Nanotechnology
Industries Association

NIA Forecast of Emerging Technologies

Nanotechnologies

Background

The Nanotechnology Industries Association (NIA) was formed in 2005 on the initiative of companies from a variety of industry sectors including healthcare, chemicals, automotive and consumer products. The NIA creates a clear single voice to represent the diverse industries' views in the multi-stakeholder debate on nanotechnology, by providing an interface with government, acting as a source for consultation on regulation and standards, developing timely technology forecasts, communicating the benefits of nanotechnologies and interacting with the media to ensure an ongoing advancement and commercialisation of nanotechnologies.

The NIA provides a purely industry-led perspective derived from the views of the collective membership, which is made up of many varied companies all at different stages of their life-cycle and with a variety of interests in the huge range of technologies that derive their benefit from the nanoscale. This enables those seeking comment from industry to have a single point of contact to the industries and avoids the need to approach individual companies for statements on specific issues. In addition the breadth of the membership enables the NIA to put forward strong proposals to government and regulatory authorities to promote an environment that supports the application and utilisation of nanotechnologies.

Introduction

The support of an ongoing advancement of nanotechnology research, development and commercialisation is central to the NIA's role as a key-contact point between regulators and policy makers on one hand and the growing nanotechnology industries on the other; through identifying and forecasting unique areas of potential competitive advantage using nanotechnology, the NIA helps to secure the full economic and societal benefits of this exiting field of emerging technologies.

The *NIA Forecast of Emerging Technologies* provides a purely industry-led forecast, which makes exclusive use of data obtained from the industrial members of the NIA, thereby delivering a clear outline of the industrial development path for nanotechnology and its advancement over the next 15 years into more complex nanomaterials, structures and systems. The forecast examines the existing opinion of the economic potential for nanotechnologies and provides a 2020-view of the emerging technologies' impact.

The Structure

The *NIA Forecast of Emerging Technologies* is based on a flexible and dynamic framework that is not constrained by a rigid process-driven approach, but that can be applied to plot widely differing technologies on the same graph and compare them. The

framework thereby represents a versatile tool to meet the latest challenge faced by technology foresight exercises: the entry into the era of complex converging technologies.

During the stepwise progress of the NIA forecast exercise, the framework is gradually populated with data provided by the industrial members of the NIA. The forecast is reviewed regularly, in order to obtain an iterative identification of the industries' long-term aspirations.

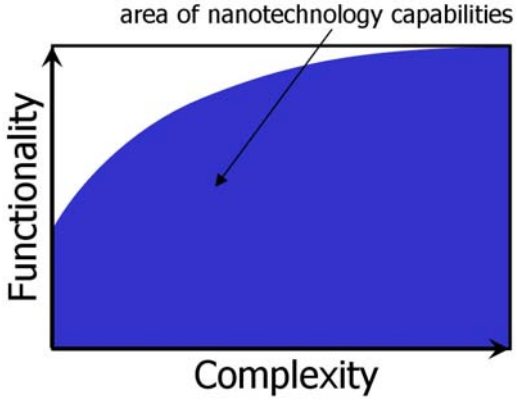

Figure 1 Illustration of the underlying concept of progression with time and complexity; the industries' collective nanotechnology capabilities as the area under the described functionality *versus* complexity curve.

Central to the *NIA Forecast of Emerging Technologies* is the model of ***progression with time and complexity***, this attribute enables the simultaneous plotting of a number of different technologies, and results in an overview of wide-ranging applications. This concept is best described graphically by adopting **Complexity** as an industry-independent dimension plotted on the abscissa, ranging from simple materials, sometimes already in manufacture on a large scale, to highly convoluted 2D and 3D constructs, that may still reside in the laboratory. The complexity ordinate indicates an increasing level of **Functionality** of a given application as an indicator of its level(s) of performance.

It is important to note that functionality is not necessarily wholly determined by complexity, as an increase in the complexity of a device does not automatically result in an increase in functionality at the nanometre scale. Figure 1 illustrates the definition of the industries' collective nanotechnology capabilities as the area under the described functionality *versus* complexity curve.

