Managing Innovation towards Sustainable Products and Substances

Presently about 100.000 chemicals are used in industrial production. From the overwhelming majority of these substances no valid data exist about the hazards for mankind and the environment. As a consequence there are great uncertainties about the impact of the use of these substances; it is one of the tacit problems in sustainable development.

For companies that want to make their business more sustainable, the selection and use of substances can be associated with innovation of processes and products. This will be influenced by external factors such as the position in the production chain, the demands in the market, the expectation of future legislative requirements, and also by internal factors e.g. the innovation and marketing strategies of the company. A case study was undertaken to assess and analyse the experiences of five companies (with production facilities in the Netherlands) in this respect. The companies that participated in the case study were:

DSM Resins, a division of the multinational DSM. They were very early in the development of alkyd suspensions, the basis for water-based alkyd paints.
Hermadix, a small paint company, that was the first to bring water-based alkyd paints with an environmental label on the Dutch market.
Philips Electronics, a multinational company, made available their experience with the out-phasing of CFC and reduction in the use of chlorinated solvents in all their production sites and about hundred of their customers, worldwide in the period 1990-1995.
Thermphos, a medium sized world player in their market niche (food grade phosphates). The company wants to make a shift to the re-use of phosphate waste from e.g. water treatment facilities and bone meal as input for their processes.
Vliegenthart, a small company that was the first to introduce a methylene chloride-free paint- remover on the Dutch market.

All five companies monitor developments in (future) SHE governmental regulation, not only in their home country, but also in other countries. Public debates on substances are also monitored. These are seen as indicators for future loss of exiting markets shares, and as early signal of new or upcoming markets.

In all the cases, the innovations concerned only a part of the company's business. By continuing the production of less sustainable alternatives the companies avoid to loose their existing markets.

Most innovations require some sort of co-operation in the production chain from suppliers and/or customers. The acceptance of the innovation by customers and the general public can greatly complicate and delay the innovation process.

The company's strategy, and the vision of the CEO and the management team, were decisive in the innovation process. Commercial managers play an important role in the innovation processes. Contrastingly, the SHE managers played only a minor role.

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Introduction

Presently about 100.000 chemicals are used in industrial production. From the overwhelming majority no complete and validated data sets are available. National and international activities to get more complete and reliable data sets proved to be inherently slow. The last decades, very little progress is made. As a consequence there are still great uncertainties about the impact of the use of the great variety of chemical substances.

Based on extrapolation of the results from hazard assessments of chemical substances that are more or less complete and validated, it can be roughly estimated that among these 100.000 substances about 30 are likely to be extremely toxic, persistent and bio accumulating (similar to dioxins), about 300 are likely to have two of these extremely undesirable properties. (RIVM, 1999). From the perspective of sustainability this implies that the use of this great variety of substances is one of the tacit problems in sustainable development. It also means that nationally and internationally, the need for innovation in substances policies is recognised.

As a result several national and international policy initiatives are taken or are still in development. The EU recently launched proposals for their REACH (Registration, Evaluation and Authorisation of Chemicals) programme. According to the REACH proposal companies that produce or sell more than 1 ton of a certain type of chemical, will get the obligation to provide the European Commission with a full data set within in few years. In the USA, companies are obliged to deliver full data sets for the so called High Production Volumes (HPVs), substances produced or sold in more than 1000 tonnes.

Besides selection on volumes, also other options for selection of the most relevant substances are considered (Van Wezel 1999, Van Wezel & Kalf 2000). The assessment of Persistency and Bioaccumulation is relatively easy and can be done quickly, while the assessment of (eco) toxic properties takes a lot of time, money and effort.

For the industry that produces or uses substances the issues outlined above pose a problem; their products or processes may not be sustainable, and may become subject to new regulation. In Europe, it is known that the growth rate of the use of chemical substances was about doubling the economic growth rates in the nineties. Decoupling economic growth from the increasing use of chemical substances (and as a consequence dispersing them into the environment) is not easy, and may affect several industrial sectors.

For companies that want to make their business more sustainable, the selection and use of substances is associated with reviewing their existing products and processes, and with innovation of processes and products. We were interested in the experiences of companies who actually work on this challenge and of companies who profiled themselves with sustainable innovations of their products and/or processes.

The purpose of this research

We wanted to understand more of the sustainable innovation process with respect to chemical substances, and the associated processes and products. Our first aim was to get insight into the contributions and roles of the various actors and stakeholders involved, and in the identification of stimulating and impeding factors in the organisational context.

