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Sustainable Chemistry – A concept with important links to waste management

Henning Friege

N³ Nachhaltigkeitsberatung Dr. Friege & Partner, Scholtenbusch 11, D-46562 Voerde, Germany

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ABSTRACT

Sustainable Chemistry is an overarching concept encompassing the design, manufacture and use of efficient, effective, safe and more environmentally benign chemical products and processes. With respect to the Sustainable Development Goals (SDGs, 2015), the Sustainable Chemistry concept may serve as an important tool to reach these objectives including a high number of targets for chemicals and waste management.

Sustainable Chemistry might become a valuable contribution to present waste management issues: Recycling of waste and recovery of resources from waste fractions are often severely restricted by the chemical composition of used products. These restrictions include components, which turned out to be hazardous, mixed materials like plastics with numerous additives, composite materials, which cannot be separated properly like plastics/wood, or low concentrated scarce metals in electronic devices. Following the concept of Sustainable Chemistry,

– higher resource efficiency and increasing use of waste-derived renewable resources without endangering food production,

– use of substances, which are not only less toxic but also better degradable under natural conditions ("benign by design"),

– design of products which allow recycling by avoidance of inseparable combinations of materials and firmly fixed modules ("design for recycling"),

might be achieved.

The paper aims to demonstrate the benefits of integrating waste management issues into the concept of Sustainable Chemistry to avoid further unilateral technical solutions, which do not take re-use or recovery of resources into account.

1. Introduction

Residential and most commercial waste are nothing but crude mixtures of used or useless products, spoiled foodstuffs, remaining materials from construction and demolition, used packaging, etc. Each of the waste components is made from distinct materials based on certain raw materials and chemicals. With respect to the two main objectives of waste management, i.e.

– disposal of residual waste safely to protect human health (urban hygiene) and the environment (water, soil, atmosphere, biodiversity),
– recovery of materials and substances from waste with the aim to substitute virgin materials (resource conservation),

it is obvious that the properties of chemicals serving as building blocks or additives in materials are crucial for successful disposal or recovery. Globalization of consumer products also means global application of chemicals used in these products and also global spread of these chemicals with waste, when the products come to their "end of life" (EoL). This leads to global availability also of hazardous chemicals as ingredients in certain goods and in waste as it has been investigated in the RiskCycle project (Bilitewski et al., 2011, 2013). The disposal of hazardous compounds in defined or mixed waste is a challenge for waste management not only in the countries where these substances have been produced, but everywhere in the world where they were applied and disposed of or recycled.

We have to differ two cases: On one hand, we might be confronted with hazardous chemicals in waste. In this case, special methods

E-mail address: Friege@N-hoch-drei.de.

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(neutralization, incineration at high temperature,…) must be used to ensure safe disposal. If waste of this type shows up in countries without an adequate industrial infrastructure, this may implicate severe problems endangering humans and environment, as it is known from many chemicals used in products decades ago. There is an enormous number of examples like PCBs banned years ago (Stockholm Convention) which are still found in many regions where they have never been produced, but used in transformers, small capacitors included in household appliances or as joint sealers in buildings. The problems caused by Persistent Organic Pollutants (POPs) like PCB need a world-wide approach (Weber et al., 2013). Disposal methods and capacities in most developing and emerging countries are not adequate to manage this type of waste. In this case, the double role of waste and valuables, i.e. contamination of used items containing valuable resources by dangerous compounds, is also a serious problem for industrialized countries, because recycling steps are restricted to incineration or other decomposition processes.

On the other hand, recovery of valuable materials from waste (used paper, plastics, metals…) is often hampered by certain chemicals

– which may not longer be used for certain purposes (e.g. cadmium stearate formerly used as stabilizer in PVC in Europe (European Commission, 2011))
– which are used for a certain scope of application, but should not be present in other applications based on the same raw material (e.g. oil based inks for printing of newspaper migrating into food packaging made from used paper (Pivnenko et al., 2016))
– which are not hazardous but a technical obstacle for the recovery process (e.g. certain combinations of metals in alloys which cannot be separated due to metallurgic reasons (Reuter and van Schaik, 2012)).