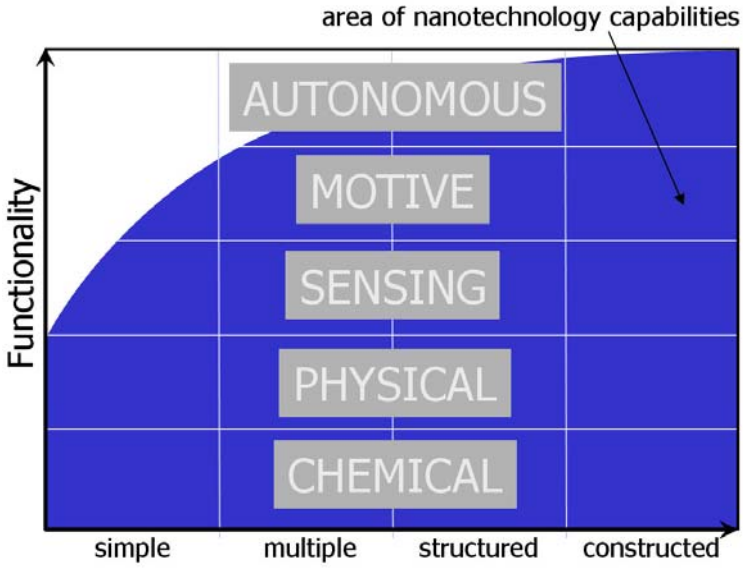

Figure 2 Division of the defining dimensions into several descriptive categories; the complexity of systems increases from simple systems, over multiple and structured to constructed systems, while the system functionality increases from chemical, over physical, sensing and motive to autonomous.

In order to facilitate the population of this chart with examples of nanotechnology-based applications, both the axes are divided into several categories, as illustrated in Figure 2. The start of both scales at the intercept of the complexity- and the functionality-axis can be envisaged as the location of a **simple** elementary article, such as a nanoparticle that performs a

basic chemical reaction; an increase in the complexity of a device with the lowest functionality can be understood as adding **multiple** components to this simple particle, while its functionality remains that of a basic chemical catalyst. The next step up in complexity leaves behind the regime of multiple complexity and introduces an element of engineering to yield the category of a **structured** component, while the final and most evolved step of increasing complexity reaches the regime of 'systems of systems', which can be understood as a **constructed** complex of several structured components. This categorisation, of course, covers both predominantly 2D structures (*e.g.* the classic silicon chip) as well as 3D structures (*e.g.* advanced DNA chips).

It becomes evident that the dimension of complexity encompasses an element of design, which increases with growing complexity to optimise the interaction of the applied building blocks.

Similar to the stepwise increase in the complexity of systems, their growing functionality can be broken down in several different ways; the following categorisation was applied for the purpose of this technology forecast: the lowest level is that of **chemical** functionality, exhibited by nanometre-sized devices with purely chemical interactions, as described above; the next level accommodates interactions that are dominated by **physical** phenomena, such as light-emitting or absorbing nanoparticles. Further increase in functionality is characterised by the regime of systems that can respond to their environment in a simple way, based on the **sensing** capability introduced to a physical functionality, while a responsive interaction with the environment and adaptation to changes in external parameters can be performed by systems that are equipped with a **motive** capability. The final step of increasing functionality is reached by **autonomous** systems that can react to external stimuli without outside input or control; these systems still only have a low degree of autonomy and remain dependent on the input of external power.[1]

The Collection of Data

The *NIA Forecast of Emerging Technologies* provides a pure industry-led view of the technological development path. In this aspect, it differs from most technology-based foresight exercises; it was developed exclusively with information provided by NIA members across a wide range of technologies, from materials producers to sub-system manufacturers to industrial end users, and illustrates the development routes into the future, as anticipated by the collective nanotechnology industries. The creation and collection of this company-specific information, however, is an ongoing process, so that the resulting plot represents an initial snapshot of the dynamically changing forecast; the resulting *NIA Forecast of Emerging Technologies* will be updated annually, and it is anticipated that new aspects of nanotechnologies will be added, while others might be taken off the roadmap, or moved to a different position on the chart, according to their status of development.

[1] Note: the *autonomous systems* described in this forecast should not be mistaken for 'grey goo', which has the unique feature of self-replication similar to that of biological systems. This technology forecast does not cover self-replicating biological systems.

This predicted fluctuation is based on an understanding of technological progress that is widely applied in the industrial world: the advancement of emerging technologies does not follow a smooth, logical path, but one that is influenced by a multitude of economic and societal parameters. Accordingly, the development of nanotechnologies is anticipated to produce unexpected phenomena as the understanding of the underlying principles increases.