Materials and methods

A case study was undertaken to assess and analyse the experiences of a limited number of companies in the Netherlands with product of process innovation associated with the use of chemical substances.

Based on our (consultancy and research) relationships with industry, and based on publications in the general press, we invited a number of companies to co-operate with us in the case studies. We strived for a variety in industrial sector, company size and position in the production chain.

We also intended to include some cases of companies that were involved in a societal controversy about substances in their products (e.g. because they produced brominated fire-retardants of substances suspected of endocrine disrupting properties). However, fine contacts with key people in these companies, and the promise not to publish confidential information were not sufficient to get the co-operation of those companies. As a key person of one of these companies explained: this is an extremely complicated and sensitive issue and it is our policy to avoid any involvement in further research in this area.

In several companies an introductory meeting as held, to concisely explore the company's experiences, to identify key actors involved, and to discuss the option of further company involvement. Finally five full case studies were carried out, in four other cases we had introductory meetings with a company representative, but it was not possible or sufficiently interesting to engage these companies for the full case studies. In each of the five cases selected, a number of interviews with people involved in the reviewing and innovation process were held. In some cases a group interview took place too. The five cases show a variety in size and sector. In three cases both products and processes were innovated, whereas in two cases the innovation concerned process innovations only. In one case the company was still in the early stage of realising the innovation, while in three cases the innovations were fully realised.

An overview of characteristics of the individual case studies is given in table 1, while in the next paragraph, concise descriptions of the individual case studies are given.

Table 1: Characteristics of the cases selected				
Company	**Sector/ products**	**Company type**	**Position in the production chain**	**Nature of innovation**
DSM Resins	Resins, raw materials fore paints	Division of the chemical multinational DSM	Middle position in the chain	DSM Resins were very early in the development of alkyd suspensions, the basis for water-based alkyd paints.
Hermadix	Paints	Small	Last producer in the chain	Hermadix was the first to bring water-based alkyd[1] paints with an environmental label on the Dutch market
Philips Electronics	Electronics	Large multinational	End user	Philips out-phased CFCs and reduced the use of chlorinated solvents in their production sites worldwide, and in 100 customer companies.
Thermphos	Phosphorus and phosphor derivates	Medium sized world player in a niche market	Early in the chain	Thermphos is working on a shift from traditional phosphate-ore as raw material to the re-use of phosphate wastes from various sources.
Vliegenthart	Paint removers	Small	Last producer in the chain	Vliegenthart was the first to introduce a methylene-chloride-free paint-remover on the Dutch market

The paint sector is somewhat over-represented in these cases, by the two small companies, while DSM Resins is a supplier for the paint industry. This seems to reflect the fact in the paint sector many product innovations take place; moreover there is a clear consumer demand for environmentally friendlier and safer paints, that stimulates innovation in this sector. As the main objective in the study was to explore the reviewing and innovation of substances, processes and products, and the actors and stakeholders involved the over-representation of the paint sector was not regarded as problematic.

The data for the case studies were gathered in 2001-2002. A standard format for the description of the cases studies was developed and used to structure the data. The case

[1] alkyd is made from renewables, in the past from linseed oil, nowadays from soy-oil. Traditional alkyd oil is solvent based. Most water based paints are of inferior quality compared to alkyd paints. Therefore, water based alkyd paints form a promising development.

descriptions (in Dutch) were verified by the contact persons of the respective organisations, before they were used in the analyses.

Concise descriptions of the individual case studies

A concise description of the individual case studies is given, in order to give the readers some insight into the cases that form the basis for our analysis.

DSM Resins

DSM Resins is a division of the chemical and life science company DSM. DSM Resins is the most multinational part of DSM, and was taken over in 1990 from Unilever. Its main locations are in the Netherlands (but not in the vicinity of the DSM Headquarters) and France. The somewhat special status within DSM gives DSM Resins the opportunity to be relatively independent in their strategies. DSM Resins comprises three worldwide business groups: coating resins, composite resins, and glass fibre coatings.

The innovation studied concerns the water-based alkyd resins (emulsions) that form a raw material for the paint industry, as compared to the traditional alkyd resins in organic solvents for traditional paints. Today DSM Resins produces both types of alkyd resins, as well as high-solid alkyd resin. The Alkyd emulsions form only about 5% of the total production in tonnes, but are relatively profitable.