These phenomena have a common ground and are linked to other phenomena being of enormous importance for waste managements strategies (“Seven general dilemmas” (Friege, 2012a, 2012b)). This also means that the road to “circular economy” (European Commission, 2015) is paved with a number of stumbling blocks:

– A mixture of several materials in one product leads to complicated and energy consuming recovery processes (increasing entropy by material mix), if indeed possible. In most cases, products made from numerous materials (i.e. electronic appliances, plastic products, functional textiles) cannot be recycled without severe loss of valuable materials. As a rule of thumb, recyclability depends on the number of separation steps and the price for valuables, which is obtained on the market (Dahmus and Gutowski, 2007), thus integrating the economic and the ecological dimension.
– High dissipation of products is an obstacle for collection, i.e. entropy increases by dissipation. The twofold entropy problem is often underestimated by policy (De Man and Friege, 2016).
– Depending on the character of the product in question, there is a time lag of some months, some years, or even some decades between the production of a good and its final fate as waste. There is severe information loss over time, i.e. the construction materials and chemicals used in a product becoming waste years after production are mostly not known. The content of materials and chemicals in a manufactured product often varies over time (Greenfield and Graedel, 2013) often discouraging recycling companies and impede investment in new technologies. Time is a scalar quantity – i.e. there is only one direction, and we cannot stop technical development.

There is no chance to overcome these problems in general. But there are some obstacles which we can get out of the way and some borders which may be shifted:

– Production of chemicals with less (hazardous) waste
– Synthesis and use of chemicals which are obviously less or non-hazardous and not persistent under environmental conditions
– Design of materials and products with respect to resource recovery after use (“design for recycling”)

2. The concept of sustainable Chemistry

As to the production of chemicals being less hazardous and environmentally safe, there are some rules of thumb introduced in the 90ies which are known as “principles of green chemistry” (EPA, 1990; Anastas and Warner, 1998) including waste prevention (in production), targeted synthesis maximizing atom economy, and design of safer chemicals and products. Sustainable Chemistry as it has been developed in the last 10–15 years since a joint workshop of OECD and German Agencies (Umweltbundesamt, 2004) is an overarching concept. “Sustainable chemistry generally includes all aspects of a product related to sustainability e.g. social and economical aspects related to the use of resources the shareholders, the stakeholders and the consumers.” (Kümmerer and Clark, 2016). This concept includes the green chemistry approach as a tool on the molecular level, i.e. in the stage of synthesis, but going beyond this level by accounting “for not only the functionalities of a molecule that are necessary for its application but also their impact and significance at the different stages of its life cycle” (Kümmerer and Clark, 2016) including the last step when the materials and the product made hereof become waste. Sustainable Chemistry is characterized by the OECD as “a scientific concept that seeks to improve the efficiency with which natural resources are used to meet human needs for chemical products and services. Sustainable chemistry encompasses the design, manufacture and use of efficient, effective, safe and more environmentally benign chemical products and processes.” (OECD, 2015). Though world-wide accepted definitions for Sustainable Chemistry are still under development, the following summary based on recent studies and discussions may be taken as “state of the art” (Blum et al., 2017):

– Sustainable chemistry contributes to a positive, long-term development in society, environment and economy. With new approaches and technologies it develops value-creating products and services for the needs of civil society.
– Sustainable chemistry increasingly uses substances, materials and processes with the least possible adverse effects. Moreover, substitutes, alternative processes and recycling concepts are used, and natural resources are conserved. Thus, damage and impairments to human beings, ecosystems and resources are avoided.
– Sustainable chemistry is based on a holistic approach, setting measurable targets for a continuous process of change. Scientific research and education for sustainable development in schools and vocational training serve as an important basis for this development.

Fig. 1 shows that Sustainable Chemistry has a number of intersections with other big issues of global development. As per definition of sustainability, it is not a firm target, but a process and an aim; the same is true for Sustainable Chemistry. With respect to the challenges described in the Sustainable Development Goals (United Nations, 2015) this overarching concept may serve as an important tool to reach these objectives including a high number of targets for the use of chemicals and waste management. This will be worked out on the global level under the umbrella of the UNEP driving the SAICM process as well as the international conventions dealing with hazardous chemicals and hazardous waste within one branch (i.e. DTIE Chemicals and Waste Branch).

In contrast to addressing the problems caused by unsafe application of chemicals and hazardous substances left over from use, the breakthrough of Sustainable Chemistry depends more on successful new business and marketing models than on more regulation, because green chemistry principles as well as the Sustainable Chemistry concept save