Industrial Research on Polymeric Materials, Today and in the Future

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Academic as well as industrial researchers, active in the field of chemistry and more specific in the field of polymers and polymeric materials, are worrying about the future of their research field because they see so many changes happening simultaneously in their environment. The chemical industry is going through a thorough restructuring, the whole society is changing rapidly and new technologies are drawing the attention away from the traditional disciplines like chemistry and polymer science.

The changing society

The changes in our "way of living" are dramatic and they happen extremely fast at the moment. For centuries we lived in an agricultural society and then the industrial revolution changed it into a society where the industrial activity was most important. But after the second world war, computers changed the activities completely and nowadays, the new means like internet again turn the things upside down and we enter the "communication era".

We invented a lot of "buzz-words" to characterize the new developments: the "knowledge society", the "new economy", "e-commerce", the "on-line society, the "life sciences based society", the "nanotechnology", "dot com companies" etc…

It is confusing, but is it also clear that these developments are changing the way we live, the way we do business, the way we teach our next generation, the way we perform research.

In industrial research for instance, there is an unmistakable shift from generating knowledge and solving problems by experimental work towards detecting, selecting and absorbing knowledge from the external knowledge infrastructure.

The new ways of communication have several other unexpected effects. For instance, they brought along a change in the nature and the behaviour of the shareholders and this has an outspoken effect on the evolution of the stock markets and thus on the economy as a whole and on the individual companies in particular.

Which are the major technologies that lie at the basis of the present transformations?

In a study performed by the Study Centre for Technology Trends in the Netherlands, but also in many other studies, it was concluded that in the period 1950-2050, three major waves of

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technology are affecting society: the solid-state technology, the biotechnology and the nanotechnology (see figure 1).

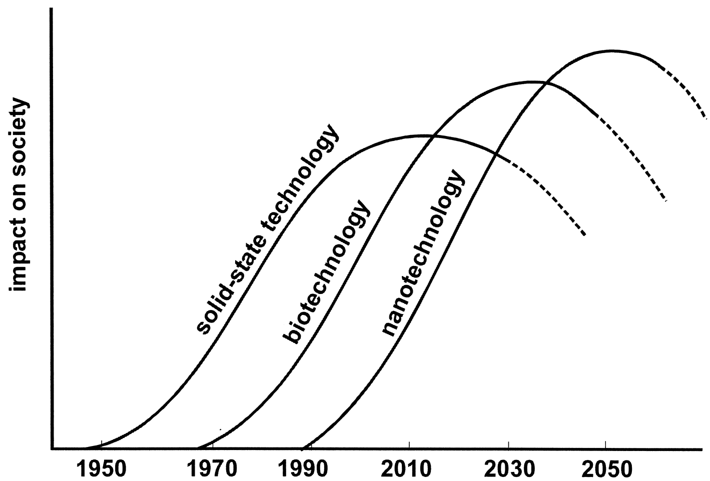

Figure 1. Waves of technology affecting society (from Nanotechnolgy, towards a molecular construction kit, ed. A. ten Wolde, STT Netherlands)

Solid state technology took off in the fifties and it is now at its maximum. You can say that it changed the world completely in 50 years. It is expected to level off now and even decline, because further developments will be taken over partly by a new technology: nanotechnology. In the mean time, another technology came up: biotechnology. Started in the 70's, it is now in its fast growing phase. It will grow further until 2020-2030. The next wave is the nanotechnology, only in its embryonic phase at this moment. It will start growing in ten years from now and only reach its maximum in the midst of the first century of the third millennium.

Although it is not clear for outsiders, the traditional disciplines, like physics, chemistry, polymer science... play an important role and are even essential in the development of these technology waves. Outsiders do not know this and that is why our youngsters do not choose to study chemistry and physics anymore.

They want to be active in the technologies that change the world, not in old-fashioned chemistry and they do not see the link.

The changing chemical industry

At this moment, a thorough reshuffling of the chemical industry is taking place. This implies more than just mergers or fusions. It is a complete regrouping of chemical activities by splitting up, exchanging parts of the business, merging etc. It looks as if the structure of the chemical industry is at the end of a life cycle and a jump to a new S-curve, with a completely new structure, is going on (figure 2).