Life-Cycle Assessments show that alkyd resins are to be preferred over acryl, because alkyd is for about 60% made from renewable materials like soy oil. The disadvantage of traditional alkyd paints are the organic solvents; these are a serious threat to safety and health especially during indoor use (the so-called Organo Psycho Syndrome) and an important emission into the general environment associated with smog and local ozone production.

DSM Resins wants to make responsible products, products that are safe, sustainable and cheap. In the eighties the strategic decision was taken, to move away from the organic solvents. Since then both high solid resins and water based emulsions have been developed. The expectation was that governmental regulation would favour the water-based resins already in the early nineties, and affect the existing markets. However, due to lobbying from competitors with vested interests, regulation came much later. That regulation was mainly health and safety driven, not environmentally. Innovative companies like DSM Resins are substantially dependent on new legislation for the creation of an interesting market. They fear that in the future new European legislation will become much slower compared with that from individual European countries, and may even stop at all after the expansion of the EU with twelve new countries.

The innovative alkyd emulsions are mainly sold in the West-European market. Despite the lower quality of latex paints, the US is latex oriented (probably due to a dominant market position of a US competitor), while Asia is not yet so much environment minded. Competition of powerful players in parts of the chain, frustrate innovation in the production chain as a whole. But also some of DSM’s customers have played a negative role by frustrating the innovation process (DSM still has many customers who prefer the traditional product). A problem for smaller customers is that alkyd emulsions require more competencies from the operators compared to alkyds in organic solvents. Education and training of operators from customer companies is therefore essential.

The production managers as well as the research and development manager are involved in strategic decision about new technological or market developments. A systematic review always precedes the decision to substitute materials.

Though the early choice for water-based alkyd resins was not the quick commercial success that was hoped for, several other benefits were realised. DSM Resins still strongly believes in these products. The high-sold alkyd resins are not so promising on the long range, as the technology implies less options for future innovation, while the drying properties seem to be structurally weak. Furthermore, the choice has made DSM resins an innovative company, with an innovative image. This is regarded as vital for the company's future.

Hermadix

Hermadix is a small company in the Netherlands, founded in 1945 with a turnover of about seven million Euro (2001) and about 30 employees. It produces a variety of paints, coatings and organic cements, both for professional markets and for end consumers. Hermadix has departments for development (4 people), production, sales, administration and distribution.

Hermadix has a record of substituting undesirable substances out of their products, since 1985. They are specialised in the development and production of environmentally friendly products; the same is true for their processes. As soon as a chemical substance is being discussed (by governments that consider legislation, discussion in professional networks, customers that inform for alternatives, attention from NGO's or the media) Hermadix starts a searching process for alternatives. The option to continue as long as possible the use of non-sustainable substances is seen as a dead-end (based on past experience). Hermadix strives to be a niche player in the coatings market, and to be a frontrunner in green and safe products. Driving persons in this policy and the resulting innovation processes, are the CEO and the leader of the development department.

When Hermadix decided to enter the market for end consumers (1995) a choice had to be made for the basis of the paints. The chosen option was to go for innovative alkyd and water-based paints. Alkyd is made from linseed or soy oil, so renewable materials. New technologies make it possible to use these materials (with a long tradition in solvent based paints) in water-based products. The raw materials for these products are supplied by big players such as Bayer, BASF and DSM Resins.

In 1993 Hermadix initiated the process to develop criteria for the Dutch Environmental label for paints. Vested interests of major players in the paint industry obstructed that initiative. Positive was the sector wide programme, started in 1995, to make the coatings sector safer and greener, and to implement SHE management throughout the sector. A few years later, a renewed initiative for an environmental label for paints, was supported by the sector organisation and was successful. Mid 2001 Hermadix obtained the first official Dutch environmental label for paints. Mid 2003, it is still the only environmentally label product in their sector. This end-consumer product is distributed via garden centres. For professional (niche) markets, e.g. for small producers of furniture, they are also successful with water-based paints and varnishes. Today the launching of an environmentally friendly water-based wood preservative is in development.

Philips Electronics
Philips Electronics is a multinational company with a turnover of 37.9 billion Euro in 2000. Philips runs 160 plants in all continents; it has (in the year 2000) 192,000 employees in more than 60 countries. Their main divisions are: lighting, consumer electronics, household devices, components, semiconductors and medical systems. Philips has research and development centres in all parts of the world. Philips has a Centre for Industrial Technology (CIT), specialised in the product and process innovation.

