Sustainable Chemistry

Positions and Criteria of the Federal Environment Agency

Umwelt Bundes Amt

for our Environment

Imprint

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Prologue

The natural resources of the earth are limited. In recent years, it has become evident that natural resources are exhaustible. The seas are overfished; food and drinking water become scarce. Fertile land is eroded or becomes salinized, and increasing human settlement has resulted in shrinking agricultural production areas. In addition, the steadily growing population worldwide and as a consequence, the increasing number of those utilizing the environment are exerting more and more pressure on the available resources[1]. The environmental potential to absorb and degrade the amount of pollutants introduced are no longer sufficient. This demonstrates the necessity to counteract such trend by developing sustainable concepts and solutions both on the global and regional levels.

For a number of years already, the Federal Environment Agency (UBA) has been promoting approaches to sustainable development. In 1997, UBA worked on a further development of the four management rules which had been laid down by the Study Commission of the German Bundestag on Protection of Humanity and the Environment - Objectives and General Conditions of Sustainable Development [2], which are considered as the basic conditions of living and acting in compliance with the ecological viability of the natural balance. UBA has formulated the following principles[3]:

1. In the long run, the exploitation of a resource must not exceed its regeneration rate or the rate of substitution of all its functions.
2. In the long run, the release of substances must not exceed the absorption potential of the environmental media or their assimilative capacity.
3. Hazards and intolerable risks resulting from anthropogenic activity and affecting humans as well as the environment should be avoided.
4. There should be a balanced ratio between the temporal extent of anthropogenic interference with the environment and the period of time the environment needs for a self-stabilizing response.

This is closely linked to the overall concept of a "sustainable and eco-friendly development which includes the precautionary principle" as drawn up by the German Advisory Council on the Environment (Rat der Sachverständigen für Umweltfragen - SRU) in its environmental expert opinion[4] published in 1994. In this document, it has been stated that sustainability and the precautionary principle are the conditions to be met by a responsible management of natural resources. The overall concept of sustainability is aimed at an ecological, economical and socially compatible conservation of resources on a long-term and global basis. The precautionary principle is aimed at maintaining scope of action also in situations where knowledge of the complex and interlinked systems existing in the environment is still incomplete. Thus, also the Federal Environment Agency has emphasized that sustainable development is only possible when taking into account the precautionary principle. Beyond the protection of ecosystems, this also includes the necessity for maintaining the quality of

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1. Umweltbundesamt - Beiträge zur nachhaltigen Entwicklung: Nachhaltige Entwicklung in Deutschland. Erich Schmidt Verlag, 2002.
2. Abschlussbericht der Enquête-Kommission: Empfehlungen zum "Schutz der Menschen und der Umwelt" umsetzen; http://dip.bundestag.de/btd/13/112/1311200.pdf
3. „Handlungsfelder und Kriterien für eine vorsorgende nachhaltige Stoffpolitik am Beispiel PVC“, Umweltbundesamt – Beiträge zur nachhaltigen Entwicklung, Erich-Schmidt Verlag, Berlin 1999; UBA 1997/1: „Nachhaltiges Deutschland – Wege zu einer dauerhaft umweltgerechten Entwicklung“, Erich-Schmidt Verlag, Berlin 1997
4. SRU Umweltgutachten 1994 - Für eine dauerhaft umweltgerechte Entwicklung. Februar 1994. Stuttgart: Metzler-Poeschel, 1994.

life, performing any economic activity in a resource-saving and fair way and designing socially just developmental activities within the society comprising all social interest groups.

In concrete terms, this means that non-renewable natural goods such as minerals or fossil energy sources should be used only to the extent that their functions can be replaced by other materials or energy sources. The exploitation of renewable resources should be guided by their regeneration rate. On a long-term basis, materials or energy should be released or consumed only to the extent that ecosystems are able to absorb them or adapt to these processes. Hazards and unjustifiable risks for human health – including interactions that have not yet been elucidated - should be avoided.

UBA is guided by this claim for a sustainable development also in the **field of sustainable chemicals management**. Already in 1999, UBA published its ideas of a precautionary and sustainable substance policy[5]. The subject is quite complex since a great number of stakeholders from the sectors of industry, government authorities and politics is involved in the production, processing and use of chemicals.

Fig. 1: *Chemicals in laboratory glassware - starting materials for many products that are involved in a great number of processes*[6]

The present document provides information on different aspects of sustainable chemistry as seen by the Federal Environment Agency and on fields of activity and approaches to achieve the objectives of sustainable chemistry in Germany and worldwide.

5 „Handlungsfelder und Kriterien für eine vorsorgende nachhaltige Stoffpolitik am Beispiel PVC“, Umweltbundesamt – Beiträge zur nachhaltigen Entwicklung, Erich-Schmidt Verlag, Berlin 1999.

6 Source: Federal Environment Agency

1. What does the term, Sustainable Chemistry, mean?

The concept of sustainable chemistry is seen as a perspective for the chemical sector in Germany. It is the objective of this concept to combine, on the basis of recent scientific knowledge, the preventive protection of environment and health with an innovative economic strategy. This strategy has been designed to create high added-value jobs. At the same time, the competitiveness of the European chemical industries is to be maintained and improved.

Research and development are needed as a basis for innovation. In this regard, the concepts and substance of sustainable chemistry are promoted by scientific societies and associations. Sustainable chemistry is a vast field being likewise important for stakeholders from science, economy, government and environmental and consumer protection associations.

It can be concluded from the great number of stakeholders involved that the concept of sustainable chemistry encompasses several fields of activity. There are different approaches with regard to the objectives to be achieved by a sustainable chemistry policy. The Twelve Principles of Green Chemistry proposed by Anastas and Warner[7] in 1998 (see Annex 1) constitute a well known example. On the European level, the twelve considerations to be taken into account when determining the best available techniques as listed in Annex IV to the IPPC Directive[8] have similarly expressed the requirements to be made for a sustainable production, addressing in particular the chemical sector (see Annex 2).

At a workshop on sustainable chemistry held in 2004, jointly with the Organization for Economic Cooperation and Development (OECD), UBA has developed criteria for a sustainable chemistry.[9].

Accordingly, the general principles of sustainable chemistry include:

- **Qualitative development: Use of harmless substances, or where this is impossible, substances involving a low risk for humans and the environment, and manufacturing of long-life products in a resource-saving manner;**
- **Quantitative development: Reduction of the consumption of natural resources, which should be renewable wherever possible, avoidance or minimization of emission or introduction of chemicals or pollutants into the environment. Such measures will help to save costs;**
- **Comprehensive life cycle assessment: Analysis of raw material production, manufacture, processing, use and disposal of chemicals and discarded products in order to reduce the consumption of resources and energy and to avoid the use of dangerous substances;**
- **Action instead of reaction: Avoidance, already at the stage of development and prior to marketing, of chemicals that endanger the environment and human health during their life cycle and make excessive use of the**

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7 Anastas, P. T.; Warner, J. C. *Green Chemistry: Theory and Practice*, Oxford University Press: New York, 1998, p.30. Oxford University Press from ACS Green Chemistry Institute Webpage

8 Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control; Official Journal L 257 , 10/10/1996 P. 0026 - 0040

9 *International Workshop on Sustainable Chemistry – Integrated Management of Chemicals, Products and Processes*, joint workshop by the Federal Environment Agency, OECD, the German Federal Institute for Occupational Safety and Health and the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, held in Dessau, 27 - 29 January 2004 ; http://www.gdch.de/taetigkeiten/nch/inhalt/jg2004/dessau.pdf

environment as a source or sink; reduction of damage costs and the associated economic risks for enterprises and remediation costs to be covered by the state;

- **Economic innovation: Sustainable chemicals, products and production methods produce confidence in industrial users, private consumers and customers from the public sector and thus, result in competitive advantages.**

2. The status of the chemical industry as a sector of the national economy

The chemical sector is one of the most important and innovative industries in Europe. It is the starting point of essential material flows. In 2006, as in the preceding years, the German chemical industry recorded a 6 per cent annual production growth - as referred to the total sales volume[10]. The best results were achieved by the manufacturers of pharmaceutical products and by producers of basic materials. In 2006, as compared to the previous year, the production of fine and special chemicals increased markedly, from 0.7 to 5.6 per cent[5]. Also on the international level, German chemical enterprises were in a good position, with a 7.4 per cent share in the world market sales in 2006. Although in the last years, the Chinese sales volume has surpassed that of Germany and also that of Japan, Germany, after the USA, Japan and China, still occupies the fourth position in the global competition of the chemical industries[5]. These basic data clearly demonstrate the economic strength of this industrial sector. Being a preferred location for settlement of the chemical industry in Europe, Germany has a particular responsibility to develop and implement sustainable concepts.

The use and the production of chemicals have been an essential source of high environmental pollution and the resulting risk to human health. In the past two decades, the chemical sector has made considerable efforts in order to remedy this situation and the negative image, which had developed essentially as a consequence of industrial accidents/hazardous incidents and findings of dangerous substances in consumer products and articles. However, such initiatives can only in part be attributed to a successful proactive self-responsibility of the chemical industry. Rather, there had to be a response to the pressing problems that had arisen in the environment, at the workplace and among consumers as a consequence of the use and handling of chemicals. Likewise, the public attention resulting from this situation has been one of the main reasons for the development of a high level of regulatory activity in the field of chemical safety over the years. The REACH Regulation[11] and the IPCC Directive[12] of the European Union jointly form an important and necessary framework in order to provide for safety in the chemical sector. In recent years, there has been a noticeable rise of self-responsibility in the chemical industry. This has to be taken into account when addressing the question of whether the present legislation is sufficient to ensure a sustainable chemicals management and production-integrated environmental protection or other instruments are considered as more important and more appropriate.

Sustainability in chemistry has to be guided by a comprehensive, i.e. integrated concept which is based on legal requirements. The enterprises concerned, their associations and customers, environmental and consumer protection associations as well as

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10 Brochure “Chemiewirtschaft in Zahlen 2007“, Verband der Chemischen Industrie (VCI); www.vci.de

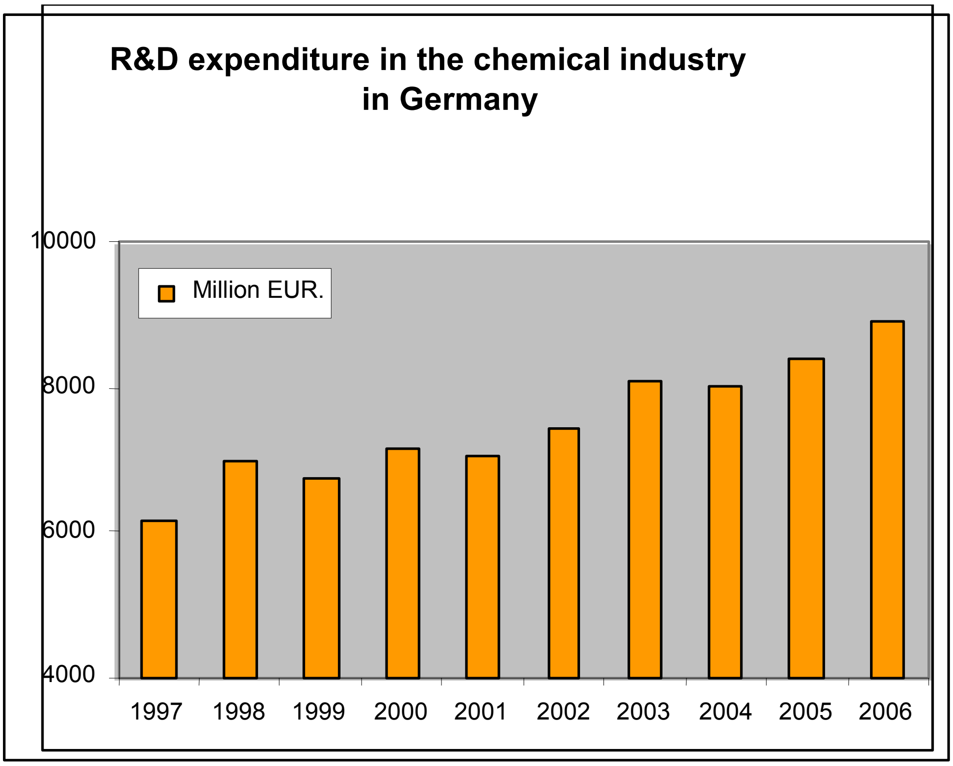
11 Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH); Official Journal of the European Community L 396 (2006)

12 Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control; Official Journal L 257 , 10/10/1996 P. 0026 - 0040

representatives of science and government should jointly promote an innovative development committed to sustainability.

