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WITHOUT CHEMISTRY THERE CAN BE NO CIRCULAR ECONOMY

The imperative of a new perspective on chemicals and materials management

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The transition to a sustainable society entails tremendous challenges when it comes to materials management. The concept of a Circular Economy focuses on reclaiming materials, recycling, repair and reuse. There is an emphasis on managing materials in a different way, but there is less attention on the intrinsic properties of the materials themselves. Often it is implied that we need to substitute raw materials with renewable, bio-based feedstock. But it isn't that simple: according to John Warner, co-founder of the 12 Principles for Green Chemistry, 65% of all chemical products need to be replaced by a sustainable alternative. And that demands a new perspective.

By Elze van Hamelen

Biomass is often praised as the cornerstone for circular approaches. My experience working with companies in the chemical sector tells me it is not that simple. In the report Taking the European Chemistry Industry into the Circular Economy , the sector explains that biomass can only be a partial solution: to replace all fossil feedstock used in the EU with biomass, we would need a land area larger than Romania.

Non-edible waste streams provide an alternative, but often there is no reliable access to these streams. Moreover, process technology requires high levels of purity of raw materials – and by definition, waste streams are polluted. Treatment is often not cost-effective. Refining biomass requires significant investments in new technologies. Biotech comes with a price, and consumers are often not willing to pay a premium. That is why, in this article, I will take a closer look at materials: what are the sustainability challenges of existing chemistry and what approaches can help us learn to live within the limits of the earth?

Risk = *Probability* x Effect

In the traditional approach to chemistry, there is an implicit assumption that chemicals and chemical manufacturing entail a certain risk. Many materials that you don't find in nature can only be formed under high pressure and high temperatures. In trying to minimize risk, the emphasis is on control and reduce the probability that an effect will occur through various management approaches.

In response to large-scale accidents within the chemical industry, the sector has put a lot of effort into minimizing risks to health and environment and increasing safety precautions. Many of these efforts took place under the umbrella of the global 'Responsible Care' initiative. In recent decades, these efforts have led to considerable and impressive improvements in areas such as workplace safety, transport, spills, and emissions.

Buildup of chemicals

While the chemical sector has made great improvements in controlling acute dangers, materials are not adequately managed over their entire life cycles. Because of this, materials end up in the environment, for example in the form of plastic islands in oceans, pesticides and medicine traces in drinking water, and Teflon in polar bears and Arctic ice. For many materials, we cannot oversee the life cycle. Many companies and governments find it challenging to set goals for 2050. But depending of the type of plastic, it may take 500 or over 1000 years before it has broken down. The bottle you threw away this morning has a higher probability of surviving the next 500 years than the coming generations of your family.

No knowledge about cocktails

In 2004, the Worldwide Fund for Nature ran the 'Detox-campaign' to create awareness among the public about chemicals in our living environment. 47 volunteers, including 39 members of the European Parliament, provided blood samples. The samples were analyzed for 101 'PBT' substances: persistent, bioacculumative, and toxic. These substances will not break down in nature, and because they do not break down they build up in the environment and in our bodies. Some of these materials have already been banned; others are still ubiquitous in common household products. 76 of the 101 chemicals were found in the blood of the volunteers.

'Biomonitoring studies' that test for chemicals in household dust, breast milk, or blood samples give comparable results. The studies test for common chemicals. Chemicals that are not tested for will not be found in the samples. In the preregistration of REACH, the European law for regulating chemicals, [143,000](#) chemicals were registered. It is estimated that of this number, [80,000](#) are used in commercial applications. Many of these materials are not hazardous for our health or the environment, if you look at them individually. However, there is not much knowledge about the compound effects of daily exposure to a low-dose cocktail of chemicals.

A big experiment

An article in *Science Magazine*, "[Planetary boundaries: Guiding human development on a changing planet](#)," marks chemical pollution ('novel entities') as one of the factors undermining the healthy functioning of the planetary ecosystem.