The Application of Data

The NIA's industrial members provided data on nanotechnology-enabled components and systems at various stages of research, development and commercialisation; the data was divided into five major categories, illustrated in the legend displayed in Figure 3, colour-coded to enable easy interpretation and placed at appropriate locations in the 2-dimensional chart of nanotechnology capabilities (*cf.* Figure 2). Figures 4a to 4d illustrate the sequential application of the collected data.

Figure 3 Legend explaining the division and colour-coding of the data supplied by NIA members.

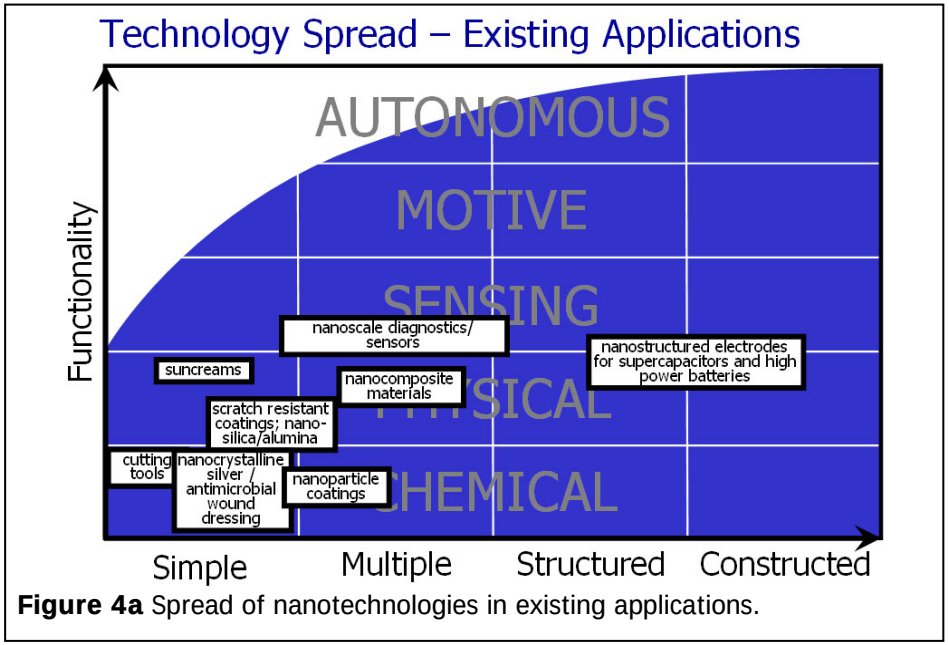

Figure 4a Spread of nanotechnologies in existing applications.

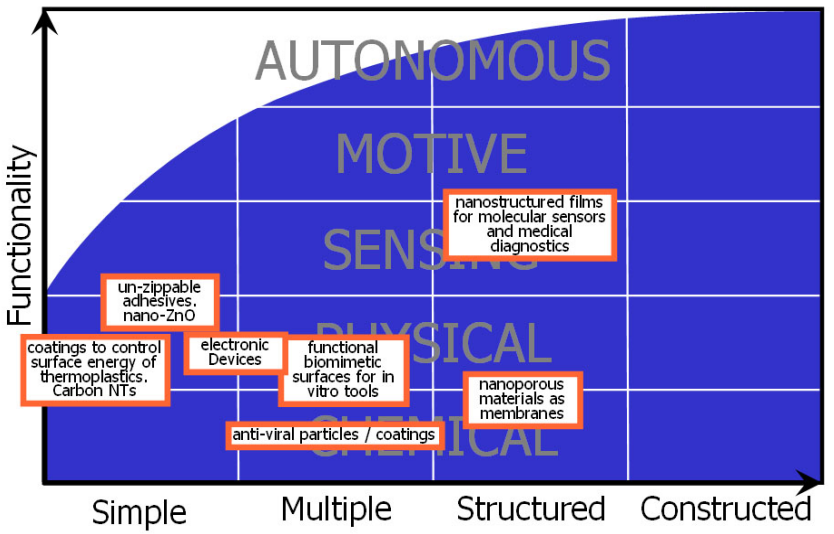

Figure 4b Spread of nanotechnologies currently under development.