It appears that the majority of German chemical companies have taken up the challenge to begin with innovation, by markedly increasing their investments in research and development in recent years (Fig. 2). In 2006, the share of research and development in the chemical sector was 5.4 per cent of the total sales volume so that the chemical industry has become one of the most research-intensive industries in Germany. This is also evident from the numbers of staff employed in the fields of research and development[13]. The association of the German Chemical industries (VCI) has reported that after a decrease seen in the 1990ies, the number of staff employed in research and development in the German chemical and pharmaceutical industries has been on a constant level or slightly increasing since 2001[14]. In 2005, the number of persons employed in the research and development departments of the German chemical industry was approximately 41 000. Obviously, the development strategies of major enterprises rely on powerful brands enjoying the confidence of industrial customers with regard to quality and safety. High trade volumes have also been achieved by some products that have been on the market for a few years only. The rapidly developing market requires companies to quickly adapt to new situations. Innovation activities of companies concentrate on three fields: Innovation in products, innovation in customer and market relations as well as innovation in processes and organisation[15].

Fig. 2: *Research and development expenditure in the chemical industry in Germany (1997-2006)*[16]



13 Address by the Federal Minister of Education and Research, Dr. Annette Schavan, on the occasion of the opening of ACHEMA 2006; http://www.bmbf.de/pub/mr_20060514.pdf

14 Eckdaten zu Forschung, Entwicklung und Bildung in der chemischen Industrie, Verband der Chemischen Industrie (VCI), state as of August 2007; p. 8

15 Lehner, U. Henkel: „Marken schaffen Vertrauen“, Chemanager 1/2007

16 Chemiewirtschaft in Zahlen 2006, p. 90, VCI 2006

Innovation cycles have become shorter in recent years, on the one hand exerting a high pressure on enterprises but on the other, enabling them to successfully place on the market products whose application meant increasing safety for the environment and human health. This is also an opportunity for more sustainability to be introduced both in chemical production and in chemical products. The growing demand of customers and the general public for safe and low-risk products will lead to a better utilization of natural resources. Thus, for example the yields of synthesizing and processing techniques can be increased or the number of steps for synthesis reduced. This will result in economic advantages for innovative enterprises. The cultivation of renewable raw materials may positively link sustainability and economic efficiency if social and ecological compatibility are taken into account (see Chapter 4.1.1. Use of renewable raw materials).

On the whole, any economic activity saving resources will strengthen the competitiveness of the German chemical sector and have positive effects on employment. However, innovation is not necessarily associated with an increase in sustainability. All actors within the supply chain should agree on the direction of innovation development to be determined by the objectives of sustainability. Cooperation of the participants and intensive communication within the supply chains are important conditions to be met to come to an understanding about the objectives of sustainability and to assign to it an appropriate status as an objective of development and innovation. There is still a considerable backlog in this regard.

Summary: Long-term economic success for enterprises will be brought about only on the basis of innovative products and technologies which at the same time meet safety standards, involve a low risk and ensure resource conservation. In this regard, the chemical sector with its above-average innovative capacity offers very good prerequisites for doing so. Fast innovation cycles offer the chance for this industrial sector to quickly establish alternatives that are safe for the environment and human health. Long product life cycles also require an expansion of recycling and recovery cycles.

3. Why does the Federal Environment Agency work on sustainable chemistry?

In the past, representatives of industry, including those of the chemical sector considered requirements of health and environmental protection as an inappropriate economic burden. Also the Federal Environment Agency had to stand up to this thesis. Some representatives of industry even perceived UBA as an opponent. Meanwhile, this situation has changed. Today, there is an increasing understanding that investment in environmental and health protection does not contradict the objective of an enterprise, which is to make profit, but in contrast, is a necessity to warrant the future and maintain the competitiveness of companies.

The targets of UBA's activities include the avoidance of negative effects of the production, processing and use of chemical products on humans and the environment. Products and methods consuming less of our natural resources will benefit the environment and simultaneously save costs for companies. The chemical industry is developing numerous new environmental technologies and thus, contributes to Germany's leading position in this field[17]. It becomes evident that in many fields, UBA and the industry are pursuing the same objectives.

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17 "Wirtschaftsfaktor Umwelt – Innovation, Wachstum und Beschäftigung durch Umweltschutz" Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Berlin, März 2006

Progress with regard to sustainable chemistry requires efforts which are aimed at a transparent dialogue with enterprises from the chemical industry, processors and users of their chemicals and products, as well as the scientific community and other social stakeholders, e.g. from environmental and consumer protection associations and trade associations. In this regard, UBA is in the position to initiate and support appropriate initiatives. This includes information transfer between science, industry and political decision-makers. The setting up of networks should be promoted to inform companies about concrete examples.

From the UBA perspective, sustainable chemistry is an important contribution to an eco-friendly innovation policy simultaneously protecting the environment and health. UBA offers itself as a forum where stakeholders may exchange ideas and discuss approaches to sustainable chemistry, develop structural approaches and promote the development of a joint understanding of objectives.

4. Fields of activity for sustainable chemistry in the supply chain

Sustainable chemistry is concerned with the entire life cycle of chemicals, i.e. their production including the raw materials required and their processing, the use of the products, and their disposal.

The objectives of sustainable chemistry include:

- avoidance or reduction of the emission of harmful substances into waters, soils, indoor and atmospheric air and
- a use of resources in the form of materials and energy that is as economical as possible.

The fields of activity of sustainable chemistry are linked to one another. There are, on principle, two main fields:

a) **sustainable production and processing, and**

b) **chemicals and products.**

4.1. Sustainable production and processing as a field of activity

UBA evaluates chemical production processes according to the criteria of Annex IV to the IPPC Directive[18], considering their potential benefits for the environment, and suggests technologies for an integrated avoidance and reduction of environmental pollution. Innovations are required in order to further develop the best available techniques (BAT). The current status of the best available techniques for special areas of the chemical sector[19] and for intersectoral aspects[20] are described in Best Available Techniques Reference Documents (BREFs). These documents are based on the exchange of information between government authorities, enterprises and their trade associations and environmental associations on the EU level. As a uniform procedure

[18] Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control; Official Journal L 257 , 10/10/1996 P. 0026 - 0040

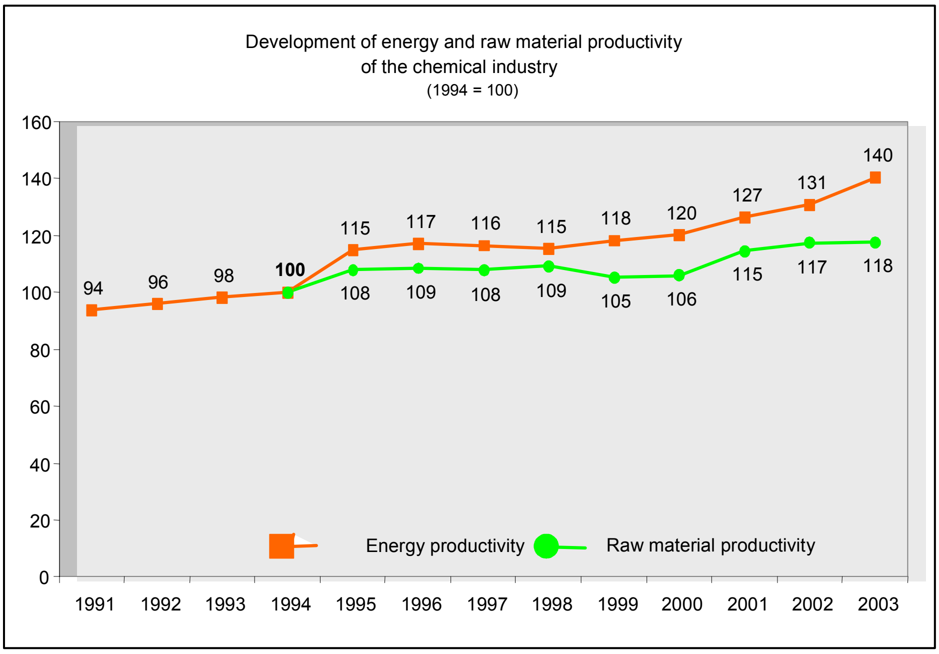
[19] BREFs for the production of inorganic and organic basic chemicals, of polymers, for the chloralkali industry, treatment/management of wastewater and exhaust gases in chemical industry, for all installations in this sector, http://www.bvt.umweltbundesamt.de/

[20] BREFs for industrial cooling systems, storage of dangerous substances and dusty goods, general principles of monitoring, economic and intermedial effects, a draft is available for a BREF on energy efficiency.

for all EU Member States, the BREF documents are to be considered by the competent authorities when issuing operating permits for industrial installations.
For the chemical industry, Arthur D. Little et al.[21] found a considerable potential for material efficiency in medium-sized companies (Fig. 3). Large chemical companies being active in a resource-demanding sector and producing basic materials take advantage of this potential already today and more than in the past. Requirements to be met in view of a general promotion of the sustainability of chemical production and processing include

- a further development of production processes and techniques, and
- the use of innovative technological approaches.

Fig. 3 *Development of raw material and energy productivity in the chemical industry (1991-2003)*[22]



A low consumption of energy and material resources is an important aspect of chemical production processes and processing technologies on their way to sustainability. For example, developers and manufacturers should increasingly consider the preceding synthesis performance of nature. Processes become more efficient and energy consumption decreases because fewer steps of synthesis are required e.g. in paper recycling. The (eco)toxicity[23] of chemicals used in processing should be as low as possible. Emission of pollutants and generation of wastes should be avoided or reduced. Renewable resources and wastes should be increasingly used as raw materials in processes, provided that their carbon dioxide balance is more favourable than that of conventional resources. Another important element of sustainability in chemistry consists in

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21 Arthur D. Little, Fraunhofer-Institut für System- und Innovationsforschung Fh-ISI, Wuppertal Institut für Klima, Umwelt, Energie, Abschlussbericht, Studie zur Konzeption eines Programms für die Steigerung der Materialeffizienz in mittelständischen Unternehmen, 2005, http://www.materialeffizienz.de/dateien/fachartikel/studie-anlage.pdf

22 Federal Statistical Office, calculations by UBA

23 Ecotoxicity describes the risk a chemical poses for the environment, particularly for the organisms and biotic communities living there.

the construction and operation of installations so that industrial accidents/hazardous incidents can be avoided.

4.1.1. Use of renewable resources

In the past, coal was the main source of raw material for the chemical industry. Meanwhile, petroleum has taken its place (77 per cent naphtha[24], 10 per cent natural gas, three per cent coal[25]). Also renewable resources are used. Their share was about eight per cent in 1991 and increased to 10.4 per cent by 2005[26]. A quantity of 2 million of the total of 2.7 million tonnes of renewable materials[27] is used by the chemical industry, the remaining balance of 0.7 million tonnes is processed by the paper and natural fibre industries. Oils serve as raw materials for example for surfactants and biolubricants; starch or polylactic acid, for bioplastic materials. Fats and oils are used to produce solvents and other products such as vitamins, amino acids, precursors of antibiotics or of polymers.

By cultivation of renewable raw materials, sustainability and economic efficiency may be constructively linked, provided that regard is given to environmental and social aspects such as

- Preservation of the natural fertility of soils;
- Economical use of water, pesticides and fertilizers (above all, phosphates);
- Protection against soil erosion;
- Adherence to quality targets for surface waters and groundwater;
- Conservation of the protected goods of aquatic and terrestrial biodiversity;
- Preservation of pristine habitats such as the rain forests; and
- Avoidance of rezoning of agricultural areas for other purposes at the expense of human food supply.

In addition, the production and use of renewable materials for energy supply should be approved only on condition that a minimum positive contribution is made to climate protection in the total balance over all production and cause-effect chains involved.

Many products made from renewable materials have the advantages of a good biodegradability and, as a rule, low (eco)toxicity. At the same time, the consumption of fossil resources is avoided. The use of natural materials takes advantage of the synthesis performance of nature: These materials are only extracted and no longer synthesized by way of complex multi-stage reactions. This also means that the formation of byproducts in major quantities [28] is avoided. In many cases where it is

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[24] A fraction from petroleum distillation.