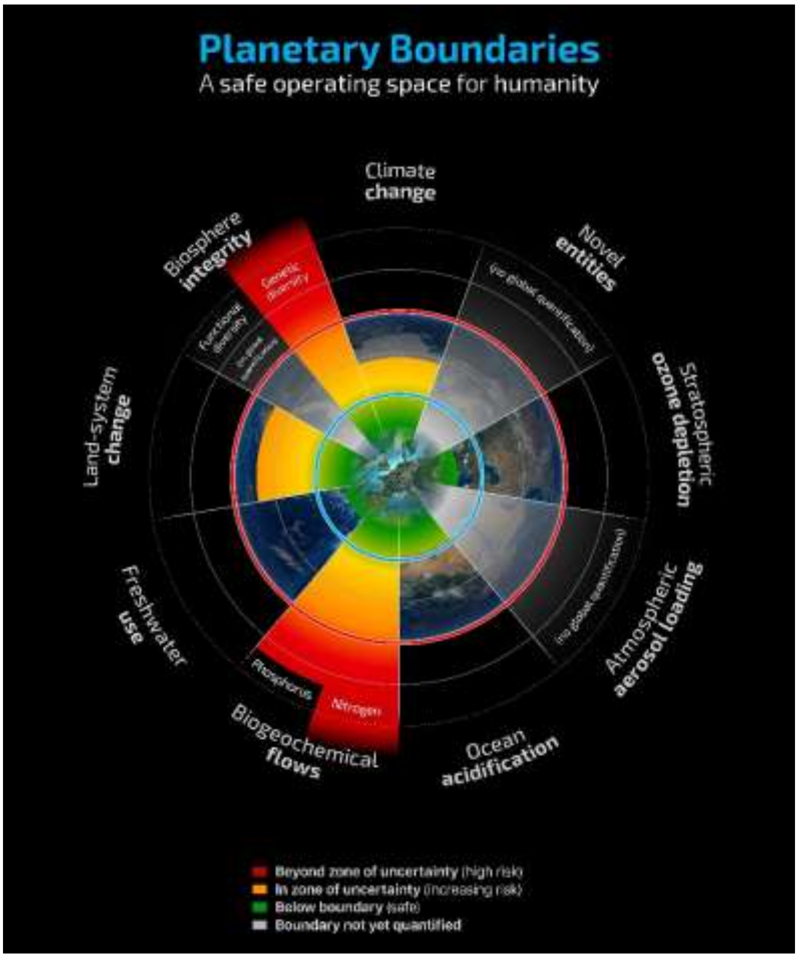

Figure 1 Steffen et al. Planetary Boundaries: Guiding Human Development on a changing planet, Science. 16 January 2015

The interaction between chemical pollution and other planetary system functions such as biodiversity is so complex that it is not possible to determine a boundary for the extent of pollution that is tolerable. It is evident, though, that the precautionary principle is not adequately applied. The authors remark that because of the data gaps and lack of understanding of the effects of chemical pollution on the planetary system, we are in fact conducting a big experiment.

Risk = Probability x *Effect*

Chemist and co-founder of the *12 Principles for Green Chemistry* John Warner argues for an approach to chemical and molecule design that is safe and benign by *design.* From a biomimicry perspective, Janine Benyus mentions the 'new recipe book for industrial chemistry.' In the choice between controlling the probability that an effect will occur (for example, avoiding an explosion), or eliminating the effect from the design of the substance (the material shows no propensity to explode), you see a radical shift: a material that is not intrinsically hazardous does not need to be managed for safety or environmental effects.

To emphasize the intrinsic properties of a material, more knowledge about these properties is necessary. That is why toxicology is a standard and indispensable part of green chemistry. What happens when this material ends up in nature? What are the impacts of the material over its life cycle? Will the material break down into benign, non-toxic components? Will it break down at all? What are the toxicological properties?

Design flaws

According to Warner, hazardous properties of existing chemicals are not due to the evil intent of chemistry; they are design flaws. When toxicology and environmental effects are not part of the design criteria, it is difficult to avoid the creation of hazardous substances. Warner mentions that no chemist in the US will take a course in toxicology as a standard part of his or her curriculum. Are chemists in Dutch universities trained in this subject? The traditional chemist will synthesize for functionality: the material should be water-repellent, able to resist high temperatures, easily molded, not break down under UV light, etc. There is an increasing interest in sustainability, but as far as I know, toxicology is not a required course within academic chemical programs. In the article 'The Chemist of the Future' (*Chemie Magazine nr. 19*), on the necessary skills of chemists in 2030, toxicology and knowledge about the environmental effects of chemicals are not mentioned.

In summary, there are three core challenges for sustainable chemistry:

- The design approach and criteria for new chemicals
- Toxicological assessments that include the social and ecological effects of a material over its life cycle
- Managing substances that do not break down in nature in closed loops

The innovation challenge

According to Warner, of all chemical products and processes:

- 10% do not have any sustainability issues
- for 25%, you can find a better alternative
- for 65%, a replacement still needs to be invented

65%! That is quite an innovation challenge! And there is a business case. There is an increasing demand for organic, 'natural,' and 'chemical-free' products, especially for products used in, on, and around humans: food, cosmetics, soap, paint, furniture, et cetera. Parents with young children are particularly attuned to the claim 'chemical-free,' seeking out BPA-

