, however, a regional localization is almost impossible. The sales in nanotechnology generated worldwide by companies located in Germany were estimated to be 33 billion Euros in 2007 (German Federal Government 2010, p. 12). Meanwhile, in Germany alone, almost 1,000 companies are working on the development, manufacturing and marketing of nanotechnological products and processes, approximately 80 % among them being small and mediumsized companies. More than 60,000 industry jobs depend on the use of nanotechnologies and nanomaterials (BMU 2010).

However, an exact specification of the market volume of products containing nanomaterials is impossible due to the transdisciplinary character of nanotechnology and due to the fact that it is very difficult to restrict the term »nano« to specific areas. Moreover, the corresponding »marketing departments« have long realized that the »nano« label means »hype«. Thus, the »nano« label is quickly given to all products which are provided with e.g. ultrafine or generally tiny particles and the surface of which has a sort of finer structure. Irrespective of general inaccuracies, market researchers assume that currently the market volume worldwide equals to 100 or even several 100 billion Euros with the trend of further increasing considerably (VDI 2010). Thus, already for 2015, the intersectoral market volume worldwide which can be influenced by nanotechnology is estimated to more than 1,000 billion Euros (BMBF 2010). Thus, in 2015, the market potential of nanotechnology would correspond to approximately 15 % of the industrial goods market. This would mean that a large part of the global production of goods, e.g. in the fields of chemistry, pharmaceutics, food, packaging, ICT, automotive and mechanical engineering as well as in energy and environmental engineering would be based on the application of nanotechnological know-how (VDI 2010, p. 34). However, such estimates are rather speculative, particularly because most product analyses do not evaluate only the »nano« share of the product (e.g. in case of »suntan lotion«, the full price of the bottles is taken as a basis for calculation instead of only the share of titanium dioxide nanoparticles). Furthermore, not all products labelled »nano« really contain »nano«. But even according to conservative (or traceable) estimates, nanotechnology actually shall play a role for approximately 10 % of all goods by the middle of the decade (Steinmüller 2006, p. 76).

PUBLIC AWARENESS AND RISK DISCOURSES – MORE »FEAR«

While, on the one hand, nanotechnology is praised as the key technology of the 21st century which is said to be able even to help fight the climate change, diseases and the world food problem, a closer look on it – e.g. on products being available on the market up to now – reveals a rather sobering picture: Though a multitude of everyday products enters the market, these products often have no distinct benefit or added value. Moreover, particularly the highly praised breakthroughs e.g. regarding resource conservation for manufacturing, consumption as well as for environmental technology in general are a long time coming.

At the same time, fundamental questions – e.g. that for potential risks – still remain unanswered: Nanostructures can be released into the environment, for example due to emissions in production or due to the use of respective products. Neither for shorter nor for longer periods of time, the potential consequences for humans and the environment are sufficiently known. Moreover, they have constituted a corresponding risk discourse. Indeed, politics (in Germany) focused on a distinct impact assessment as well as on a social and political support of this technology at an early stage in order to safeguard the interests of the economy and of consumers: Comprehensive research programs have been launched, new scientific institutes have been founded, common commissions of different groups of actors have been established and numerous public forums for dialog have been initiated (German Federal Government 2010, p. 12 f.). Nevertheless, it is not possible yet to make any unambiguous statements based on current scientific knowledge with regard to the question of which nanomaterials in which configuration might entail specific risks for humans and the environment. Particularly the possible inhalation of dust containing nanomaterials which is stable in a biological environment is associated with increased risks to health, because these dust particles might penetrate to the pulmonary alveoli and – in case of biological stability – might involve inflammations and chronic diseases (even cancer).

Besides the risk discourse related to health, the (necessary) discourse on nanotechnologies also includes fundamental ethical and social issues, e.g. regarding privacy and data protection aspects in view of increasingly efficient methods for sensor-based monitoring as well as of the collection, storage and transmission of medical and/or lifestyle data using nano-based products and processes. Also, bioethical aspects play a role, in particular with regard to interventions in the human organism, for individualized medicine as well as for fundamental questions on the image of humanity and on the man-machine relationship (Grunwald 2008), which could become relevant due to the application of nanotechnology. It is of decisive importance to scientifically reflect these issues and to discuss them in public in order to develop adequate solutions and to be able to present new perspectives. Here, it is important to evaluate both risk issues and ethical aspects in the context of the respective fields of application, because focusing solely on the scale of nanotechnology is not a reasonable criterion for a specific evaluation of this field of technology (BMBF 2010, p. 35).