[25] Hirth, Thomas, Die Natur als chemische Fabrik, GDCh-Workshop Nachhaltige Chemie, 20.03.2007, http://www.gdch.de/strukturen/fg/hirth.pdf

[26] Peters, Dietmar, Nachwachsende Rohstoffe in der Industrie, Fachagentur Nachwachsende Rohstoffe e.V. (FNR), 2006

[27] Presently, the most important renewable materials include: vegetable oils (800 000 t), animal fat (350 000 t), starch (640 000 t), cellulose/ rayon pulp (320 000 t), sugar (240 000 t), natural fibres (204 000 t); other vegetable raw materials (117 000 t). Figures taken from:- Auf einen Blick: Umwelt-Gesundheit-Sicherheit; Daten der chemischen Industrie, Stand August 2006; www.vci.de; - Peters, Dietmar, Nachwachsende Rohstoffe in der Industrie, Fachagentur Nachwachsende Rohstoffe e.V. (FNR), 2006

[28] Sheldon stated the E-factor (the ratio of unit of waste and byproducts divided by unit of product) for pharmaceuticals to be 25 ->100, and for fine chemicals, 5 – 50. Sheldon, R. A., Chem. Tech. 1994, 24(3), 38

intended to avoid the use of organic solvents for extraction, supercritical[29] carbon dioxide (CO_2) may serve the same purpose.

It is the objective of technical advances to increase the levels of utilizable substances to be derived from plants, to recycle biological wastes and use plants and plant parts not used so far as raw materials, and to optimize methods of substance extraction. For example, it is possible to produce basic chemicals on the basis of renewable materials. Thus, based on the transformation of glycerin, a byproduct of the biodiesel production, the Solvay company has developed a process to produce epichlorohydrin, which so far could only be achieved by petrochemical methods[30].

Often, utilizable compounds are present in certain plant parts only. Biomass liquefaction processes are suitable to produce simple building blocks for chemical synthesis from complete plants. It is true that as a result, on the one hand, exhaustible natural resources are preserved. However, on the other, the building block chemicals produced by means of this procedure are not necessarily more readily degradable or less toxic.

Hence, the use of renewable resources as basic substances for the chemical industry does not *per se* include the advantage of sustainability. As in the case of biotechnological methods (also see chapter on biotechnology below), the user has to examine whether their use is associated with benefits for the environment. In addition, the chemical industry is competing with food and energy production for agricultural and forestry raw materials. Biomass production as a result of the clearing of forests for plantations is incompatible with the objectives of a sustainable development because such approach is associated with the destruction of habitats, emission of greenhouse gases and pollution of the environment with pesticides and fertilizers. Certificates confirming eco-friendly and socially acceptable cultivation would make it clear whether renewable raw materials were produced in line with the objectives of sustainability.

Altogether, there is a considerable development potential for the use of biomass in chemical production. Although a great number of techniques are still in a developmental stage, there is a considerable potential for contributing to a sustainable chemistry.

4.1.2. Process optimization

Frequently, resource efficiency can be improved by process optimization, for example by introducing modern and automated process control systems. Already at the planning stage, it is possible to optimize procedures on a computerized basis[31]. Thus, the amount of waste generated is reduced by avoiding a rejection of batches already at the pilot stage[32].

Meanwhile, some universities have begun to teach basic rules of sustainable chemical synthesis, for example[33], the recirculation of solvents, auxiliary materials and cooling

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[29] In thermodynamics, the critical point (critical state) is a thermodynamic state of a substance which is characterized by equal densities of the liquid and the gaseous phase. The differences between the two physical states cease to exist at this point. Below the critical temperature, a liquid can be formed by an increase in pressure; above the critical temperature, this is no longer possible.

[30] McCoy, Michael, Glycerin Surplus - Plants are closing, and new uses for the chemical are being found, Chemical & Engineering News, February 2006 Volume 84, Number 6, p. 7

[31] Simulation chemischer Prozesse, cav chemie-anlagen + verfahren, 4/2007, www.cav.de, cav 482

[32] Optimal gerührt–Bestimmung der Mischzeit mit Simulationsverfahren, cav chemie-anlagen + verfahren, 5/2007, www.cav.de , cav 468

[33] SUSOR Sustainable Syntheses Optimization Rules, www.oc-praktikum.de/de/articles/pdf/Susor_de.pdf

water or the use of alternative methods of energy supply such as microwaves or ultrasound.

The chemical industry needs energy in a great variety of forms: as mechanical energy, process heat, cold, compressed air or in the form of highly purified water. Examples of measures reducing energy consumption include combined heat and power (CHP), combined heat, cooling and power (CHPC)[34], as well as stepless drive systems and heat recovery.

In order to increase the efficiency of procedures and avoid negative effects on the environment, it will not suffice to consider only single steps of synthesis. Entire production processes, including upstream production operations for starting and auxiliary materials and downstream processing operations are to be examined for alternatives or new pathways of synthesis. Multi-stage synthesis can sometimes be replaced by new, selective techniques[35] with only a few reaction steps. This can help to save natural resources and avoid the formation of undesirable byproducts.

4.1.3. Innovative technological approaches

The chemical industry is developing innovative techniques in order to achieve in the future a production which is more efficient in terms of resources, and in order to benefit the environment. Such approaches include for example biotechnology and nanotechnology, selective catalytic procedures and optimized separation processes. Other innovations to be mentioned include microreaction and microsystem technologies as well as the use of procedure-optimized solvents. The possible benefits of the specific contributions of these different techniques will depend on the requirements for the individual uses.

- **Solvents**

Solvents (Fig. 4) are important auxiliary materials for chemical synthesis. A comparative assessment should encompass their entire life cycle. Organic solvents are often unsafe in (eco)toxicological terms, and being volatile organic compounds (VOC), they contribute to ozone formation in ambient air. Moreover, most chlorinated solvents are persistent[36] and accumulate[37] in organisms. Alternatives are provided by solvent-free procedures or other solvents such as water, or ionic liquids and supercritical fluids[38] such as carbon dioxide.

Ionic liquids are molten organic salts with a low melting point and very low vapour pressure. They are non-inflammable, easily separable, and there is no risk of explosion. Reactions in these media often proceed selectively and produce high yields. However, little is known about the effects of ionic liquids on humans or on organisms in the

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34 According to the power supply centre of the firm of Schering (now Bayer Schering Pharma) at their Berlin (Wedding) branch, combined heat, cooling and power generation has resulted in a decisive increase of efficiency of the plant as compared to combined heat and power generation only.

35 Chemical procedures are referred to as selective if only one reaction (no side reaction) takes place resulting in the preferential formation of a single reaction product.

36 In biology and environmental chemistry, persistence designates the property of substances to persist in the environment over long periods of time in a state unchanged by physical, chemical or biological processes.

37 Bioaccumulation refers to the accumulation of substances in an organism after absorption from the animate or inanimate environment.

38 In the supercritical state, there is no difference in behaviour between the liquid and gaseous phase of a substance.

environment[39 40]. Examinations have shown that some ionic liquids are no less effective in (eco)toxicological terms than conventional organic solvents[41]. In addition, the production of ionic liquids is energy-intensive, which is why an efficient recycling of the salts used is important.

Fig. 4: *Solvents are important additives to adhesives*[42]

Supercritical fluids – such as supercritical carbon dioxide or water – have a high dissolving capacity, they can be separated without residue formation and can be efficiently recovered. Supercritical carbon dioxide is also used in extraction methods and in the cleaning of textiles.

- **Optimized separation processes**

Processes for the separation of mixtures of substances account for more than 40 per cent of the total energy demand in chemical production[43]. Processes for the separation of mixtures of substances or for cleaning characterized by simultaneous substance separation during the reaction, such as reactive rectification and extraction, reduce the amounts of energy and material consumed, and at the same time, also their costs are frequently lower than those of conventional procedures. As compared to formerly used techniques, yield and selectivity can be increased with less costly apparatus and less

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39 Brennecke, J. F.; Maginn, E. J.: Ionic Liquids: Innovative Fluids for Chemical Processing, AIChE Journal, Vol. 47, No.11, (2384-2389), November 2001

40 Kralisch, Dana et al., Energetic, environmental and economic balances: Spice up your ionic liquid research efficiency, Green Chem., 2005, 7, 301-309

41 Cf. publications by the UFT Center for Environmental Research and Environmental Technology, Bremen, Jastorff, B. et al., for example: Ranke et al, Biological effects of imidazolium ionic liquids with varying chain lengths in acute *Vibrio fischeri* in WST-1 cell viability assays, Ecotoxicology and Environmental Safety 58 (2004) 396-404

42 Source: Federal Environment Agency

43 Eissen, Marco et.all, „10 Jahre nach „Rio“ – Konzepte zum Beitrag der Chemie zu einer nachhaltigen Entwicklung“, Angew. Chem. 2002, 114, 402-425

working steps. At the same time, the risk of industrial accidents/hazardous incidents is reduced.

- **Improved catalysts**

Today, catalysts are used in 80 per cent of chemical processes performed[44]. In a number of cases, catalysts are required to make synthesis possible at all, and they accelerate the process. Catalysts reduce the energy demand and help to avoid wastes[45] [46] As compared to former procedures, less byproducts will form because the course of processes is more targeted and selective. Chiral catalysts avoid the formation of racemates[47] so that as a result, complicated methods for the separation of enantiomer[48] mixtures are required[49].

An example is presented by the direct synthesis of propylene oxide developed by Degussa AG where propene reacts directly with hydrogen peroxide[50]. The chlorohydrine process used until now for propylene oxide production has a high energy demand and generates large quantities of waste water with a high salt content and high emission of organochlorine compounds. Another example of improved catalyst technology is represented by organometallic catalysts (metallocene catalysts) allowing the targeted production of polyethene and polypropene plastics with desired properties. These new plastic materials may replace other materials whose production is characterized by high material and energy demand, such as polyvinyl chloride, polycarbonates, polyaziridine or polyimide[51][52].

- **Nanotechnology**

Nanomaterials are characterized by a diameter of less than 100 nanometers[53]. They may be used for a great number of purposes. A list compiled in the USA comprises

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44 Kadyrov, Renat, Chemiebausteine optimal koppeln, Elements Degussa - Science Newsletter 2007(19) 27

45 UBA-Texte 17/03 und 21/04, Marscheider-Weidemann, Dr. F. et al., Abfallvermeidung bei Produktionen für organische Spezialchemikalien durch den Einsatz hochspezifischer Katalysatoren

46 Katalyse, Nachrichten aus der Chemie, 53, März 2005, 313-315

47 In chemistry, a racemate (derived from Latin: acidum racemicum = tartaric acid, the first substance successfully subjected to racemate separation) designates a mixture of two chemicals that have completely symmetric structures but behave like mirror images of one another, like left and right hand, being referred to as enantiomers.

48 Enantiomers are stereoisomers of chemical compounds that have the same constitution, i.e. the same chemical formula, and connectivity of their atoms is identical. Because enantiomers have opposed configurations in all stereocentres, there are theoretically always a (-) and a (+) enantiomer present of which, however, under the practical conditions of nature often only one is present. The spatial structures of a pair of enantiomers behave exactly like mirror images of one another. They are also referred to as optical isomers.

49 The term, chirality stands for the property of a molecule to differentiate itself from its mirrored image so that it cannot be brought into conformity with the original by means of rotation. Molecules behaving like original and mirrored image and otherwise being identical are referred to as enantiomers. A mixture of both enantiomers is referred to as racemate.

50 Pilotanlage zur Direktsynthese von Wasserstoffperoxid läuft erfolgreich, Degussa News vom 09.März 2005, http://www.degussa.de/degussa/de/innovationen/highlights/

51 Eissen, Marco et.all, „10 Jahre nach „Rio“ – Konzepte zum Beitrag der Chemie zu einer nachhaltigen Entwicklung“, Angew. Chem. 2002, 114, 402-425

52 Rouhi, Maureen; Chiral Chemistry, C&EN, June 13, 2004, pp. 47-62

53 After the definition by Paschen, H. et al, TA project nano technology. Büro für Technikfolgen-Abschätzung beim deutschen Bundestag, Arbeitsbericht Nr. 92, 2003

more than 600 consumer products containing nanomaterials[54]. Meanwhile, also on the German market many nanomaterials and nanoproducts are offered. Many others are being developed[55]. It is assumed that nanotechnology applications have a high growth potential[56].

The properties of nanomaterials can be exactly determined during production. In a number of cases, their use can be of benefit to the environment. Thus, thinner coatings help to save raw materials because less solvents and materials are needed[57 58 59]. Optimized component parts of solar and fuel cells increase the efficiency of energy conversion. Exhaust gases and waste water can be effectively cleaned by means of nanoporous filters and membranes requiring only little space. Nanoscale catalysts also increase the yields of chemical syntheses. Owing to the so-called lotus effect, coated surfaces become self-cleaning, which helps to save cleaning agents. Protective paints for ships based on nanomaterials are being tested as alternatives to chemically effective antifouling coatings.