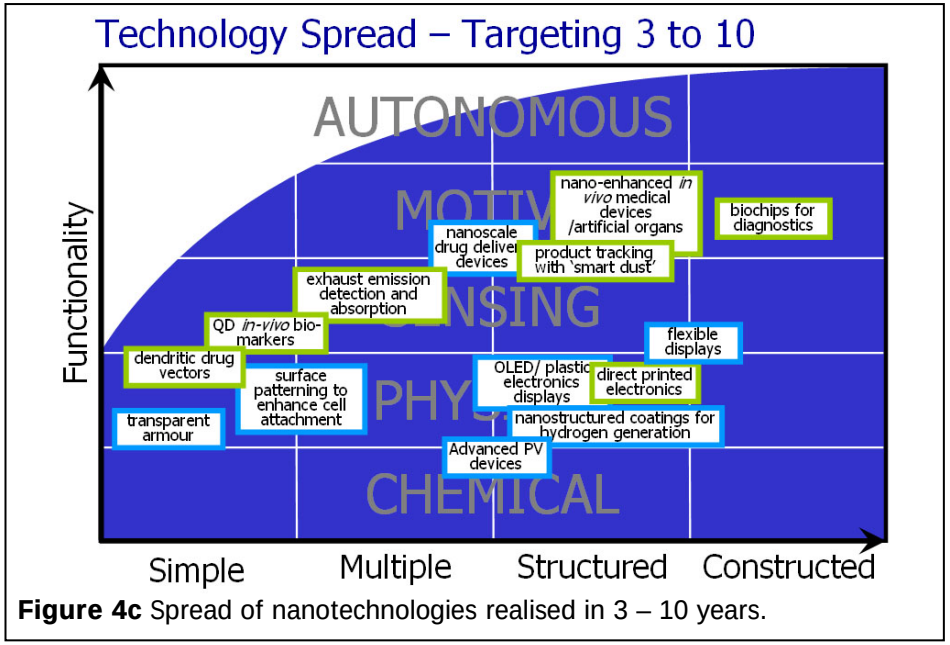

Figure 4c Spread of nanotechnologies realised in 3 – 10 years.

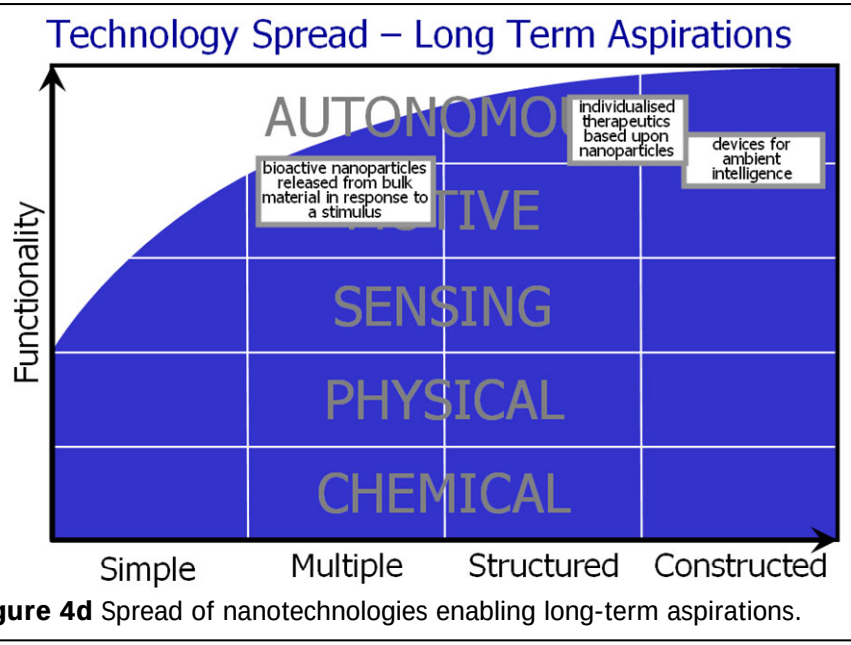

Figure 4d Spread of nanotechnologies enabling long-term aspirations.

The Amalgamation of Data

In the last step of this foresight exercise, the colour-coded examples of the five major categories of time-dependent nanotechnological development were combined and the contours of their respective locations superimposed onto the 2-dimensional chart of nanotechnology capabilities, as illustrated in Figure 5. The resulting plot enables the extraction of some overall trends in the development of nanotechnologies.