Altogether, it can be stated that – at a relatively early stage – accompanying research in the fields of social sciences and the humanities also has been understood as an essential »partner for discourse« against the background of the development of nanotechnology as a key technology which has been recognized as such very early. Though, first of all, the focus has been on socio-economic aspects, very shortly social, ethical and legal implications in a broader sense have come to the fore as well (Coenen 2010; TAB 2008). In this process, which has been pushed not only by science, but also – particularly in the United States – by research managers and even politics, a rather traditional understanding of scientific and risk communication (initially) prevailed. Here, first of all, the objective was to inform people about nanotechnologies focusing on the opportunities they offer (Böl et al. 2010, p. 14). As a counterpart particularly of nanofuturistic visions (of horror) (e.g. Joy 2000), namely the far-reaching expectations of possible opportunities were used in the communication with the public in many cases and very intensively through transmission by the media. This, in turn, was discussed in the media and in the public immediately and very critically. At the same time, another aspect of the nanotechnology discourse was the concern whether strongly exaggerated expectations might arise with regard to nanotechnology and necessarily might be followed by disappointments e.g. against the background of extremely far-reaching (positive) visions (i.a. Roco/Bainbridge 2002), which had been developed in a strategy of »hype and hope« particularly in the United States (Paschen et al. 2004).

As things developed, it became obvious that the political and scientific discussions on nanotechnology mainly focused on the concern that the public or finally the consumers could respond to the newly implemented key technology with similar fears concerning risks and thus with rejection as it already was the case with some subareas of biotechnology and genetic engineering (e.g. green genetic engineering, cloning). Thus, there was the concern – e.g. due to repeated and insistent warnings by some non-governmental organizations, mainly by the ETC (2006) – »that with regard to the perception of risk, imaginable impacts on health and the environment might entail a general rejection of nanotechnology« (Böl et al. 2010, p. 15). It could be illustrated by several studies that such a concern was not generally unfounded and that, for this reason, a transparent and differentiating discussion and provision of information regarding nanotechnology and the resulting specific production processes, products and applications is required (Fleischer et al. 2010).

Particularly against the background of nanomaterials being increasingly used in consumer-near products and of an increasing and stronger exposition of employees, consumers and the environment becoming probable, consumers meanwhile are evaluating the fields of application in a very differentiated way and are calling for an explicit labelling. In particular in view of a distribution of nanotechnology-based everyday products such as cosmetics, cleaning agents, clothes and household articles, the aspects of food safety and consumer protection are becoming more and more significant (Fleischer/Quendt 2007). However, in Germany and also in Europe, information about the use of nanomaterials in products is not (uniformly) regulated by law, but to date mostly depends on the decision of the product manufacturer. Thus, in Europe, e.g. the labelling of nanoscale components in cosmetics will be mandatory only as of 2013 (BMBF 2010, p. 29). Nevertheless, particularly the areas of food and health are considered to be those fields of application which are most likely to be hit by controversies. Moreover, it has to be assumed that the way the relevant actors are dealing with consumers' needs for information and safety will significantly influence the attitudes and perceptions of the consumers (Böl et al. 2010; Sigrist et al. 2007). In Germany, Great Britain and in Switzerland, this could be identified within the framework of several public dialog procedures and consumer conferences. According to Möller et al. (2009, p. 110), the following relevant demands made by consumers can be stated in detail:

- labelling in order to allow an informed choice of products and to avoid that consumers are misled with regard to products;
- active information policy concerning research projects and initiation of public debates;
- more comprehensive risk research, risk prevention and corresponding measures of risk management;
- authorization procedures for nanoscale substances in food or additional assessment of already authorized substances in case they are nanoscale.

In general, the interactions as well as the contrast of expectations and the real perception of benefits are obvious. Finally, it is exactly this interaction which can strongly influence the (further) line of development and implementation of a field of technology. »Consumer decisions can represent the critical corrective with regard to exaggerated expectations. At the same time, exaggerated expectations might make consumers suspicious of an entire research area and consequently might prevent investors from contributing to its further development.« (Böl et al. 2010, p. 15).

INNOVATION CULTURE – PRAGMATIC MANAGEMENT OF RISKS AND OPPORTUNITIES

As surveys show, in the middle of the past decade, the majority of the European citizens initially considered nanotechnologies as generally beneficial to society and not as particularly risky. Correspondingly, according to Eurobarometer surveys, the majority was in favour of promoting nanotechnologies (Gaskell et al. 2006). Recent empirical studies on risk perception regarding nanotechnology make the concern of a general rejection of nanotechnology by the population appear rather unfounded as well. The result of a representative survey of the population concerning risk perception (Zimmer et al. 2008) was that two thirds of the respondents expect nanotechnology to offer more benefits than risks and that there are positive expectations particularly with regard to medical applications. However, it has to be taken into consideration here that many respondents comment on opportunities and risks of nanotechnology though many studies from numerous countries reveal that they have only little or even no knowledge at all regarding this technology (von Rosenbladt et al. 2007; Siegrist et al. 2007). At the same time – just as it has been shown – in many cases there was a lack of specific knowledge concerning the risks of nanotechnology in production and application and many governments and authorities in charge arranged to think more intensively than before not only about possible consequences of using this technology, but also to envisage tangible measures for regulation and prevention.