However, there are still insufficient data available with regard to the effects of nanoparticles on human health and the environment. There are indications of toxic and ecotoxic effects of nanoparticles because, in contrast to larger particles, these may be absorbed by the cells of living organisms. However, the studies performed are not yet comprehensive enough to substantiate assessments. There is also a lack of information concerning exposure and of standardized procedures to detect nanoparticles in environmental media. Studies on this subject have to encompass the entire life cycle of products including their disposal. Experts on the national[60], EU[61] and OECD levels are currently compiling and evaluating data and information, focussing on the identification of research requirements and the development of new methods for the assessment of environmental and health risks. In a joint activity by several of its ministries, the German Federal Government has participated in the discussion about the chances and risks of nanotechnology. In the context of a Commission named "NanoDialog 2006-2008", representatives of policy, economy, science, authorities and associations have been

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54 „Project on Emerging Nanotechnologies" at the Woodrow Wilson International Center for Scholars (state as of 13 March 2008) http://www.nanotechproject.org/index.php?id=44 or http://www.nanotechproject.org/consumerproducts

55 UBA-Texte 10/07, Führ, M. et al., Rechtsgutachten Nano-Technologien – ReNaTe, S. 88-97, März 2007, www.umweltdaten.de/publikationen/fpdf-l/3198.pdf

56 Luther, W., Malanowski, N. u. a., Nanotechnologie als wirtschaftlicher Wachstumsmarkt, VDI Technologiezentrum GmbH (Hrsg.) im Auftrag des BMBF; 2004 (Kohlenstoffnanoröhren, Polymer-nanokomposite, Aerogelen, organische Halbleiter, anorganische Nanopartikel) http://www.nanotruck.de/druck/service/literaturliste.html or http://www.nanotruck.de/fileadmin/nanoTruck/redaktion/download/nanotech_als_wachstumsmarkt.pdf

57 Steinfeld, M., v.Gleich, A., Petschow, U., Haum, R., Chudoba, T. und S. Haubold: Nachhaltigkeits-effekte durch Herstellung und Anwendung nanotechnologischer Produkte. Schriftreihe des IÖW 177/04.

58 Umweltbundesamt, Nanotechnik: Chancen und Risiken für Mensch und Umwelt, August 2006 http://www.umweltbundesamt.de/uba-info-presse/hintergrund/nanotechnik.pdf

59 Oakdene Hollins Ltd commissioned by the UK Department for Environment, Food and Rural Affairs (DEFRA), Environmentally Beneficial Nanotechnology - Barriers and Opportunities, May 2007 http://www.defra.gov.uk/environment/nanotech/policy/pdf/envbeneficial-report.pdf

60 Research strategy of the Federal Environment Agency, the Federal Institute for Risk Assessment (Bundesinstitut für Risikobewertung - BfR) and the Federal Institute for Occupational Safety and Health (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin - BAuA), http://www.umweltbundesamt.de/technik-verfahren-sicherheit/nanotechnologie/index.htm

61 SCENIHR (Scientific Committee on Emerging and Newly-Identified Health Risks), 29 March 2007, The appropriateness of the risk assessment methodology in accordance with the Technical Guidance Documents for new and existing substances for assessing the risks of nanomaterials. http://ec.europa.eu/health/ph_risk/committees/04_scenihr/scenihr_cons_04_en.htm,

discussing the pros and cons of different nanomaterials for sustainable development[62], [63]. In November 2008, the commission presented the results to the public.

Because of the existing gaps in knowledge regarding the risks, UBA recommends to keep nanomaterials in closed systems in production processes and in products, to bind them into solid forms in order to avoid direct contact with humans and the environment.

- **Micro process engineering / microsystem technology**

In micro process engineering, chemical processes are conducted in apparatus having dimensions in the micrometer or millimeter ranges[64]. These technologies employ reactors of very small dimensions for production or processing.

In contrast to conventional procedures, microreaction technology provides a number of advantages, particularly for the production of fine and special chemicals[65] [66]. These advantages include

- a high selectivity and higher yields as compared to conventional-scale procedures, side reactions are avoided, raw material and energy efficiency are improved and the quantity of waste generated is reduced;
- a degree of safety of the production procedure being higher than that of conventional procedures as well as a high and constant product quality owing to continuous process operation, and
- a higher flexibility with regard to variation in market requirements owing to modular procedures.

It has been prognosticated that by the year 2010, about 10 to 15 per cent of all fine and special chemicals would be produced by means of microreaction technology.

- **Biotechnology**

Industrial biotechnology uses biological processes to produce or process chemicals in bioreactors with the help of bacteria, yeasts, moulds and the enzymes contained in these. In a number of cases, a multi-stage chemical synthesis can be replaced by a single-stage biotechnological system. Industrial biotechnology, also referred to as white biotechnology[67], does not only replace existing processes but above all, forms the basis to produce new materials which are interesting both in scientific and economic terms. In biotechnological procedures, operations are usually performed in aqueous media, at low

62 Bundesumweltministerium, Umweltbundesamt und Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA), Tagung „Dialog zur Bewertung von synthetischen Nanopartikeln in Arbeits- und Umweltbereichen"; Iku GmbH, Synthetische Nanopartikel, Abschlussbericht November 2005, http://www.dialog-nanopartikel.de/downloads.html, Claus, Frank; Lahl, Uwe, Synthetische Nanopartikel – Entwicklungschance im Dialog, UWSF – Z:Umweltchem Ökotox 2006 (OnlineFirst): 3, http://www.dialog-nanopartikel.de/UWSF_Entwicklungschancen.pdf

63 Dubbert und Rappolder: Nationale und internationale Aktivitäten zu den Chancen und Risiken der Nanotechnik im Umweltbereich. UMID 2/2007, S. 20-23.

64 German glossary on micro process engineering, Industrieplattform Mikroverfahrenstechnik – MicroChemTec, http://www.microchemtec.de/content.php?pageId=2402

65 „Auf die Plätze… Mikroreaktoren halten Einzug in die Produktion von Feinchemikalien", Chemie Technik, Nr. 7, 2004

66 Kralisch, Dana et al., Assessment of the ecological potential of microreaction technology, Chemical Engineering Science 62 (2007), 1094-1100,

67 White biotechnology: Industrial biotechnology comprising the use of biological processes in technological procedures and industrial production.

temperatures and normal pressure, which means that less energy is required and the risk of industrial accidents/hazardous incidents is lower than in the application of conventional chemical processes. The chemicals used are compatible with biological systems and thus, often more favourable in terms of environmental and health protection than in conventional synthesis procedures.

In many cases, renewable resources or residual substances are used as nutrient media, for example molasse and whey[68]. The catalytic properties of enzymes enable the synthesis of particularly pure optical products[69]. According to a study performed in 2006, the share of products manufactured by means of biotechnology in the chemical industry amounted to five per cent of the total sales volume. An increase to up to 20 per cent has been predicted for 2010[70].

The economic and ecological opportunities offered by white biotechnology are great. However, biotechnological procedures are not necessarily more eco-friendly than the classical chemical ones. Users must check in the individual case whether the biotechnological procedure to be applied is indeed associated with benefits to the environment. For example, reactions in an aqueous medium often require large amounts of water, and large amounts of waste water are generated. The energy demand increases if the desired products have to be isolated from diluted solutions, resulting in higher expenditure on drying. Moreover, also biotechnological processes will produce waste.

New biotechnological processes are aimed at using residual substances and wastes and developing a production of basic chemical substances and products from biomass. There is still a need for a further development of new biocatalysts, for the optimization of procedures and for the preparatory processing of products. In October 2006, UBA, in collaboration with the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and the German Association of Biotechnology Industries (Deutsche Industrievereinigung Biotechnologie - DIB) held a workshop on the ecological and economic advantages of white biotechnology[71].

Microorganisms - whether genetically modified or not – may present a risk in biotechnological processes if they escape from containers into the environment. As a rule, however, these risks can be controlled quite well due to the use of closed systems.

Commonly, genetically modified plants are not grown in closed systems but in the open nature. There is no doubt that also plants are interesting and promising bioreactors. The amylose-free[72] potato is an example of how green genetic engineering can be used for raw material production. Nevertheless, the cultivation of genetically modified plants continues to be a controversial issue. If careful consideration according to the German

68 Hüsing, B. et al.:(2003): Biotechnologische Herstellung von Wertstoffen unter besonderer Berücksichtigung von Energieträgern und Polymeren. UBA-Texte 64/03.

69 See footnote No. 45

70 Braun, M., Teichert, O. und Zweck, A.: Übersichtsstudie Biokatalyse in der industriellen Produktion – Fakten und Potenziale zur weißen Biotechnologie. Zukünftige Technologien Consulting Band 57 (Januar 2006)

71 Dubbert, W.und Heine, T. (Hrsg.) Weiße Biotechnologie – Ökonomische und ökologische Chancen. Umweltbundesamt und Deutsche Industrievereinigung Biotechnologie, 2007, http://www.umweltbundesamt.de/uba-info-medien/mysql_medien.php?anfrage=Kennummer&Suchwort=3260

72 Amylose (Greek: amylon = starch flour or amylum) is a component of natural vegetable starch, for example maize or potato starch, with a mass share of about 20-30 per cent, in addition to amylopectin.

Act to Regulate Genetic Engineering has shown that also long-term risks for humans and the environment can be excluded, cultivation is justifiable in the opinion of UBA.

Presently, there are still many unresolved problems. For example, the risks for the environment involved, e.g. effects on wildlife flora and fauna as a consequence of the spreading of plants and outcrossing of transgenic organisms[73] have to be carefully examined because possible damage can be irreversible. There are still large gaps of knowledge with regard to long-term and combination effects[74]. In addition, there is still insufficient knowledge about the coexistence with genetically unmodified crops. From the UBA perspective, it is also problematic to use genetically modified food crops for biological substance production since confounding cannot be completely excluded. Under the present conditions, UBA therefore does not consider the so-called green genetic engineering as sustainable. It has to be added that in the opinion of UBA, green genetic engineering will not succeed in Europe in the near future due to lacking social acceptance.

4.2. Chemicals and products as a field of activity[75]

Already in 1999, the Federal Environment Agency has formulated essential objectives of a precautionary and sustainable substance policy[76]. The general targets are still valid, i.e. there should be

- no irreversible introduction of persistent and/or bioaccumulating foreign substances into the environment, irrespective of their toxicity;
- no introduction of carcinogenic, mutagenic or reprotoxic substances into the environment;
- no anthropogenic release of natural substances with the above-mentioned properties resulting in an increase of the natural background exposure;
- a reduction of the introduction of other toxic or ecotoxic substances to a level unavoidable for technical reasons; and
- a reduction of the introduction of substances whose effects are unknown unless they can be retrieved from the environment.

Chemicals and products as a field of activity within a sustainable chemistry policy is aimed at the use of safe chemicals and the development of safe conditions for the handling of chemicals. At the same time, it is intended to increase the share of chemicals of high inherent safety[77], particularly in open uses. Inherent safety means in this context, that

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73 Transgenic organisms are genetically modified organisms whose genomes contain additional inserted genes originating from a different species. This type of genetic modification has to be distinguished from traditional breeding methods, which were based on existing hereditary material and its beneficial, arbitrary selection by accidentally occurring mutations.

74 Effects of several substances that overlap or occur simultaneously.

75 Legislation on chemicals distinguishes between *chemicals* (pure substances), *preparations* (mixtures of chemicals) and *articles*. In *articles*, the function is not essentially determined by the substance contents but rather, by their form and shape. *Preparations* and *articles* are frequently summarized under the term of *products*, which in the following is used in this sense. Where the term *production* is used, it refers to the *production of chemicals*, *preparations* and *products*.

76 Umweltbundesamt: „Handlungsfelder und Kriterien für eine nachhaltige Stoffpolitik am Beispiel PVC, Erich Schmidt Verlag, Berlin 1999

77 Inherent safety of chemicals = a lack of risks and potentially impairing properties

a) these chemicals have no or only a low number of dangerous properties and
b) therefore do not involve any incalculable risk for humans or the environment.

Fig. 5: *Glass containing one of the most important resources of our planet: water*[78]

An increasing share of inherently safe chemical substances in products means that eventually, also these products will become safer for the environment and health.

In addition, a minimum of resources should be used in the production of chemicals and products (Fig. 5), i.e. (see Chapter 4.1)

- with a high yield and under atom-economical[79] and mild conditions,
- with a low consumption of energy and auxiliary materials and
- with a low or no generation of liquid and solid wastes.

The Federal Environment Agency requires that chemicals are only introduced into the supply chain if their effects on the environment and human health are known. In this way, manufacturers and processing establishments assume their responsibility for a safe handling of substances.