The Philips case concerns the phasing out of CFCs, in the period 1990-1996 in line with the Montreal Protocol, and the reduction of chlorinated solvents within the Philips organisation worldwide and for about 100 of its customers all over the world. In 1990 Philips used large quantities of CFCs as degreasing and cleaning agent, e.g. in precision-cleaning in the production of optical and medical systems.

Triggered by the Montreal Protocol, and the general public concern of the ozone gap, the Board of Directors decided in 1988 to phase out all CFCs and to reduce the use of chlorinated solvents worldwide before 1996. In 1990 an informal project group was founded; later this became formally part of the Centre for Industrial Technology, then the group comprised 12-14 technological experts.

The fist priority was the so-called *no-clean* option: to avoid the use of CFCs and chlorinated solvents by changes in product specifications or production processes, whereby cleaning was no longer necessary. When this was not possible, the focus was on alternative cleaning systems (e.g. vacuum cleaning) or on substituting the cleaners by water-based, alkaline, semi-water or alternative organic cleaners. If local plants wanted to continue their use of per and tri Chlorinated solvents, no CFCs) they had to prove that it was impossible to use alternatives.

Initially Philips wanted to use external know-how to support this programme. However, sufficient external know-how seemed not available. Therefore it was decided to develop this know-how in the CIT. As a consequence time was needed for building up the needed expertise.

In the fist phase of the programme, the usage of CFCs was identified company wide. Then, via quick scans, the possibilities for the *no clean* option by changes in product or process specifications were assessed. Options for alternative cleaning systems or cleaning agents were also identified. These options were discussed with the local staff. Thereafter, local plants were supported with adequate technological know how, to identify and implement technological solutions in all cases.

In the end of 1995 the company programme was completed successfully: CFCs were phased out completely and the project group was ended. But the group of experts formed an expert group in cleaning technologies that works for Philips and their customers. Today the options of laser cleaning and the use of super-critical carbon dioxide as cleaning agent are further developed.

Thermphos
Thermphos is an independent international company producing phosphorus and phosphor-derivates. The company started in 1999 after a management buy-out from a unit of Celanese. Its main location is in Vlissingen, the Netherlands, were it has about 350 employees. Its main

products are very pure, ”food grade” phosphorus and phosphorus derivates for the food industry and other high-tech applications, and phosphoric acid, which has the “technical grade”. Both are produced in bulk quantities.

The raw material for the phosphorus production is phosphate-ore. That contains an increasing amount of undesirable by-products, which lead to large quantities of solid waste (in the Netherlands a part can be re-used in construction materials for road construction). Phosphorus is not recycled yet. The production process, at 1500 ^{o}C requires a lot of (electrical) energy. As a result the production is complex, not environmentally friendly and expensive. Today Thermphos is the only producer for its market in Europe. Competition form China is growing.

Apart from this, Western Europe is confronted with environmental problems stemming from too much phosphates in soil and soil water (mainly stemming from manure and fertiliser). In principle, this problem can be reduced by recycling Phosphorus in manure, sludge from wastewater treatment, or bone meal.

For Thermphos the above mentioned recycling of phosphorus would have several advantages: it would make them less depending from Phosphorus-ores from countries far away, it would greatly reduce the production of solid waste and the company would contribute to the reduction of a complex environmental problem. This is why Thermphos embarked on a trajectory that aims at the use of 20% recycled raw materials in 2005. An informal working group is stimulating the innovation within the company, coached by on a member of the Board of directors. Both managers and employees are convinced that a shift towards more sustainable production processes is vital for the company’s future.

Technologically, the recycling is possible, but it requires the co-operation of the potential suppliers (who are presently generating solid waste): waste water treatment facilities (it requires some minor changes in their process), slaughterhouses, etc. It also requires the acceptation from its customers. This is a main problem in the food sector. Food producers do not want their products to become associated with ”manure” or “waste water”. Rationally it is not difficult to prove that the production process at 1500^{o}C guarantees that e.g. BSE toxins that could be in bone meal cannot be in the food grade product, but images are not that rational. Another difficulty is the legally different status of waste compared to secondary raw materials. As recycling does not yet exist in this business, the remaining materials are officially defined as waste. An implication thereof is that import and export is forbidden in the EU. This makes it impossible to import and recycle “waste” from e.g. Germany. Presently Thermphos is setting up some pilot projects with agents that are interested to become a potential supplier. A difficulty is the bulk nature; in the installation 80,000 tonnes of raw material is needed for a pilot production, because otherwise it is not possible to see the effects of the new input on filters in the production process.