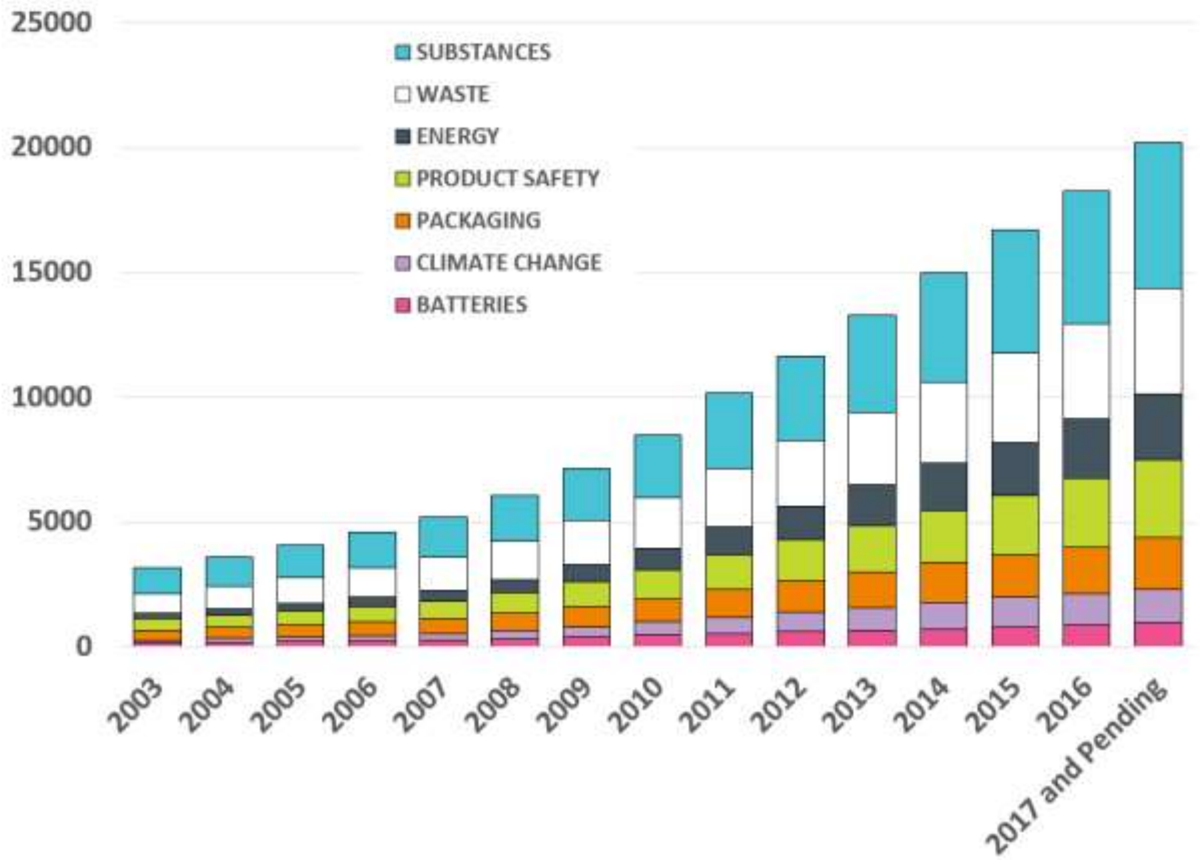

Figure 2 C2P Global Regulations by subject: Cumulative total; ©Compliance & Risks 2017

free drinking cups, non-toxic textiles, and strawberries grown without pesticides, for example.

Costs and risk

There is another aspect to the business case: in the last 12 years, worldwide legislation for 'Extended Producer Responsibility' has increased five-fold. External costs are slowly but surely being brought back to the companies that create them. For some companies, the costs to comply with rules and legislation before bringing a new product to market can roughly equal the

R&D budget. Materials that are non-hazardous and safe by design can reduce the overall cost and time to market drastically. Add to this the cost savings with regard to storage, safety training, transport, treatment waste disposal, liability, reputation, and attracting young talent. Sustainable chemistry can be very attractive financially.

Search for alternatives

There is an increasing demand for so-called 'alternatives assessments,' such as GreenScreen® and Scivera, which review existing toxicology assessments, scientific literature, and current 'blacklists,' and compare materials the 'hazard endpoints' of various materials. However, the search for better alternatives is just a part of the solution. What are the materials that need to be invented? What is the design approach for these materials?

Systems Approach

Partial solutions and a treating-the-symptom approach often lead to sub-optimal solutions in the sustainability movement (not just within chemistry). For example, the transition plan *Chemie maakt het verschil* (chemistry makes the difference), from the Dutch topsector Chemie (Leading Chemical Industry), proposes solutions such as 'The car of the future.' Is replacing cars one-by-one the solution? Shouldn't we take a broader perspective and evaluate the entire transport system? Each time I am stuck in a traffic jam I am amazed at how inefficient the system is. And that is the core of the problem: the system.

There is a comparable proposal in the category of resources and raw materials. The concept 'packaging of the future' is illustrated by a picture of a disposable cup for coffee and tea. Using a cup once and then throwing it away is a perfect example of consumer society. Is there a place for disposable cups in a sustainable society?