These criteria also apply to products with regard to their composition, which should be both ecological and safe in terms of health. Meeting such targets is facilitated by concepts of a customer-friendly and use-oriented chemicals management such as

78 Source: Federal Environment Agency
79 In a 100 per cent atom-economical reaction, all reaction partners are completely contained in the resulting product (addition reactions and rearrangements are atom-economical, substitution and elimination reactions are less atom-economical).

chemical leasing ([80]see also Chapter 5.3.1) - as well as of energy and material flow management[81] and life cycle assessment[82]. Product-related material flow management is based on product life cycle assessment. According to ISO 14040[83], life cycle assessment is a method to assess the environmental aspects and product-specific potential environmental effects associated with a product. By means of this system, the material and energy flows of a product are analyzed and assessed throughout its entire life. The potentials identified as a result are used to substantiate decisions in the strategic planning and development of products. Examples include life cycle analyses of graphic papers or reusable packaging material for beverages. For energy and material flow management and life cycle assessment, the Federal Government has established the German Material Efficiency Agency (Deutsche Materialeffizienzagentur - Demea[84]).

By creating innovative products, the chemical industry can contribute to the conservation of natural resources. New thermal insulation materials reduce the energy demand, new surfaces help to save cleaning products, release agents and degreasers, new detergent formulations decrease energy consumption by washing operations. Innovations of the chemical industry help to develop alternative energy sources, for example solar energy, and to increase the efficiency of energy conversion.

In the following, it is explained whether the present situation meets this requirement, and which direction development should take in the opinion of UBA.

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80 Jakl T, Joas R, Nolte R, Schott R, Windsperger A (2004); Chemical Leasing – An Intelligent and Integrated Business Model with a View to Sustainable development in Materials Management. ISBN 3-211-40445-7 Springer Wien New York
Jakl, Joas, Nolte, Schott, Windsperger: Chemikalien Leasing. Ein intelligentes und integriertes Geschäftsmodell als Perspektive zur nachhaltigen Entwicklung in der Stoffwirtschaft.; Springer-Verlag Wien New York, 2003.
Lebensministerium Österreich: CHEM – News XIII „aktuelle stoffpolitische Schwerpunkte der Abteilung für stoffbezogenen Umweltschutz – Chemiepolitik; 2004

81 Energy and material flow management is aimed at optimizing material and energy flows. The main objectives of such management include resource and/or material efficiency and the creation of sustainable cycles.

82 According to ISO 14040, the concept of life cycle assesment (LCA) is defined as the compilation and assessment of inputs, outputs and the potential environmental effects of a product system over the entire life cycle.

83 The international standard, ISO 14044 is a summary of the previous standards, ISO 14041 - ISO 14043 and deals with the subject of life cycle assessment. Acording to ISO 14040 (current edition: July 2006), a complete life cycle assessment (LCA) comprises the following elements: definition of the goal and scope of the LCA (ISO 14040); environmental management – life cycle assessment – goal and scope definition and inventory analysis (ISO 14041); environmental management – life cycle impact assessment (ISO 14042); environmental management – life cycle assessment – life cycle interpretation (ISO 14043).

84 Bundesministerium für Forschung und Technologie (BMBF), Deutsche Materialeffizienzagentur: http://www.materialeffizienz.de/

4.2.1. REACH as a component of sustainable chemistry[85]

REACH is a new chemicals management system for the EU which has been in effect since 1 June 2007. REACH stands for the **R**egistration, **E**valuation and **A**uthorisation of **CH**emicals[86]. This Regulation is intended to ensure that in the future

- enterprises of the chemical industry provide evidence of the safety of their chemicals for the proposed uses;
- effects of chemicals on the environment and health are known;
- chemicals with particular dangerous properties are subject to an authorization procedure;
- not only the manufacturers and importers of substances but also the users of substances are responsible for safety and have to fulfil certain obligations.

All manufacturers and importers of substances must generate data on these substances and make them available as soon as they produce or import more than one tonne of a substance per year. The time of registration and amount of data depend primarily on the tonnage produced annually. High tonnage substances have to be registered first and require more data. For quantities of ten tonnes or more per year, the manufacturers have to prepare a chemical safety report which includes risk assessment.

Manufacturers and importers have to transmit the information on their substances to downstream users, together with an extended safety data sheet. The latter will review the information received and carry out their own safety assessments, if required. The technical dossiers are evaluated by the European Chemicals Agency (ECHA) in Helsinki and the Member States in a stepped procedure. The use of particularly dangerous materials is subject to authorization. Authorizations by the European Chemicals Agency are only granted for appropriately controlled substances or if no suitable alternatives to their use are available.

During the legislation process, REACH was most controversially discussed because the chemical and the processing industries feared that its requirements would be economically unbearable. The assumption that REACH would reduce the number of chemicals available on the market and thus restrict the possibilities of innovative solutions involving chemicals has meanwhile been disproved by a study commissioned by the chemical industry proper[87].

REACH forms a framework for the chemical sector to proceed toward sustainability, because under REACH

- the participants will communicate information on hazardous properties and safe uses of substances in the supply chain;
- the most dangerous substances are subject to authorization and thus, will be under control;

85 Steinhäuser, K.; Richter. S.: „Nachhaltige Chemie – Perspektiven für Wertschöpfungsketten und Rahmenbedingungen für die Umsetzung“ in Nachhaltige Chemie – Erfahrungen und Perspektiven, Metropolis-Verlag, Herausgegeben von Angrick, M; Kümmerer, K.; Meinzer, L.; Marburg 2006

86 Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)**;** Official Journal of the European Union L 396 (2006)

87 “REACH – further work on impact assessment – a case study report, KPGM Business Advisory Service; July 2005

- in the future, the actors will be allowed to produce and use chemicals only if their use is safe.

Therefore, REACH forms the basis for all participants, namely manufacturers, users, authorities and partly also consumers and the public, to become aware of the risks from chemicals. This requirement is to be met particularly for production quantities of ten tonnes per year and above, per manufacturer and importer. According to UBA, the amount of data to be submitted for quantities between one and ten tonnes is in most cases insufficient for performing a hazard assessment.

REACH is an important module for the structure of sustainable chemistry. It contributes to an improved safety of chemicals and their uses in the near future. Its focus is the acquisition of information on chemicals. However, this is no guarantee for a generally sustainable working of all manufacturers, downstream users and final users. Therefore, further steps are necessary.

4.2.2. Dangerous chemicals and inherent chemical safety[88]

Chemicals whose properties are less dangerous than those of their predecessors mean a step towards more safety, which is why fewer risk reduction measures are required for their use. REACH provides for the necessary information on exposure and effects in order to be able to reduce the risks involved for humans and the environment to a justifiable level. In the field of chemical safety - and likewise under REACH – the risk is defined as the ratio of the predicted environmental concentration (the PEC value for the environmental medium) and an effect threshold derived from test results (the PNEC[89] value for the environmental sphere)[90]. If the calculated (or measured) exposure is lower than the effect threshold, the substance is regarded as safe. However, a substance fulfilling this condition does not automatically comply with sustainability targets.

More stringent requirements are made by the concept of inherent chemical safety, i.e. inherently safe chemicals will no longer involve a risk if the principles of a safe handling of chemicals are applied. For example, from the perspective of occupational safety, only those substances are considered as inherently safe that are not classified as dangerous for human health[91]. From the perspective of environmental protection, sustainable chemicals must not cause any short or long-term problems after having entered the environment. This concept is based on the assumption that manufacturers and users do not (or are not able to) always comply with costly safety and protective measures. This is important above all for small and medium-sized enterprises, which often look for simple solutions.

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88 Inherent chemicophysical properties are those belonging to a chemical substance by its nature. In the present context, the term of inherent chemical safety refers to the absence of properties known to involve risks for humans and the environment. As a result, there are no potential risks irrespective of exposure.

89 PNEC = predicted no-effect concentration (the concentration below which exposure to a substance is not expected to cause adverse effects).

90 European Chemicals Bureau: Technical Guidance Document in Support of Commission Directive 93/67/EEC on Risk Assessment for new notified substances, Commission Regulation (EC) No 1488/94 on Risk Assessment for existing substances and Directive 98/8/EC of the European Parliament and of the Council concerning the placing of biocidal products on the market, Revised Version 2003 [http://ecb.jrc.it/tgd/]

91 R. Packroff, Inherently Safe Chemical Products, paper presented at the Workshop “Sustainable Chemistry – Integrated Management of Chemicals, Products and Processes“, 27-29 Januar 2004, Dessau. Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA), Dortmund 2004

In terms of environmental protection, sustainability of chemicals means in particular that they are not persistent, not distributed over long distances (short-range chemicals)[92] and have no irreversible effects.

Particularly dangerous chemicals have to be restricted with regard to their use or banned by means of legal measures. This applies for example to carcinogenic, mutagenic or reprotoxic substances[93] and substances particularly critical for the environment because they are persistent, bioaccumulative and toxic[94]. Such substances are subject to authorization under the REACH Regulation.

In contrast, chemicals not having dangerous properties and not causing any negative effects on the environment throughout their life cycle can be considered as sustainable. This means that they neither have known adverse effects nor persist in the environment over periods of time so long that adverse effects unknown so far could become a problem in the future. Although not giving particular reasons for concern, a majority of substances require care when used because of single effect parameters, however, without justifying a legal ban or a restriction of their use[95].

However, the criterion of inherent chemical safety cannot be considered as absolute for all chemicals: As soon as the dangerous property is required for the function of the chemical when used, the inherent risk cannot be avoided. Thus, fuels have to be flammable, pesticides toxic and reagents aggressive or corrosive. However, chemicals need not have dangerous properties as long as they do not serve any function. Fig. 6 shows inherent properties characterizing the sustainability of chemicals.

Criteria for the sustainability of chemicals also include the conditions of their production and the environmental impacts associated with their use. As far as production is concerned, the specific resource demand (with regard to energy, raw materials and auxiliary materials) is a very important criterion[96]. Other aspects include the yield obtained during production, pollutants emitted into air, water and soil, such as the quantity of liquid and solid wastes generated during production and use. When comparing the same substance from two manufacturers having established different production procedures, these characteristic parameters will often differ. In this regard, there is a considerable potential for improvement of numerous synthesising and processing methods (see Chapter 4.1).

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92 M. Scheringer: Persistenz und Reichweite, Wiley VCH, Weinheim 1999

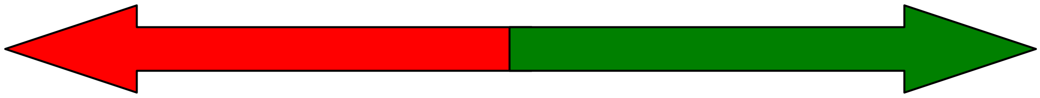
93 Carcinogenic, mutagenic, reprotoxic = CMR substances

94 Persistent, bioaccumulative and toxic = PBT substances; very persistent and very bioaccumulative = vPvB substances

95 K. G. Steinhäuser, S. Richter, P. Greiner, J. Penning and M. Angrick: Sustainable Chemistry – Principles and Perspectives, ESPR – Environ Sci & Pollut Res **11** (5), 284-290 (2004)

96 Steinhäuser, K.; Richter. S.: „Nachhaltige Chemie – Perspektiven für Wertschöpfungsketten und Rahmenbedingungen für die Umsetzung“ in Nachhaltige Chemie – Erfahrungen und Perspektiven, Metropolis-Verlag, Herausgegeben von Angrick, M; Kümmerer, K.; Meinzer, L.; Marburg 2006

Fig. 6: Characteristics of inherently safe chemicals



Not sustainable

- CMR properties
- Respiratory sensitiser
- Very high acute (eco)toxicity
- PBT- and vPvB properties
- High persistence and wide spatial range

Sustainable

- No irreversible and chronic effects
- Low acute (eco)toxicity
- Low persistence
- No bioaccumulation
- Narrow spatial range

Summary: The concept of inherently safe chemicals having no harmful effects and only a narrow spatial range may contribute essentially to the sustainability of uses. The development of such substances is an important objective for the chemical industry. Wherever such substances are not available, for example because the dangerous property is important for functionality, the safe use of these chemicals has to be ensured by means of protective measures and measures to reduce emissions.

4.2.3. Requirements for products

Dangerous substances may become released over the entire product life cycle, i.e. during production, use, recycling and disposal, posing risks to the environment and health. Emissions from industrial plant have markedly decreased in the past years. Thus, exposure to chemicals released from products[97] has gained in importance. In addition, they often enter the environment in a diffuse manner or may directly affect consumers in sensitive areas as e.g. by the respiratory route in indoor environments. Their release can hardly be controlled.