By the transition to secondary raw materials, Thermphos becomes confronted with new product chains, and other types of legislation. Emotional and political factors play an important role. As a consequence, Thermphos will have to develop a less technology-oriented approach of their innovation trajectory.

Vliegenthart

Vliegenthart Ltd is a small company of about fifteen employees in the Netherlands, and a location in France. Vliegenthart was founded in 1839. In 1989 the company was granted a Royal Warrant. In 1997 they moved to a new location in Tiel were all available environmental know-how was used. The main products are paint-removers, derivates of vegetable oils, siccatives (traditional paint driers), and classical clear varnish (for ships).
Besides the Dutch and Western European market, substantial export to the Middle East and the Far East takes place. In the Netherlands, Vliegenthart is one of the largest producers of paint-removers. Vliegenthart has no research and development department, and its strategy is to work closely with external technological partners in case of product innovations.

In 2002 Vliegenthart came on the Benelux market with a paint-remover without hazardous solvents. Usually paint-removers contain methylene chloride, a suspected carcinogen and chlorinated product. In fact, Vliegenthart foresees that in the future, the use of methylene chloride will probably be forbidden.

An important development was that a UK-based firm had developed an alternative formulation for paint removers. The product is environmentally friendly, non-toxic and non-corrosive, and can be sold without R- and S- sentences on the label. The only drawback is that the product is more expensive than the traditional non-sustainable products.

It is Vliegenthart's strategy to use and produce only products that are safe for mankind and for the environment. An important criterion is to administer the company with the care of a prudent man: the stakes of the employees and its customers are important in the selection of raw materials and the development of products.

The innovative process is guided and managed by the CEO, in co-operation with the production managers and the commercial people. All employees participate in environmental and health and safety education and training.

Presently most of Vliegenthart's paint-removers still contain methylene chloride. The introduction of the new product is very recent, and the market for the new product is not yet sufficient to make a complete shift to the new product.

Analyses

The review process of the existing processes, substances and products

Some companies periodically review systematically their processes, substances and products as part of more general reviews of business activities, or as part of environmental management (e.g. in the frame of ISO 14001, DSM, Thermphos, Philips Electronics). In the two small companies (Hermadix, Vliegenthart, this was done less systematically, but nevertheless quite effective.

All five companies, in someway or another, monitor developments in (future) SHE governmental regulation, not only in their home country, but also in the Nordic countries, Germany and the USA (Frontrunners in environmental legislation or representing important markets). These developments are reviewed and evaluated. New (future) legislation is regarded as an indicator of future market changes, and this is an input for the review of the existing processes, substances and products. When for instance the Danish government discussed the option of a ban on solvent-based paints for professional indoor use, this was for DSM Resins and Hermadix an indication of an important change that would affect their markets.

> The following legislative requirements have influenced our activities over the last fifteen years:
> - Banning of carcinogenic substances
> - Banning of lead
> - Banning of asbestos
> - Banning the use of coal tar (containing Poly Cyclic Aromates)
> - Limitations in quantities allowed in stock by local authorities
>
> *CEO of Hermadix*

Motives for innovation

Besides the external triggers from (expected) legislation, also other indications were important for the companies. Discussions in professional networks, or activities of sector organisations (Hermadix, DSM Resins) were important. Explicit demands from customers, as well as media attention for undesirable impacts of substances also stimulated innovation.

> By incorporation of legislation and by anticipation of new regulations, the trend in dealing with substances is to make it part of the general business strategy. This is like the situation in the automotive industry around 1970. Then the discussion on car safety was seen as a threat to the industry, while today that has transformed into a selling point for cars. The chemical industry is now in a phase where they have to transform information on substances from a threat to a selling point.
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> *HSE Officer DSM Resins*

Apart from these triggers from the company's environment, the company strategy, and the vision of the CEO and the management team, were decisive. Product development and technological innovation were sustainability oriented in all five cases. The company's reputation, to be innovative and to work on sustainable businesses was important in all five cases. Besides environmental orientation, also the health and safety impacts of substances and products are important (DSM Resins, Hermadix, Philips Vliegenthart).
The drive for environmental innovation is mainly the inner drive for Thermphos, were it is mainly market driven at DSM, Hermadix and Vliegenthart. In the Philips case we see that legal obligations can directly trigger the own motivation and competencies as well.