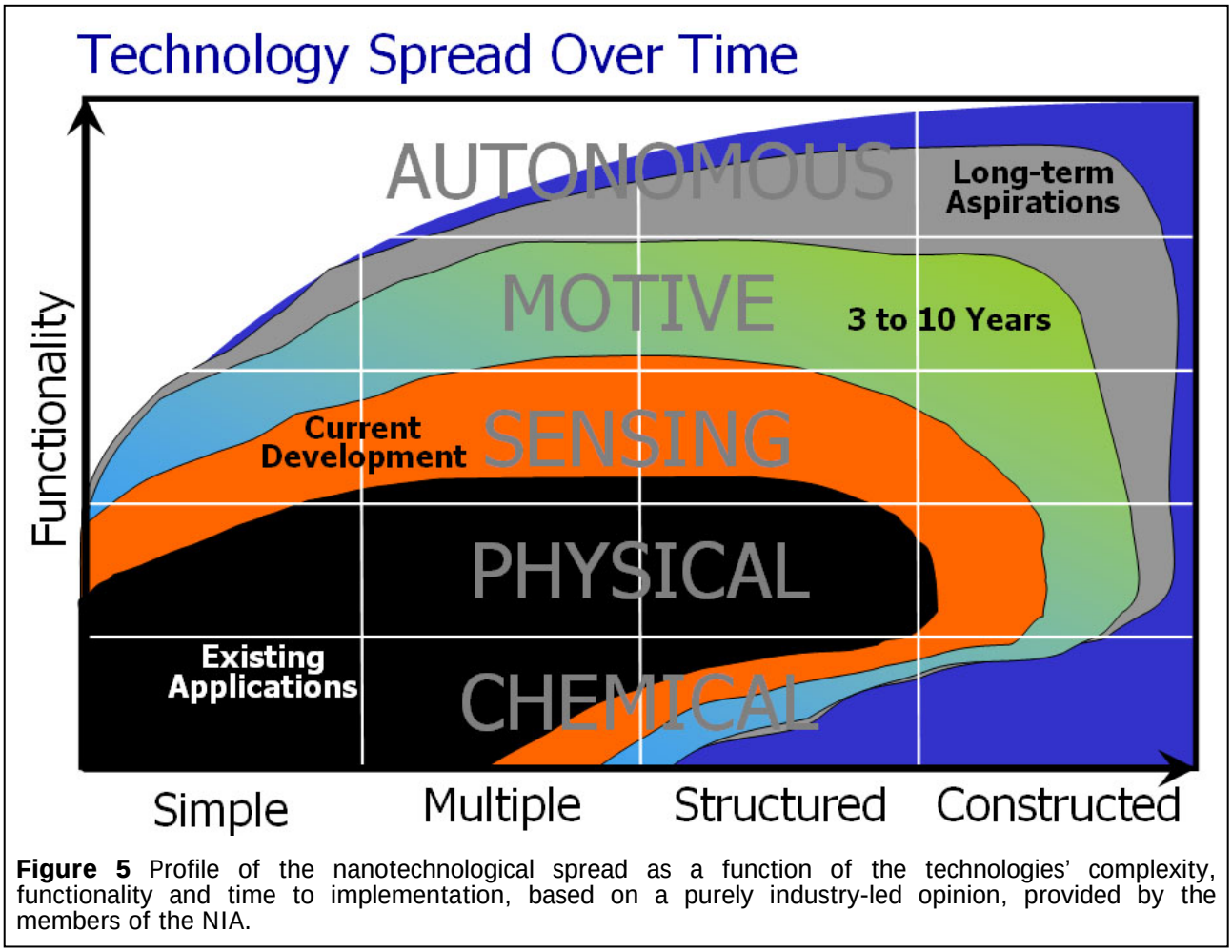

Figure 5 Profile of the nanotechnological spread as a function of the technologies' complexity, functionality and time to implementation, based on a purely industry-led opinion, provided by the members of the NIA.

Conclusion and Outlook

The NIA recognises that the advancement of nanotechnologies raises news issues, which need to be addressed in multi-disciplinary stakeholder debates. It is important to note that those nanotechnologies currently under debate by regulators, industries, scientists and the public, as well as in various multi-stakeholder bodies, are located in the bottom left corner of the chart. Even the concerns raised by far-fetched science-fiction scenarios often focus on areas far away from where the leading edge of technology is taking us, because we are currently not only lacking the tools that enable us to develop the long-term aspiration, but also the societal theories that could capture the impact of future technologies; both frameworks will need to be developed in parallel.

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The most important responsibility for current nanotechnology stakeholders, however, is to secure an objective debate of the currently commercialised and the more developed emerging technologies, in order to lay a robust foundation for both the advancement of nanotechnologies and the development of adequate assessment frameworks. The *NIA Forecast of Emerging Nanotechnologies* represents a starting point to meet this challenge, and it will be reviewed regularly, in order to keep track of the paradigm shift induced by nanotechnology.

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