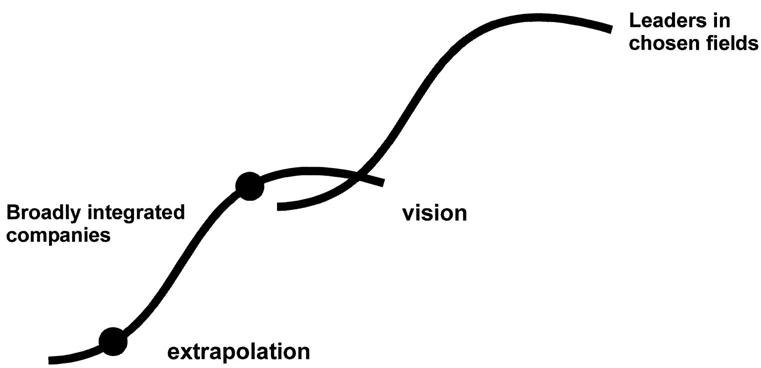

Figure 2. The structure of the chemical industry seems to be at the end of a life cycle

At the beginning of an S-curve, you can predict what will happen by extrapolating. At the end of a lifecycle you need vision, as you are changing into something completely new.

The driving forces for this restructuring are divers. Financial forces as well as macroeconomics and political forces and furthermore social issues and technological developments play a role.

The chemical industry seems to move from broadly integrated companies, that cover almost the entire field from crackers up to pharmaceuticals, towards leaders in chosen fields. In the past, old mature businesses and young growing businesses lived together in one company. But the market approach, the managerial needs, the resources needed and the knowledge intensity of these businesses are quite different. More important maybe, the returns that can be expected from emerging fields like biotechnology are substantially higher than these expected from the cyclical businesses in commodity chemicals and polymers. This urges many companies to focus on so called 'life sciences' and to merge their commodity businesses.

Also in the field of Food and Pharma, a concentration of businesses is taking place, leading to a limited number of huge companies, together with a lot of spin-off companies in the field of life science products and performance materials. A further consolidation in these new midsized companies is to be expected.

An important problem in the ongoing changes is how to position the business in polymeric materials. In this field the question about the right business approach arises very sharply:

chemical utility (PE, PP), customer intimacy (engineering plastics) or innovation (functional polymers). Clearly there is an overlap in the approach.

A lot is expected from functional polymers.

In the business of functional polymers however, the real profits are made at the end of the business column with the device based on those polymers. The volumes of polymer needed are very small, which makes it difficult to make a profit by the polymer itself.

Most of the developments in this field are done by other industries: electronic industry, photographic industry, medical materials industry, etc. as perfect knowledge of the application and the end market is essential. For the time being, these functional polymers seem to disappear from the chemical industry.

Whether this is the right evolution is questionable. It is most likely that sooner or later the production of these substances will be done by the chemical industry, in the same way as the low molecular weight intermediates or active compounds for the pharmaceutical industry are produced by the chemical industry. This could create a specialty materials field that is closely linked to the "life sciences" business.

The changing materials science

In the last chapter of his book on 'Supramolecular Chemistry', Jean-Marie Lehn compares 'natural' and 'synthetic' compounds in a very nice picture. He puts 'controlled complexity' against 'diversity' and puts forward that nature reached a tremendous level of control and complexity with a limited amount of building blocks. In synthetic chemistry, we have synthesized an awful number of molecules and building blocks, but with very limited control and complexity. In the last years, progress is made in two ways. The diversity in molecules synthesized by living organisms is increased by biotechnology. On the other hand a substantial jump has been made in synthetic chemistry (low and high molecular weight) towards more control and complexity, the so-called molecular nanotechnology. (figure 3)

Indeed, a surprising new synthetic power has been developed in recent years. This power is built on a combination of several elements:

- more precision and control in catalytic and radical polymerisations
- the creation of completely new molecular architectures (dendrimers, dendrons, dendritic wedges, hyperbranched systems, polycatenanes, polyrotaxanes…..)
- the use of supramolecular organisation by weak interactions e.g. co-operative hydrogen bonding.