The importance of the innovation for the company and its business

In all the cases, the innovations analysed here, formed only a part of the companies business. DSM Resins, Hermadix, and Vliegenthart continued to produce the less sustainable alternatives for the new product. Thermphos wants to substitute about 20% of their most important raw materials, while for Philips Electronics the use of cleaners was only important in cleaning processes, but did not touch the core of their business either. Production facilities had to be adjusted, but only in the DSM Resins case a relatively large investment in a new production line was necessary.

We can conclude that in all cases the companies did not take to much risk; they did not want to loose their existing markets. Large investments were only in one case necessary. Depending on the development in market-demand (sales) the less sustainable products will be out-phased, or be kept in production for the time being.

In the Thermphos case, a potential image problem played a role. In the food industry, a major market for the company, recycling is associated with waste and with food-safety scandals. This is an impeding factor for the change towards renewable materials, even though it is easy to see that in this case it is clearly a non-rational factor.

> "Technology push is usually not a good trigger for innovation, for really bringing new products to the market. Technology push works only for product development for `the day after to morrow', not for the short run" .
>
> *Product manager DSM Resins*

In some cases, important go no-go decisions had to be taken. These were always associated with major business decisions such as the decision to develop a new technology (DSM Resins, a major reconstruction of the production facilities (Hermadix) or buying a technological licence (Vliegenthart). However, only in the Philips case the innovation was irreversible, due to the Montreal protocol and its associated obligations. In all the other cases, the companies avoided a real *point of no return.* They made investments in their new business, but kept their (technological and marketing) options open, led by developments in market demands.

The identification and evaluation of alternatives processes, substances and products

When potential sustainable alternatives are identified and evaluated, a number of factors are taken into account. First of all, it is important whether the technology for the innovation is already proven, must be further developed or is still in development. The small companies (Hermadix, Vliegenthart) only considered proven technologies that were available on the short run. Contrastingly, DSM Resins and Thermphos, companies that have an own research and development department, evaluated the feasibility of technologies that were still in development – of course that implied consequences in terms of time and competencies needed for the further development and the associated financial investments.

A second important factor in the assessment of alternatives is the (expected) quality performance, of the alternative. Are the processes reliable? Are the products of similar or higher quality compared to the existing products?

The third aspect, clearly related to the technology and quality aspect, concerns the financial aspect. What about the expected costs of the alternative processes? What about the price that customers are likely to be willing to pay for the alternative products? How large is that market? What about the investments to be made in the (further) development of the technology or in product development?

The technological, quality and economic factors – though not without uncertainties - form the hard data in the evaluation of alternative processes, substances and products.

Other important factors are the regulatory consequences of the innovation. Here it is often problematic to predict the pace of new legislation. DSM Resins invested in the development of water-based alkyd products, because they believed in this technology, and because they expected more than ten years ago that legislation would lead to the need to phase-out solvents-based paints in a few years. However, due to several reasons, new legislation came much later, and only for some of their markets. As a result, their decision to go for the more sustainable technologies was economically not rewarded.

A complicated factor can be the acceptance of the innovation by the general public, by customers that sell their products on the consumers, or by NGOs. This is prominent in the case Thermphos. The food industry is afraid that the general public will not understand that the phosphoric acid made from the phosphor produced by Thermphos will be the same and just as safe (after treatment at 1500^{o}C) in the case that phosphate from waste-water treatment facilities or from bone-meal coming from slaughterhouses is used as raw material instead of phosphate-ore (guano) as raw material. Food safety is a very sensitive issue for global food companies, and the public may wrongly associate the customers valuable brand with waste-water or waste products, let alone that it will be associated with unjustified and hazardous use of suspected raw materials (e.g. with BSE).
In a different way, but to a certain extend similarly, this is also relevant in the DSM Resins case. There the development of acceptance by, and demand from the general public for water-based paints was slower than was expected by DSM Resins.
We can conclude that the assessment of the acceptance of a new product implies relatively great uncertainties, especially when the producer has no direct contact with the end-consumers in the production chain.

The number of tests on substances seems ever increasing. The accumulation of tests complicates the interpretation of their results. Governments tend to use all test results, increasing the pressure on companies.