Moreover, many consumer goods are produced in countries outside of Europe where in many cases, there are less stringent requirements regarding occupational safety and environmental protection. This has resulted not only in environmental pollution from production processes outside of Europe but also in elevated contamination levels in products.

In order to avoid the presence of dangerous substances in products, a robust knowledge base is needed to provide information about the properties of substances and their use in the products. Frequently, there are no methods available to analyse and assess substances contained in products and knowledge is lacking with regard to suitable substitutes. Among other conditions, sustainable products require:

[97] Legislation on chemicals distinguishes between *chemicals* (pure substances), *preparations* (mixtures of chemicals) and *articles*. In *articles*, the function is not essentially determined by the substance contents but rather, by their form and shape. *Preparations* and *articles* are frequently summarised under the term of *products*, which in the text is used in this sense. Where the term *production* is used, it refers to the *production of chemicals, preparations, products and articles.*

- Scientifically substantiated methods for the assessment of substances in products based on
    - criteria for components with problematic inherent substance properties,
    - information about exposure and emission behaviour of components during the product life cycle including the recycling phase;
- Methods to analyze levels of pollutants and emissions, for example gas emissions or leaching;
- Identification of product groups that
    - reach the market in particularly large quantities,
    - represent or contain particularly problematic chemicals,
    - occur in particularly sensitive areas (e.g. products for young children or pregnant women), or
    - contain dangerous substances that can be substituted particularly easily; and
- Development of substitutes as well as information and recommendations for action to substitute dangerous substances in order to offer alternatives to consumers, manufacturers and legislative bodies.

The European legislation on chemicals covers the classification and labelling, restriction and authorization of substances and preparations[98]. Based on REACH, more information than before will be made available in order to promote the production of sustainable products. Meanwhile, only products which contain registered and safe chemicals are manufactured within the EU. In addition, there are numerous legal provisions imposing requirements with regard to substances used for certain product groups or referring to selected substance groups[99].

Nevertheless, REACH will not automatically prevent all problematic uses of dangerous substances in products. It will apply to all chemicals not earlier than in 2018. Sustainable product-related environmental protection will require further legal provisions, particularly for manufactured articles, because

- REACH is applicable above all to substances produced or imported in quantities of more than ten tonnes per year while for substances produced or imported in lower quantities and for special uses, information requirements are frequently insufficient. Hence, problematic uses cannot be excluded also in the future.
- Imported articles are not always produced using chemicals registered in Europe; under REACH, the importer is only obliged to notify chemicals which are intended to be released from articles and components giving rise to particular concern. This leads to a lower level of environmental and health protection for imported articles, as compared to articles produced in the EU, and in single cases, to competitive disadvantages for manufacturers in the EU.

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[98] Important European Directives and Regulations to be mentioned include: the Dangerous Substances Directive (67/548/EEC), the Chemical Restrictions Directive (76/769/EEC), the Biocidal Products Directive (98/8/EC), the Dangerous Preparations Directive (1999/45/EC) and the Existing Substances Regulation (EEC) No. 793/93.

[99] An example of legislation making requirements with regard to substances used for a single product group is represented by Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment. An example of legislation dealing with a selected substance group is given by Regulation (EC) No. 842/2006 on certain fluorinated greenhouse gases.

- REACH requires authorization only for particularly dangerous substances. Other problematic chemicals which do not fulfil all criteria for substances requiring authorization may still be contained in imported products. At best, importers of foreign articles will give recommendations for their safe use. Therefore, special product-related regulations will be required also in the future, for example for substances having adverse effects on the climate or the ozone layer, or substances having other problematic effects not being subject to authorization.

Hence, REACH is above all a procedure to obtain data on inherent substance properties and safe uses. Thus, it forms the basis for comparative substance and product assessments covering the entire product life cycle.

An important innovation under REACH consists in the fact that manufacturers or importers have to transmit information about substances and their safe use to downstream and industrial users. For the first time, downstream users are thus given the possibility to compare the substances handled and used by them for the manufacture of their products. In addition, it is in the own interest of commerce to offer only safe products to consumers. It is therefore probable that the market pressure demanding substitution of dangerous substances and products will increase in the future. However, the concrete effects of REACH will become evident only some time after its entry into force.

For the time being, it will remain indispensable to make requirements for the use and composition of products leading to critical exposure of humans and the environment to chemicals. In the long run, efforts should concentrate on equal requirements in terms of chemical legislation to be made for all products, whether produced within or outside the EU. Equal standards for products will ensure that the high level of European requirements becomes effective on the global level and thus, manufacturers in the EU will not suffer disadvantages.

5. Measures to introduce and propagate sustainable chemistry

5.1. Strategies to introduce sustainable chemistry

In spite of partly existing economic advantages associated with sustainability concepts in chemistry and problem solving, they do not take on automatically in the chemical industry. There are many aspects that can have inhibitory or promoting effects[100]. Enterprises will convert their operations to alternative processes, products or chemicals if

- product and process innovations promise financial advantages,
- legal provisions require standards that can no longer be met by using the existing procedures or products,
- a manufacturer wishes to be granted a certification for a product (environmental or health label such as the Blue Angel),
- conversions are required due to pressure from business partners, customers or a critical public.

Obstacles to conversion include

- lacking knowledge about existing alternatives and their benefits,
- long periods required for development associated with uncertain chances of success,

[100] http://www.gdch.de/taetigkeiten/nch/inhalt/jg2004/dessau.pdf

- high investment costs and a late return of investments,
- existing installations that are supposed to make profit and pay off,
- uncertainties with regard to the reliability of the alternative in the absence of pilot plant or prototypes,
- established and antiquated business policy in the fields of products, processes, safety and efficiency of installations,
- insufficient knowledge of markets and insufficient cooperation relationships.

For example, micro process engineering will probably be accepted more readily as soon as large scale[101] reference installations demonstrate that they offer functionality and profitability at the same time[102]. As compared to large enterprises, small and middle-sized companies of course do not always have the same potential to invest in new techniques and technologies and to develop their markets. To promote sustainable chemistry, it is first of all important to overcome communication barriers and to concentrate investments. Appropriate strategies to reach this goal include:

- Development of marketable sustainable products and procedures and overcoming of knowledge gaps about existing alternative approaches by means of
    - interdisciplinary research and development,
    - communication of good examples that have been successful on a pilot scale,
    - concentration of resources at all upstream stages before marketing,
    - collaboration of actors responsible for innovation and marketing management with those responsible for environmental protection and sustainability[103];
- Improvement of the flow of information and collaboration between scientific and industrial partners along the entire supply chain, for example with approaches such as open innovation strategy[104] or organization of contacts when preparing conferences[105];
- Small innovative enterprises develop technological or product solutions to offer these as a service to other companies for use by the latter against payment of licence fees (multiplication effect of innovations)[106].
- Several companies share development costs and distribute them over several projects[107] in order to make use of the development on a partnership basis or to be able to compete on the market with concentrated efforts.

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[101] So far, there is some small-scale plant for the production of small amounts of high-quality and high-priced substances, but no large-scale plant for the production of large amounts of chemicals.

[102] BMBF, VDI/VDE/IT, Trends in der Mikrosystemtechnik 2006, Rahmenprogramm Mikrosysteme – Innovationsunterstützende Maßnahmen, www.mstonline.de/publikationen/download/MST_Trends_2006.pdf

[103] IZT Institut für Zukunftsstudien und Technologiebewertung, Arbeitsbericht Nr. 10/2004: „Zukünfte der Informationsgesellschaft im Diskurs: eine Auswertung von fünf internationalen Konferenzen (2003-2004)“, http://www.izt.de/pdfs/IZT_AB10_Auswertung_internationale_Konferenzen.pdf

[104] Open innovation strategy means that enterprises buy services from other companies in order to accelerate their in-house innovation process while in contrast, closed innovation strategy means that companies provide all services independently, from manufacture to marketing of a product [Herzog, Philipp; Offen für Ideen von außen, Nachrichten aus der Chemie, 55, Mai 2007].

[105] Transkript, Nr. 5, 13. Jahrgang 2007, S. 56

[106] Positionspapier der DECHEMA e.V., Weiße Biotechnologie: Chancen für Deutschland, Nov. 2004, http://www.achema.de/data/achema_/DECHEMA_Positionspapier_Nov %202004f.pdf

- Installation of networks together with databases for communication and information in order to be joined by potential partners and to propagate successful problem solutions and examples. Networks of this type include
    - SusChem (European Technology Platform for Sustainable Chemistry) having the objective to form consortia for focal points of research and concentrating on the key areas of materials technology, reaction and process engineering and industrial biotechnology[108],
    - SubChem (sustainable substitution of hazardous chemicals), a joint research project dealing with options for the design of innovative systems for a successful substitution of hazardous substances, funded by the German Federal Ministry for Education and Research (Bundesministerium für Bildung und Forschung - BMBF)[109]
    - Sustainable Chemistry Network (SCN) of the OECD promoting the collaboration on subjects of sustainable chemistry on the OECD level. This collaboration is to activate, on a short-term basis, the exchange of information, new developments and incentives to intensify the application of sustainable chemistry. The SCN performs case studies and provides guidance on special subjects on an intermediate and long-term basis, in order to streamline information exchange, evaluate new developments and create incentives promoting sustainable chemistry. At the meeting of the Chemicals Committee and Working Party on Chemicals, Pesticides and Biotechnology held in June 2007, Germany took the leadership in the activities on incentive systems to promote the implementation of sustainable chemistry. In this context, an internet platform for the OECD on sustainable chemistry is being set up by UBA.
- Inclusion of commerce by means of Product Panels (example from Denmark), where manufacturers, commerce, trade unions, authorities and environmental protection and consumer associations evaluate selected product groups along their life cycles. A successful German example is represented by the “Forum Waschen für die Zukunft" (Washing for the Future Forum), which has developed criteria for sustainable washing and consumer information projects[110].

5.2. The role of science, training and education

Paul Anastas, one of the founders of green chemistry in the USA, maintains that sustainable chemistry cannot be enforced by means of legal provisions but has to materialise in peoples minds[111]. Although this opinion should be seen quite critically because it rejects legal requirements for the enforcement of green chemistry, it nevertheless points out the important role of education, training and science.

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107 Luther, W., Malanowski, N. u. a., Nanotechnologie als wirtschaftlicher Wachstumsmarkt, VDI Technologiezentrum GmbH, im Auft. des BMBF; 2004 http://www.nanotruck.de/druck/service/literaturliste.html or http://www.nanotruck.de/fileadmin/nanoTruck/redaktion/download/nanotech_als_wachstumsmarkt.pdf

108 Hoer, R., GDCh, SusChem–eine Erfolgsstory, Chemie in unserer Zeit, 2007, 41, 117 www.suschem.org

109 v. Gleich, A. et al, SubChem Gestaltungsoptionen für handlungsfähige Innovationssysteme zur erfolgreichen Substitution gefährlicher Stoffe, Dezember 2003, http://www.tecdesign.uni-bremen.de/subchem/startgerman.html

110 http://www.gdch.de/taetigkeiten/nch/inhalt/jg2004/dessau.pdf

111 Anastas, P. T.; Warner, J. C. Green Chemistry: Theory and Practice; Oxford University Press: New York, 1998; Anastas, P.T. Meeting the Challenges to Sustainability through Green Chemistry, Green Chemistry. April 2003, G 29-34

This starts with the chemistry lessons at school. Lessons teaching only theoretical knowledge will hardly enable students to apply such knowledge in their everyday life and understand technical associations. A sustainable way of utilization of our environment requires the ability to think in new dimensions and measure against new yardsticks. OECD has defined basic scientific education as the ability to apply the knowledge gained, to recognize scientific questions and draw conclusions from facts. Only the teaching and training of such abilities will enable people to apply the essences of sustainable development to specific subjects such as energy and climate, mobility, or textiles. This also applies to the approach of sustainable chemistry and its links with everyday life. In Germany, extensive teaching material is available on this subject. However, to our regret, it is rarely used[112].

Sustainable chemistry should also become a subject in university curricula for industrial chemists. To this end, it is necessary for stakeholders in chemistry to form networks jointly with related sciences, relationships between structure and effect are recognized and knowledge is gained on how economical use of energy and material resources are taken into account already at the stage of planning of syntheses. An essential step into this direction is known under the name of Sustainable Organic Chemical Lab Course (Nachhaltiges Organisches Praktikum – NOP)[113] , which has been developed by several German universities and is continually updated. Because of the great interest shown, it has meanwhile been translated into English and Italian; translation into other languages is envisaged.

It is the aim of the Green Chemistry Network (GCN) affiliated with the University of York in Great Britain to promote awareness of sustainability in chemistry at universities and schools as well as in industry and commerce. Also this network prepares educational resources. In addition, it offers a number of awards to industrial and academic researchers.[114].