It is unquestionable that – with regard to managing these issues – a responsible assessment of the risks and opportunities involved is required for both individuals and society as a whole and that corresponding discourses have to be conducted in a transparent, public and continuous way. Besides such debates – which refer to concrete aspects of nanomaterials and nanoproducts as well as to possible consequences for humans and the environment – several activities and discussions can be identified in the context of discourses and accompanying forums of cultural, political and social sciences as well as of the humanities which, for example, are dealing with the question of which possibilities exist in society to develop and to implement an »innovation culture« in a field of technology such as nanotechnologies (Kahan et al. 2009). Such an innovation culture includes e.g. discursive development and establishment of general concepts which are committed to the principles of sustainability and/or socio-ecological prevention. Correspondingly, the necessary and politically desirable intention would be to achieve a reasonable degree of »orientation« as well as a »reduced complexity« of the technology field with regard to society's perception. In terms of a »dialogical development of a general concept«, this might contribute to reducing uncertainties regarding possible opportunities, risks, successes and failures in the development and application of innovative key technologies, to removing unnecessary obstacles to an establishment of the technology or to prevent an inadequate »hype« as well as an exaggerated »technology push« resulting from that.

Finally, it is about a changed understanding of the role (e.g. and also of cultural aspects) of science (or its methods used for gaining knowledge) in society and a stronger integration of this (new) understanding in politics. From the perspective of a participatory approach for discourse, the »evaluations of lay people based on real-life would no longer have to be considered as an expression of lacks of knowledge to overcome« and »the driving forces of scientific and technical progress would have to be analyzed thoroughly and by abandoning traditional conceptualizations« (Böl et al. 2010, p. 14). In recent years, these opinions or findings have developed increasingly in Europe as well – following the example of the United States. Correspondingly, this has been reflected in the public's perception of nanotechnology and in the discussions with regard to its public perception. Here, it has become apparent, among other things, that the cultural, political and ideological attitudes of the (respective) population essentially co-determine the perception of risks and opportunities as well as the – even political – evaluation of nanotechnology (Currall 2009; Fleischer et al. 2010; Kahan et al. 2009).

In contrast to the United States (and partly to other European countries) where nanotechnology was and still is politically communicated within a rather technophile framework (TAB 2008), the German policy approach represented by the German Federal Government's »Nano Kommission« is focusing on the precautionary principle as well as on sustainability and environmental aspects (BMU 2010) – aspects which have been of particular importance in society and politics for quite some time now. Thus, largely shared cultural and political influences are followed up – without neglecting the issue of innovation (Grunwald 2008). Altogether, this corresponds to a constructive approach for discourse with the objective of giving a »hope, hype and fear technology« a sustainable and generally acceptable direction of development.

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REFERENCES

BMBF (Bundesministerium für Bildung und Forschung) (2010): Aktionsplan Nanotechnologie 2015. Bonn

BMU (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit) (2010): Verantwortlicher Umgang mit Nanotechnologien. Bericht und Empfehlungen der Nanokommission (der Deutschen Bundesregierung) 2011. Bonn/Berlin

Böl, G.-F., Epp, A., Hertel, R. (eds.) (2010): Wahrnehmung der Nanotechnologie in internetgestützten Diskussionen. BfR Wissenschaft 04/2010, Berlin

Coenen, C. (2010): Deliberating Visions: The Case of Human Enhancement in the Discourse on Nanotechnology and Convergence. In: Kaiser, M., Kurath, M., Maasen, S., Rehmann-Sutter, C. (eds.): Governing Future Technologies. Nanotechnology and the Rise of an Assessment Regime. Sociology of the Sciences Yearbook 27, pp. 73–87

Currall, S. (2009): New insights into public perceptions. In: Nature Nanotechnology 4, pp. 79–80

Decker, M. (2006): Eine Definition von Nanotechnologie: Erster Schritt für ein interdisziplinäres Nanotechnology Assessment. In: Nordmann, A., Schummer, J., Schwarz, A. (eds.): Nanotechnologien im Kontext. Philosophische, ethische und gesellschaftliche Perspektiven. Berlin, pp. 33–48

Bundesregierung (2010): Antwort der Bundesregierung auf die Kleine Anfrage der Abgeordneten René Röspel, Iris Gleicke, Dr. Ernst Dieter Rossmann, weiterer Abgeordneter und der Fraktion der SPD – Drucksache 17/3557 – Stand und Perspektive der Nanotechnologien. Deutscher Bundestag, Drucksache 17/3771, Berlin