When stakeholders use the worst-case scenario from a great number of tests, it becomes increasingly difficult to sell any substance or product on the market.

Product manager DSM Resins

Impacts on the production chain
In two of the cases, chain impacts were very important. DSM Resins, produces half products for the business-to-business markets. The success of their technological innovation, is heavily depending on the activities of their customers (such as Hermadix). In this case the technological innovation at DSM preceded the market based-innovation from Hermadix. As most coating companies were reluctant to make similar steps, the DSM innovation is only a partial success. In the Termphos case, there are no great impacts on the chain down-stream.

However, the crucial factor here is the co-operation of the up-stream companies that might become involved (they do not regard themselves as part of this chain). In the Philips case, we see that the innovation programme initially intended for in-company use only, helped more than 100 customers to innovate as well. The Hermadix and Vliegenthart, as smaller niche players, were able to build on technological innovations from others; their innovation further impacted only distribution and sales.
The cases show that increased co-operation in chains may be crucial. Education to the general public, and specific communication or education of customers or potential suppliers can be essential in the innovation process.

> Because all not-core activities have been outsourced, the chain that used to be inside, is now mainly outside the companies. As a consequence, every change or innovation is likely to impact various stakeholders along the chain, and requires their co-operation.
>
> *Product manager DSM Resins*

The time frame of the innovation process
The time needed from the decision to go for the innovation, to the actual realisation in the market varied considerably. In the two small companies the innovations were realised within about half a year. This was possible because they used new but proven technologies, because the risk in their specific market niche could be assessed adequately, and they only had to make arrangements with their direct customers; no other stakeholders were involved.

The other extreme was formed by the DSM Resins and the Thermphos case, were the time needed to actual realisation was in the order of 10-15 years. Here new technologies had to be developed, and the acceptance by the end-consumers (not their customers) is vital. In the Thermphos case also the co-operation of the waste-water treatment facilities is essential, because they have to make some changes in their process too (to eliminate some minor components in their solid waste that complicate the processes of Thermphos).

The Philips case has a time frame of about 7 years. Here it concerned a great variety of processes in many countries, but the CFC played no role in their products. The incentives where formed by the worldwide ban stemming from the Montreal protocol. Adequate support, and lose co-operation of the Philips technological centre with the various production facilities, made it possible to solve the technological problems, and implement the alternative processes within 5-7 years also in about 100 customer companies.

An important conclusion is that for more radical innovations, that imply a technological trajectory and the involvement of several stakeholders, the timeframe is substantial. A period of ten-fifteen years is much longer than the usual timeframe of either company managers or of governmental programmes to improve the (working) environment.

The actor and stakeholders perspective
Notably, in four cases commercial people (marketing managers, sales managers) were formally or informally leading the innovation process (Hermadix, Vliegenthart, DSM Resins Thermphos). In the Philips case commercial people were involved too. In the DSM case this was most obvious: it was the duty of the commercial manager to stimulate product changes,

but also to monitor developments in (environmental) legislation in relevant countries. In the smaller Hermadix and Vliegenthart cases this was less clear, as the internal organisation was – like in many other SMEs- not so clearly structured, and division of labour was less prominent. At Hermadix the owner-director takes all the major decisions; this certainly includes the commercial decisions, but also the environmental decisions. He has an open ear for the voice of NGO's and is keen on market opportunities for more sustainable products. At Thermphos the driving force behind the transition process was initially the manager research and development. To give this man a more strategic position to manage the innovation, he was transferred to the marketing and sales department.

Very remarkable is the minor role of the SHE managers in these cases (only a substantial role in the Philips case that was initiated by the Montreal protocol). In these five cases they seemed to have very little impact on innovation of the company's primary process or its products. They seemed to deal mainly with the relationship with local authorities, and with stimulating and co-ordinating SHE-management activities. This raises questions about the role SHE managers actually play in sustainable innovation.

The role of stakeholders in the production chain, and also of governments, sector organisations, professional organisations and media was already highlighted in the sections on reviewing products and motives for innovation. Vested interests from powerful competitors can impede or delay the innovation process (DSM Reins, Hermadix). A higher price, or somewhat lower quality compared to less friendly products frustrated the market demand for more sustainable products in two cases (Vliegenhart, DSM Resins).

Company culture

Generally we can distinguish two major attitudes in the five cases. In the small companies Hermadix and Vliegenthart, taking initiatives and to go for action is part of the company culture. People involved describe themselves as do-ers. The same was true for the Philips Industrial Technology Centre, the driving force in the Philips case.