The high importance attributed to sustainable solutions in chemical research is emphasized by the Nobel Prize in Chemistry 2005 awarded to Yves Chauvin, Robert H. Grubbs and Richard R. Schrock “for the development of the metathesis methods in organic synthesis”[115]. In the argument to substantiate the awarding, the contribution of metathesis reactions to sustainable chemistry was specifically emphasised. All over the world, numerous research groups try to find solutions for sustainable energy production and supply with the help of chemistry, for example to produce and store hydrogen by means of sunlight[116].

Science and scientific societies have played an important role in having sustainable chemistry come true. In a statement made in 2002, the Gesellschaft Deutscher Chemiker (German Chemical Society - GDCh) submitted a proposal how to update Chapter 19 of Agenda 21[117]. The latter has specified several concrete targets for the development of sustainable chemistry. The GDCh established a working group named

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112 Demuth, R., Parchmann, I. Ralle, B.: Chemie im Kontext – Sekundarstufe II, Cornelsen Verlag Berlin 2006, ISBN-10: 3-06-031130-7

113 König, B. et al: Nachhaltigkeit im organisch-chemischen Praktikum; http://www.oc-praktikum.de/

114 Green Chemistry Network: www.chemsoc.org/gcn

115 The Nobel Prize in Chemistry 2005, supplementary information to press release 5 oct 2005: Metathesis–a change-your-partners dance; http://nobelprize.org/nobel_prizes/chemistry/laureates/2005/

116 Koch, W.: Sustainable Chemistry – not without Chemistry, Vortrag beim EU-Workshop“Sustainable Chemistry – Implementation of a Scientific Concept in Policy and Economy“, Berlin, 15 May 2007

117 GDCh: Erklärung der Gesellschaft Deutscher Chemiker zur Fortschreibung des Kapitels 19 der Agenda 21, 2002, http://www.gdch.de/oearbeit/johannesburg_de.pdf

“Sustainable Chemistry”. Developmental trends and characteristics of sustainable chemistry have been laid down in a book entitled "Green Chemistry – Nachhaltigkeit in der Chemie” (Green Chemistry – Sustainability in Chemistry)[118] .

On the occasion of the German EU Presidency, UBA held a workshop entitled "Sustainable Chemistry - Implementation of a Scientific Concept in Policy and Economy" in June 2007[119]. This event served as an international forum to present options for a sustainable management in chemical industry. It became clear that sustainable chemistry policy is an indispensable element of a general sustainable development.

Likewise, other countries have made efforts to promote the emergence of sustainable chemistry in the field of science by setting up networks for an exchange of experience with regard to the success of pilot projects. The scientific journal Green Chemistry[120] has been published since 1999 and is increasingly gaining in reputation. The interest of the scientific community has been shown by several hundred participants of the First International IUPAC Conference on Green-Sustainable Chemistry held in September 2006 in Dresden, Germany.

These examples show that the idea of sustainability has reached chemical science. Although sustainable chemistry is still a small field within chemical science and above all in the chemical industry, the concept is increasingly adopted. UBA contributes to information networking by organising conferences and taking part in scientific meetings and discussions in working groups.

5.3. The role of management and management concepts

5.3.1. Chemical leasing

Chemical leasing[121] stands for a service-oriented business model that shifts the focus from selling chemicals on a volume basis towards making them available for rendering a service (Fig. 7).

For example, the price for the service of a solvent degreasing operation is based on the area of surface cleaned instead of the quantity of solvent sold. In the new business model, the manufacturer of the chemical becomes a service provider.

Fig. 7: *Illustration of the chemical leasing model: The chemical in the bottle turns pale in front of the goal, i.e. the finished product (in this case, a computer mainboard)*[122]

[118] *Green Chemistry* - Nachhaltigkeit in der Chemie; 1. Auflage - Juni 2003, ISBN-10: 3-527-30815-6

[119] EU Workshop on „Sustainable Chemistry – Implementation of a Scientific Concept in Policy and Economy“, Umweltbundesamt; 15./16. Mai 2007 in Berlin; www.sustainablechemistry2007.de

[120] *Green Chemistry*, RSC-Publishing; http://www.rsc.org/publishing/journals/GC/article.asp

[121] Jakl T, Schwager P. „Chemicals Leasing Goes Global – Selling Services Instead of Barrels: A Win-win Business Model for Environment and Industry“, Springer Wien New York, 2008
Jakl T, Joas R, Nolte R, Schott R, Windsperger A (2004); Chemical Leasing – An Intelligent and Integrated Business Model with a View to Sustainable development in Materials Management. ISBN 3-211-40445-7 Springer Wien New York
Jakl, Joas, Nolte, Schott, Windsperger: Chemikalien Leasing. Ein intelligentes und integriertes Geschäftsmodell als Perspektive zur nachhaltigen Entwicklung in der Stoffwirtschaft.; Springer-Verlag Wien New York, 2003
Lebensministerium Österreich: CHEM – News XIII „aktuelle stoffpolitische Schwerpunkte der Abteilung für stoffbezogenen Umweltschutz – Chemiepolitik; 2004

Chemical leasing is an instrument to put sustainable chemistry into practice because the profit does not depend on the quantity of chemicals sold but on their best economical use per service unit. It is the purpose of such approach to decrease the quantity of chemicals used, save costs and reduce resource consumption. In this model, the manufacturer or importer of the chemicals enters into direct contact with his customer and hence, is involved in the onward life cycle of the chemicals and translates the know-how about the use of his chemicals into a business of his own. In the ideal case, by doing so, he also accepts the responsibility for a safe use of the chemical.

This business model has already been tested for a number of uses, for example in the field of metal machining (cleaning/degreasing, deoxidising, casting, cooling/lubricating), in the field of chemical synthesis (catalysis), in food industry (extraction, water treatment) and in the field of auxiliary materials (cooling of goods, technical gases).

A study performed in 2002 by the Austrian Ministry of Life (Federal Ministry of Agriculture, Forestry, Environment and Water Management) concluded that a full application of the model in Austria in all suitable fields could save 53 000 tonnes of chemicals each year. This corresponds to one third of the total quantity of chemicals used in that country. This would also mean a reduction of the quantity of pollutants emitted and waste generated. In this business model, the economic benefit is associated with benefits for the environment, occupational health and consumers.

Therefore, expectations are high. However, a number of open questions remain, for example:

[122] Source: Federal Environment Agency

- In which industries in Germany the model would be feasible?
- Which would be the quantity of chemicals that could be saved in Germany?
- How should contracts between leasing partners be designed to create a fair distribution of advantages for environment, health and economy?
- What are the conditions to be fulfilled in order to protect business and trade secrets?

These questions also form the background of efforts by UBA, the Austrian Ministry of Life and the United Nations Industrial Development Organization (UNIDO)[123] to develop quality criteria. Such criteria are intended to warrant sustainability, for example with regard to production, inherent safety, safe use, disposal etc., of the chemicals used in chemical leasing.

5.3.2. Management systems for a sustainable chemical sector

According to a survey conducted by the German Association of Chemical Industries (Verband der Chemischen Industrie - VCI), 50 per cent of the member companies that participated in the inquiry have introduced one or several registered or certified environmental management systems[124]. Such systems for environment-related evaluation are only one out of a variety of instruments to control entrepreneurial activities on a long-term basis and at the same time, in a reliable and successful way.

Environmental management systems to be mentioned include above all ISO 14001[125] as an international standard and the EU Eco-Management and Audit Scheme (EMAS II)[126]. They contain guidelines and recommendations as well as environmental performance indicators. The requirements made by EMAS are higher than those of ISO 14001 and include a comprehensive environmental inventory including the environmental effects over the entire life cycles of products with external communication of the results. A number of simplified environmental management approaches has been recommended for small and medium-sized businesses[127] [128].

There are several methods available for the assessment of environmental effects and sustainability criteria, for example:

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123 In collaboration with the Austrian Ministry of Life, the United Nations Industrial Development Organization (UNIDO) has initiated pilot projects in Mexico, Egypt and Russia to test and to promote chemical leasing in newly industrializing countries; "Chemical leasing" UNIDO (United Nations Industrial Development Organization); http://www.chemikalienleasing.de/

124 Verband der chemischen Industrie (VCI), 2006: “Responsible Care 2006”, p. 24, http://www.vci.de/Umwelt_Responsible_Care/default2~cmd~shd~docnr~119560~lastDokNr~114664.htm

125 International Organization for Standardization (ISO) TC 207 Environmental Management, http://www.tc207.org/About207.asp

126 EMAS II (Eco-Management and Audit Scheme), Regulation (EC) No 761/2001 of the European Parliament and of the Council of 19 March 2001 allowing voluntary participation by organisations in a Community eco-management and audit scheme. http://ec.europa.eu/environment/emas/about/summary_en.htm

127 Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Umweltbundesamt, Umweltmanagementansätze in Deutschland, 2005, http://www.umweltdaten.de/publikationen/fpdf-l/3062.pdf

128 Kahlenborn, W., Freier, I., Adelphi Consult et al, Hintergrundpapier zur Studie „Umweltmanagementansätze in Deutschland“, http://www.ums-fuer-kmu.de/upload/Downloads/Hintergrundpapier_final.pdf

- Environmental performance indicators for organizations and enterprises (such as DIN EN ISO 14031)[129];
- DIN EN ISO 14040: Environmental management – Life cycle assessment – Principles and framework) as an international standard for the integrated assessment along the product life cycle (Life Cycle Assessment = LCA);
- Eco-efficiency analysis developed by BASF AG[130], which has meanwhile been completed by a social component resulting in the SEEbalance® (socio-eco-efficiency) analysis.

Life cycle analyses are costly and time-consuming and require a great number of data. In databases such as ProBas (process-oriented basic data for environmental management instruments), UBA provides information on life cycle analyses and energy and material flow management[131].

EMAS-validated environmental product declarations (in German: "Geprüfte Umweltinformation” - validated environmental information) which may be used by companies for advertising purposes are incentives for them to develop sustainable products[132]. Principles of product labelling using environmental labels and declarations are described in the ISO 14020 series[133]. Environmental declarations according to ISO 14025 contain life cycle and environmental data for a comparison of goods and services. BASF AG has developed an eco-efficiency label for products based on their eco-efficiency analysis[134].

Enterprises committed to sustainable management will, as a rule, also use comprehensive organizational approaches. In doing so, they intend to both satisfy their customers and ensure a secure future for their company. Methods serving this purpose include:

- Quality management systems according to DIN EN ISO 9000;
- Principles of good laboratory practice (GLP)[135];
- EFQM Excellence Model by the European Foundation for Quality Management: for goods, services and management performance that exceed minimum

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129 Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Umweltbundesamt, Leitfaden Betriebliche Umweltkennzahlen, 1997, http://old.cleaner-production.de/wwwcpg/htmlneu/view.php?obj=25244

130 BASF: Ökoeffizienz-Analyse; http://corporate.basf.com/de/sustainability/oekoeffizienz/?id=d3qRXAcSDbcp3le

131 Umweltbundesamt, Öko-Institut e.V.: Prozessorientierte Basisdaten für Umweltmanagementsysteme, http://www.probas.umweltbundesamt.de/php/index.php

132 EMAS II (Eco-Management and Audit Scheme), Regulation (EC) No 761/2001 of the European Parliament and of the Council of 19 March 2001 allowing voluntary participation by organisations in a Community eco-management and audit scheme. http://ec.europa.eu/environment/emas/about/summary_en.htm

133 BMU, Umweltbundesamt, BDI, Umweltinformationen für Produkte und Dienstleistungen, 2004, http://www.positivlist.com/download/ISO14025.pdf (since July 2006 ISO 14025 as a standard)

134 BASF: Ökoeffizienz-Analyse http://corporate.basf.com/de/sustainability/oekoeffizienz/label.htm?id=V00-2RT20Abjkbcp1PK

135 Directive 2004/10/EC of the European Parliament and of the Council of 11 February 2004 on the harmonisation of laws, regulations and administrative provisions relating to the application of the principles of good laboratory practice and the verification of their applications for tests on chemical substances

requirements made by legal provisions and other rules and contribute to social responsibility and ecological sustainability[136];

- OHSAS 18001, an occupational health and safety management system specification: evaluation of production processes;
- System Safety and Quality Assessment (SQAS) [137]: e.g. European Single Assessment Document (ESAD) by the Verband Chemiehandel – (VCH – German association of chemical trade and distribution), based on the Responsible Care® initiative of the chemical industry, which has been dealing with safety, health and environmental aspects of the trade in chemicals[138].
- The Responsible Care® initiative of the chemical sector for a sustainable development[139]: It comprises the dialogue with stakeholders in order to improve and report on the performance and management of chemical products (product stewardship);
- Corporate Social Responsibility (CSR) by the EU Commission: Corporate social responsibility has been defined as a concept for companies to go beyond minimum legal requirements on a voluntary basis in order to address social needs[140].
- Supply Chain Management: It demanded that suppliers and other upstream stages of production be included in the evaluation of the performance of an enterprise in order to be able to consider also social standards in developing countries[141].