Drexler, E. (1986): Engines of Creation. New York

Drexler, E., Peterson, C. (1994): Experiment Zukunft – Die nanotechnologische Revolution. Bonn

Eigler, D.M., Schweizer, E.K. (1990): Positioning single atoms with a scanning tunneling microscope. In: Nature 344, pp. 524–525

ETC (Action Group on Erosion, Technology and Concentration) (2006): Nanotech Rx. Medical Applications of Nano-scale Technologies. www.etcgroup.org/en/materials/publications.html?pub_id=593

Feynmann, R. (1959): There's Plenty of Room at the Bottom. Manuscript/Talk presented at the annual meeting of the American Physical Society at the California Institute of Technology, December 29th 1959. www.zyvex.com/nanotech/feynman.html

Fleischer, T., Quendt, C. (2007): »Unsichtbar und unendlich« – Bürgerperspektiven auf Nanopartikel. Ergebnisse zweier Fokusgruppen-Veranstaltungen in Karlsruhe. Wissenschaftliche Berichte FZKA 7337, Karlsruhe

Fleischer, T., Hocke, P., Kastenholz, H., Krug, H.F., Quendt, C., Spangenberg, A. (2010): Evidenzbewertung von gesundheitsrelevanten Auswirkungen synthetischer Nanopartikel. Ein neues Verfahren für die Unterstützung von Governance-Prozessen in der Nanotechnologie? In: Aichholzer, G., Bora, A., Bröchler, S., Decker, M., Latzer, M. (eds.): Technology Governance. Der Beitrag der Technikfolgenabschätzung. Berlin, pp. 239–246

Gaskell, G., Stares, S., Allansdottir, A., Allum, N., Corchero, C., Fischler, C., Hampel, J., Jackson, J., Kronberger, N., Mejlgaard, N., Revuelta, G., Schreiner, C., Torgersen, H., Wagner, W. (2006): Europeans and Biotechnology in 2005: Patterns and Trends. Final report on Eurobarometer 64.3. A report to the European Commission's Directorate-General for Research. http://ec.europa.eu/public_opinion/archives/ebs/ebs_244b_en.pdf

Grunwald, A. (2008): Auf dem Weg in eine nanotechnologische Zukunft. Philosophisch-ethische Fragen. Freiburg

Joy, B. (2000): Why the future doesn't need us. www.wired.com/wired/archive/8.04/joy.html

Kahan, D., Braman, D., Slovic, P., Gastil, J., Cohen, G. (2009): Cultural cognition of the risks and benefits of nanotechnology. In: Nature Nanotechnology 4, pp. 87–90

Möller, M., Eberle, U., Hermann, A., Moch, K., Stratmann, B. (2009): Nanotechnologie im Bereich der Lebensmittel. Zürich

Paschen, H., Coenen, C., Fleischer, T., Grünwald, R., Oertel, D., Revermann, C. (2004): Nanotechnologie. Forschung, Entwicklung, Anwendung. Heidelberg

Roco, M., Bainbridge, W. (eds.) (2002): Converging Technologies for Improving Human Performance. Arlington

Siegrist, M., Keller, C., Kastenholz, H., Frey, S., Wiek, A. (2007): Laypeople's and Expert's Perception of Nanotechnology Hazards. In: Risk Analysis 27(1), pp. 59–69

Smalley, R.E. (1999): U.S. House Testimony. www.house.gov/science/smalley_062299.htm

Steinmüller, K. (2006): Die Zukunft der Technologien. Hamburg

TAB (Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag) (2008): Konvergierende Technologien und Wissenschaften. Der Stand der Debatte und politischen Aktivitäten zu »Converging Technologies« (author: Coenen, C.). TAB-Hintergrundpapier Nr. 16, Berlin

TAB (2009): Nanotechnologie – nachhaltig und zukunftsfähig oder riskant für Mensch und Umwelt? In: TAB-Brief Nr. 36, pp. 26–27

VDI Technologiezentrum (2010): Nanotechnologie in Ostdeutschland. Status Quo und Entwicklungsperspektiven. Zukünftige Technologien Nr. 86, Düsseldorf

Von Rosenbladt, B., Schupp, J., Wagner, G.G. (2007): Nanotechnologie in der Bevölkerung noch wenig bekannt. In: Wochenbericht des DIW 45, pp. 673–677

Zimmer, R., Hertel, R., Böl, G.-F. (eds.) (2008): Wahrnehmung der Nanotechnologie in der Bevölkerung. Repräsentativerhebung und morphologisch-psychologische Grundlagenstudie. BfR Wissenschaft 03/2008, Berlin

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