Contrastingly, in DSM and Thermphos the people involved describe themselves as thinkers. In these companies the choice for innovation was well reflected upon, they developed a vision on future (more) sustainable business, and then go for it.

In all five cases, the culture is rather informal and communicative. Hierarchy is not dominant, and does not hinder cross-functional co-operation, neither horizontally nor vertically. The innovation processes were driven by inspiration and enthusiasm of a core group of people involved, who believed in the innovation, and its positive impact on sustainability. For most of them this was also a reason to perceive their work as more meaningful then before.

Discussion

To our surprise, in four of the five cases (the exception is Thermphos), the innovations in the use of chemical substances were clearly triggered by the anticipation of new (environmental or health and safety) legislation. In the area of chemical substances and products new legislation creates markets for innovative sustainable products; without such incentives it will not be very attractive for large players (like DSM Resins or Philips) to invest in the development of innovative technologies for the substitution of unsustainable substances, nor will it be attractive for small niche players (like Hermadix and Vliegenthart) to invest in more sustainable product formulation. To a certain extend, this is similar to the findings of Ashford (1993) who puts much attention to the value of technology-forcing regulation for source reduction. The difference is, however, that in our cases, the regulations are usually not intended to *force* new technologies. In our cases even discussions about new regulations in other countries than the main markets of the company, were perceived as a signal for new upcoming markets that deserved to be anticipated: ”soft” regulation seems to work via a market mechanism.

An underlying problem in the rapid deployment of innovations is that substitution of chemical substances by more friendly alternatives is usually not associated with tangible benefits in terms of improved product quality. It is often a difficult challenge to develop friendlier products of similar quality, for about the same price, e.g. in the paint sector.

Furthermore, the time frame from technological development till product innovation, and phasing out of the unsustainable chemical products in the market, is substantial. The trajectory from technological development to a dominant position of the innovative product in the market may well be 10-20 years. Slow development of the new market demands, and defensive strategies of less innovative companies with vested interests are critical factors.
For governments that want to stimulate sustainable innovation, but also for visionary leaders in industry, the long time frame poses a problem: the time needed is longer than the “term of office” from the policy makers or most CEOs. Therefore governmental and business policies are likely to change in such a period, while the innovation is best stimulated by consequent policies.

Agents in the end of the production chain use chemical products for a certain function in their products or processes. They have more freedom to select other technologies or use other substances compared to the producers who are early in the production chain and usually are not able to deliver the alternatives themselves. The end of the production chain is also much more sensitive for the image aspect as perceived by the general public, and the reputation as perceived by governments. Producers early in the chain are more technology driven, but become increasingly confronted with changing demands throughout the chain.

The minor role of EHS managers in the innovation process is notable. In these cases, the EHS professionals had little influence on the innovation of chemical products and processes. The role of CEOs, commercial managers and R&D managers is vital in these trajectories. Commercial, regulatory and technological factors therefore play a greater role in the decision making process than environmental or health and safety factors. The world of the Board of Directors of Thermphos is dominated by markets, takeovers and commercial networks, while the technologists and the EHS manager discuss environmental issues. This gap can be overcome, as that case clearly shows. However, this requires vision on sustainability of the higher management, and strategic acting of the EHS managers. For policy makers, the gap indicates that communication and co-operation with companies via the EHS managers is probably not very effective for simulating innovation in the area of chemical substances.

When the results of this study are compared with those of Zwetsloot (2001) on the management of innovation by frontrunner companies in environmental management and health and safety, we see less influence from environmental management systems (ISO 14001) or occupational health and safety management systems (OHSAS 18001). In the five cases presented in this study, these management systems do not explicitly address the review of existing technologies, processes and products associated with chemical substances. As a result these systems are not generating a consequent stimulus for sustainable innovation in the area of chemical substances. Contrastingly, from the five frontrunners in EHS management two of that five companies had explicitly procedures for the creation of new business opportunities and related marketing while three companies also addressed research and development activities (and technological development) via their management system (Zwetsloot 2001). The differences between these studies can be explained by a notable unused potential to stimulate innovation though strategic EHS management, and by the differences in the selection of cases: frontrunners in environmental management and health and safety, versus interesting cases of product and or process innovation. Obviously, the potential of management systems to stimulate innovative solutions deserves more attention many companies.

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