These examples show that sustainable chemical management encompasses more than merely technical and product-related measures. Above all the companies themselves must provide for an overall evaluation of their entrepreneurial activities and the resulting effects. To this end, companies must assume responsibility also for the long-term effects on the environment, on occupational health and consumer protection. This requires appropriate measures to be taken already in advance and to consider these aspects in operational management. Such considerations should also include the upstream supply chain, also with regard to possible social effects in less developed countries, for example to avoid child labour and damage to health and environment in less developed countries. In this respect, standards for responsible management in the individual sectors of industry are helpful and should be taken into account in entrepreneurial activities.

6. Sustainability in global chemicals management

Numerous environmental problems can no longer be solved on a national or EU level but must be tackled by means of global approaches. Today and in the future, the international economy will increasingly rely on a global and free trade. A study

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136 Nachhaltige Unternehmensentwicklung umsetzen, UmweltMagazin, März 2007, p.63
137 CEFIC Safety and Quality Assessment System, http://www.pharox.net/pls/portal30/sqas.al_sqas_entry.show
138 http://www.vch-online.de/index.php?option=com_content&task=view&id=23&Itemid=27
139 http://www.responsiblecare.org/
140 Communication from the Commission, COM (2006) 136 final, 22.3.2006
141 Seuring, Stefan et al, Zum Entwicklungsstand des Nachhaltigen Managements von Wertschöpfungsketten, UmweltWirtschaftsForum 14. Jg., H. 3, September 2006

performed by Deutsche Bank[142] has shown an increase in the sales volumes of the chemical industry in the last ten years by more than five per cent per year, to 2 000 billion Euro. Above-average growth has been observed in China, India and Korea while that recorded for the European Union and the USA has been slightly below the average, and Japanese growth has shown a stagnation. In the meantime (status as of 2006), China has become the most important chemical manufacturer second to the USA, as measured by world market shares, immediately followed by Japan and Germany[143]. Moreover, the OECD has stated that the production of chemicals will rapidly grow also in other non-OECD countries, particularly in Brazil, Russia and India, so that the share of OECD countries in this production will decrease from 75 per cent in 2007 to 63 per cent in 2030[144]. Thus, it becomes clear that in the future, initiatives to develop sustainable chemistry will not be restricted to Germany, the European Union and the industrialized OECD countries.

National standards for protection of the environment and health are recognized by agreements of the World Trade Organization (WTO) only on condition that they do not represent any open or hidden protection measures for national economies[145]. An approach to this problem was made by the signatory countries at the 4th WTO Ministerial Conference held in 2001 in Doha when the relationships between global trade and environmental protection were analysed by investigating the cooperation between multilateral environmental agreements and WTO [146].

However, to resolve global environmental problems such as protection of the climate, of the ozone layer, of biodiversity and natural resources and also to ensure chemical safety, it does not suffice that global trade agreements draw attention to the fact that the flow of goods may be restricted if environmental or health risks are likely to arise from these. Rather, the solution of such problems asks for global strategies because environmental effects will not remain limited to single territories and may also impair countries with high environmental protection standards. Also, measures of risk reduction based on the rules of global chemical management will be recognized more readily by WTO than national measures where trade-restricting motives could be suspected.

Global initiatives for sustainable chemical production and chemical safety are required, above all because of countless products being manufactured in non-EU countries – among them countries lacking adequate standards for the protection of natural resources, environment and health - and placed on the European market. In some industrial sectors, the formerly existing domestic production and the problems involved are being shifted to non-EU countries. This applies for example to textiles and leather, which are meanwhile produced predominantly in Asia under poor conditions of occupational safety and environmental protection.

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142 Perlitz, U., Deutsche Bank Research:„Chemische Industrie in China – International auf der Überholspur“, Februar 2007; http://www.dbresearch.com/PROD/DBR_INTERNET_EN-PROD/PROD0000000000191202.pdf

143 Brochure „Chemiewirtschaft in Zahlen 2007“, Verband der chemischen Industrie (VCI); www.vci.de

144 “Draft Briefing Note on Environment Ministers Policy Conclusions on the role of OECD in SAICM Implementation”, Annex 2 to a document for the 41st Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology; ENV/JM(2007)15, 09 May 2007

145 United Nations Conference on Environment and Development (UNCED), Rio de Janeiro, 3-14 June 1992; Agenda 21, the Rio Declaration on Environment and Development, the Statement of Forest Principles, the United Nations Framework Convention on Climate Change and the United Nations Convention on Biological Diversity; http://www.un.org/geninfo/bp/enviro.html

146 Existing forms of Cooperation and Information Exchange between UNEP/MEAs and the WTO; TN/TE/S/2/Rev.2 16 January 2007

In order to avoid the shifting of problems, efforts are made to develop uniform and globally valid standards by means of legally binding international agreements. They are intended to firmly establish legal principles to protect environment and health on an international level. The European Union is highly interested to have its technical standards becoming part of these agreements, for example information on the state of the art or risk management regarding dangerous chemicals.

The development of global chemical management is based on the decisions of the UN Conference on Environment and Development held in Rio de Janeiro, Brazil, in 1992: Chapter 19 of Agenda 21[147] addresses the "environmentally sound management of toxic chemicals, including prevention of illegal international traffic in toxic and dangerous products".

In 2002, the World Summit on Sustainable Development in Johannesburg supplemented this pledge by a chapter on sustainable consumption and production requiring a “sound management of chemicals throughout their life cycle (…) aiming to achieve, by 2020, that chemicals are used and produced in ways that lead to the minimization of significant adverse effects (…)"[148].

These global conferences resulted in a number of international initiatives and agreements on chemical safety, for example:

- Globally Harmonized System of Classification and Labelling of Chemicals (GHS)[149];
- Stockholm Convention on Persistent Organic Pollutants (POPs)[150] and guidelines for Best Available Techniques (BAT)[151] and Best Environmental Practices (BEP) for industrial minimum standards;
- Rotterdam Convention on Prior Informed Consent (PIC) regulating the international trade with dangerous substances, an information exchange procedure prior to the export of chemicals requiring the exporting country to obtain the explicit agreement from the country intended to receive the toxic chemical [152];
- Basel Convention on the Control of Transboundary Movements of Hazardous Wastes (including used chemicals) and their Disposal[153].

The currently most essential development of international chemicals management is the Strategic Approach to International Chemical Management (SAICM)[154] aiming at the creation of a comprehensive global system of improved chemical safety. It is intended to

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147 http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21chapter19.htm

148 World Summit on Sustainable Development(WSSD), Johannesburg, August 26 – September 4, 2002; Johannesburg Plan of Implementation, III. Changing unsustainable patterns of consumption and production, Paragraph 23; http://www.un.org/esa/sustdev/documents/WSSD_POI_PD/English/POIChapter3.htm

149 Globally Harmonized system (GHS); adopted in December 2002, published at http://www.unece.org/trans/danger/publi/ghs/ghs_welcome_e.html; first revision adopted in 2005; second revision adopted in 2006, second revised edition published in 2007; http://www.unece.org/trans/danger/publi/ghs/ghs_welcome_e.html

150 Stockholm Convention on Persistent Organic Pollutants (POPs) www.pops.int

151 Best Available Techniques (BAT) on the EU level include Best Environmental Practices (BEP)

152 Rotterdam Convention on Prior Informed Consent (PIC); www.pic.int

153 Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal; www.basel.int

154 Strategic Approach to International Chemical Management“ (SAICM); http://www.chem.unep.ch/saicm/

merge the great number of single initiatives. Although the instrument is not legally binding, it shows that the international community of nations is making efforts to find ways towards its worldwide application.

In the future, the formation of global networks of different initiatives on chemicals management will gain in importance. This applies above all to international conventions on chemicals management. A very important platform is also provided by the OECD programme for Environment, Health and Safety (EHS)[155]. In the context of this programme, the countries involved develop and validate internationally valid test and assessment procedures to be used in legislation on chemicals. Other priorities include guidelines for Mutual Acceptance of Data (MUA), technical criteria of the GHS for the classification and labelling of substances, and guidelines on sustainable chemistry and nanotechnology. In Germany, UBA has been in charge of the activities regarding sustainable chemistry and is developing a platform for information exchange (also cf. Chapter 5.1).

In view of a global economy, it is insufficient to develop sustainable chemistry only on the regional and national levels. Sustainable chemistry as a subject should also be carried into international forums. It is the aim of such efforts to establish high standards for data requirements, high evaluation standards, best available techniques and environmental protection practices on a global level. This helps to protect human health and the environment worldwide, simultaneously increases export opportunities for advanced and innovative technologies and products and promotes a sustainable development in newly industrializing and developing countries.

7. Conclusion

Sustainable chemistry

- contributes to a reduction of the risks posed by dangerous chemicals and pollutants for the environment as well as for human health and thus, helps to avoid damage costs; contributes to a decrease of resource consumption; provides incentives to innovation for enterprises and sciences, which, in a globalized world, requires development and maintenance of international collaboration;
- is an important element of general sustainable development because it refers to an economically important industry with intensive relations to other industrial sectors; helps to protect natural resources as well as human health;
- will be a successful strategy only on condition that innovations to production procedures and products are aimed at the protection of the environment and human health.

It is important to define requirements and quality criteria for sustainable chemistry and provide for possible solutions to be measurable, assessable and practicable. Hence, the concept of sustainable chemistry has to develop and propagate successful approaches.

Activities of the Federal Environment Agency will include

[155] OECD; Environment, Health and Safety (EHS) http://www.oecd.org/about/0,2337,en_2649_34365_1_1_1_1_1,00.html

- Information and discussion forums and dialogues on sustainable chemistry involving stakeholders such as enterprises, authorities, scientific institutions and non-governmental organisations;
- Management concepts (for example chemical leasing) taking into account product life cycles, propagation and promotion of other successful approaches;
- Development of product legislation and labelling (such as the Blue Angel) serving as a quality hallmark for consumers and commercial users and making the purchase of particularly eco-friendly and socially acceptable products less complicated;
- Active participation in the consultation process for the redesigning of BREFs for the chemical sector;
- Further development of the criteria, definitions and standards for sustainable uses of chemicals;
- Collaboration in the context of the OECD Sustainable Chemistry Network (SCN) bringing together stakeholders in the subject fields of sustainable chemistry in order to publicize innovative and sustainable solutions for products and product technologies;
- Presentation of the concept of sustainable chemistry before international forums on chemical safety, especially as a contribution to the application of the Strategic Approach on International Chemicals Management (SAICM) on the national and regional levels.

Annex 1

The Twelve Principles of Green Chemistry*

- Prevention: It is better to prevent waste than to treat or clean up waste after it has been created.
- Atom Economy: Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
- Less Hazardous Chemical Syntheses: Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
- Designing Safer Chemicals: Chemical products should be designed to effect their desired function while minimizing their toxicity.
- Safer Solvents and Auxiliaries: The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
- Design for Energy Efficiency: Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
- Use of Renewable Feedstocks: A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
- Reduce Derivatives: Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
- Catalysis: Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
- Design for Degradation: Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
- Real-time analysis for Pollution Prevention: Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
- Inherently Safer Chemistry for Accident Prevention: Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

*Anastas, P. T.; Warner, J. C. *Green Chemistry: Theory and Practice*, Oxford University Press: New York, 1998, p.30. By permission of Oxford University Press from ACS Green Chemistry Institute Webpage

Annex 2

The twelve considerations listed in the IPPC Directive*

- Use of low-waste technology;
- Use of less hazardous substances;
- Furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate;
- Comparable processes, facilities or methods of operation which have been tried with success on an industrial scale;
- Technological advances and changes in scientific knowledge and understanding;
- Nature, effects and volume of the emissions concerned;
- Commissioning dates for new or existing installations;
- The length of time needed to introduce the best available technique;
- Consumption and nature of raw materials (including water) used in the process and their energy efficiency;
- The need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it;
- The need to prevent accidents and to minimize the consequences for the environment;
- The information published by the Commission pursuant to Article 16 (2) or by international organizations.

* Council Directive 96/61/EC of 24.09.96 concerning integrated pollution prevention and control; Official Journal L 257 , 10/10/1996