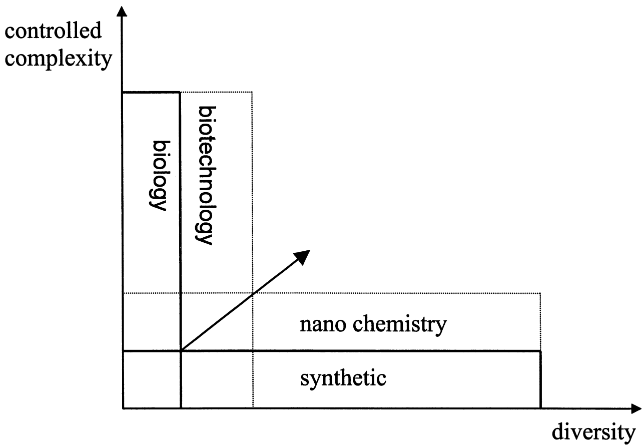

Figure 3. Natural and synthetic chemistry

This combination led to the controlled synthesis of complex molecular and supramolecular systems, in this way mimicing nature.
This creates new possibilities that were simply not there before. As Jean-Marie Lehn said: "The novel features that appear at a higher level of complexity do not and even cannot conceptually exist at the level below".[1]
Applications for these new systems just started to be explored e.g. light harvesting, slow release as well for drugs as for cosmetics and for plant protection.
Most of the applications are situated in the domain of the functional systems or the so-called nano-chemistry. This is the formation of structures on the nanolevel, by building up from the molecular level. They will be found in the electronic field, the photographic field, the medical materials field. Applications in the medical field range from diagnostics via drug delivery up to implants, tissue engineering, medical devices and medical instruments.
J.M. Lehn drew an arrow in the diagram and said that progress will be made in that direction. This could mean that continuous mutual interaction between the two fields: biotechnology and molecular nanotechnolgoy could offer countless apportunities for completely new developments.

What can we learn from nature?

Nature uses a limited number of building blocks for its materials. The same building blocks are used for functional applications (e.g. enzymes) and for structural applications (e.g. wool, silk). These are certainly not the best possible building blocks to get optimal structural properties. Mechanical properties of synthetic materials are often better.

But nature uses other criteria in choosing its building blocks. Natural materials are completely recyclable and nature works in closed loops consuming minimum energy.

In the synthetic approach we will stick, for the time being, to the cheap monomers based on cracking of fossil raw materials. Our focus is on low cost and getting the best possible structural properties, not yet on complete recyclability or optimal thermodynamics. Although ultimately we will have to work in closed loops too, for the time being, as long as we are burning 92% of the crude oil for energy production, energy recovery from polymeric materials waste will be an accepted way of recycling.

Furthermore, our processes, as we want them to be fast, will be high energy consuming.

Before we make the jump towards real renewable resources, we will first have to make the jump from burning fossil resources towards using them as raw material. Only at that moment re-use and back to feedstock recycling becomes a sensible activity.

However, some people predict that crude oil will become extremely expensive when the use as energy source decreases. In that case renewable resources, like biomass, might become cost competitive. Maybe we do have to solve several problems at the same time.

All developments that contribute to a reduction of burning oil as an energy source will become extremely important in the near future. For instance the development of light weight construction materials for automotive, the developments of functional materials for fuel cells and solar cells, materials for other alternative energy sources, polymer electronics, etc.

It is striking that nature succeeds, despite the limited number of building blocks, in getting adequate structural properties anyway.

Nature is able to do so by complete control on the molecular level (MW, MWD, sequence, tacticity), by ordering on the nano-level and by perfect macroscopic design. In this respect we can learn a lot from nature, as well for structural applications of synthetic materials, as for functional applications or a combination of the two.

In the synthetic materials, we make use of fast and easy processing techniques in the melt, but until now these processing technologies do not allow the ordering at the nano level that makes natural materials so unique.

However, the first attempts in structure formation during processing (apart from crystallisation) are made, making use of molecular recognition and self assembly.

Nature is also a perfect designer on the macroscopic level. At this moment we are able to simulate perfect structures with synthetic composites, using supercomputers. Nature seems to be able to produce these structures. The production of such structures with synthetic materials is still beyond the present technology.

Conclusion

A lot of synergy is possible between the two important knowledge fields: material sciences and life sciences. Companies that master both fields, might have a competitive advantage. Opportunities in the overlapping domain have to be defined.

The possibility of using biotechnology for the bulk production of chemicals (monomers) and polymers is already investigated. Enzymatic modification of materials is probably easier to establish.

The use of experimental techniques out of the life sciences field (e.g. the combinatorial approaches) in the materials field is also already going on.

A substantial market for specialty polymers for applications as medical materials is about to emerge and a similar situation exists with respect to specialty materials for the electronic industry and the photographic industry. It is quite probable that a hybrid industry will emerge in between the latter two, as the electronic industry is moving towards the molecular level and the functional molecules, while the photographic industry is moving towards electronic image processing. They might meet on the nano-level.

Application of principles out of nature in the synthetic structural materials could lead to real breakthroughs.

Fast processing techniques that allow for controlled structure formation from the nanoscopic level via the morphology up to the macroscopic level is already an important area for research.

I think we are only at the beginning of a completely new development in the field of synthetic materials. A bright future is waiting for this new polymer and material science, combining principles out of biology and out of synthetic chemistry.

However, taking into account the present situation in the chemical industry, the results of these new developments will most probably be commercialised in small start-up companies.

(1) J.-M. Lehn, *Supramolecular Chemistry* (VCH, Weinheim, 1995)