Blueprint

Treating symptoms is not sufficient; we need a systems approach. That is why the Dow sustainability strategy appeals to me. Sustainability activities are evaluated on three dimensions:

- **Handprint**: the effect of the product
- **Footprint**: the environmental and social impacts of the product over its life cycle
- **Blueprint**: the infrastructure that is necessary for sustainability

By consistently applying the perspectives in tandem, we are more likely to come to integral solutions. For example: a solar panel has a positive handprint, but the footprint can reduce this positive impact. Perhaps we can make weapons or cigarettes with an optimal footprint, but based on the handprint, can we see them as sustainable?

The way we currently organize ourselves in business and society, the way we extract resources and manufacture products, is structurally unsustainable in the very literal sense that the current situation cannot be sustained – exponential and endless growth in a closed system is only possible in theory. In the real world, we are crossing boundaries that can be observed in the loss of biodiversity and arable land, effects of climate change, looming resource shortages, and pollution of water, air, and soil. That is why the last question is the most interesting: what is the blueprint for a society that can last hundreds or even thousands of years?

Ex'Tax

An example: The port of Rotterdam contains an infrastructure that is ready for CO_2 storage. Without a tax on CO_2 emissions, it is not cost-effective to put it into use. How can our tax system stimulate or hinder sustainable innovation?

A couple of years ago, the top five accounting offices calculated the effect of implementing an Ex'Tax in the Netherlands. Ex'Tax shifts the taxing of labor to the taxing of consumption. In other words, labor becomes cheap, and consuming becomes expensive. Ex'Tax is about taxing the 'extracted value' (not the added value, VAT). Implementing the Ex'Tax would mean an enormous boost for employment. Circular approaches that require more labor will become affordable.

Disposal or recycling?

Another example: A recyclable product is particularly sustainable if there is a system to recycle it. Glass is only environmentally friendly when it is recycled, not when it ends up in a landfill. Within Vinylplus, the voluntary initiative of the European PVC sector, the industry self-funded system for recycling PVC. Within

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LINEAR & TRADITIONAL	CIRCULAR" AND BIOMIMETIC
• 'Heat, beat, treat': chemical reactions under high temperature, high pressure and chemical treatment • Organic solvents • Fossil feedstock and fossil energy • High purity of feedstock is imperative • Use of the entire periodic system • Resources sourced globally • Controlling risk by taking safety precautions	• Chemical reactions take place at room temperature and pressure • Water as solvent • Low energy chemical reactions • Local feedstocks, diverse sources • Degradation is part of design: 'timed degradation' of 'triggered instability' (John Warner), 'Nature's disassembly processes' (Benyus) • Functionality is created by the structure, not the material itself • Living systems only ulitilize 25 elements; Carbon, Oxygen and Natrium make up 96% of atoms in living systems. Other elements are used in trace amounts • Controlling risk by adapting the inherent properties of the materials
Together, these are the enabling technologies for the circular economy" – Janine Benyus	

Figure 3 Table based on Janine Benyus & John Warner

the initiative, concerning stabilizers such as lead were successfully phased out. Unfortunately, the recyclable waste stream still contains these legacy additives. Can you use this waste stream or not?

Within REACH a company must provide data for every material that enters the market (no data, no market). For a contaminated substance that has been classified as waste, the paperwork to reclassify it as a raw material is so cumbersome that it is cheaper and easier to dispose of it.

What is the blueprint for sustainable chemistry? The intersection of green chemistry, biomimicry, and a system perspective that balances the handprint, footprint, and blueprint is a good place to start.

In conclusion

The demand for sustainable chemistry is often driven by consumers, whereas the formulation of new molecules takes place deep in the supply chain. Chemists are rarely involved in product development, but materials challenges are part of many sustainability issues. Chemistry is the basis of almost every product supply chain. As sustainability professionals, we are most successful when we can bridge different disciplines and specialized areas of knowledge. If we really want to speed up the transition to a sustainable society, we will have to actively encourage and engage the chemical sector. After all, chemists are the only people who can design new molecules.

Referenced links

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https://thenaturalstep.org/pvc/
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About Elze van Hamelen

Elze is an Advisor at The Natural Step Germany, and Associate Partner at the Sustainable Growth Associates network. Elze holds an MBA in Sustainable Management and an MA degree in Organisational Sociology, combining different perspectives within an organisation, such as policy, strategy, change, culture, cooperation, behaviour and communication.

Elze is passionate about the strategic implementation of sustainability using The Natural Step framework, and she's convinced that innovations in chemistry and materials management are key to accelerating the transition to sustainability.

About The Natural Step Germany

The Natural Step Germany is part of The Natural Step's global network, a highly respected provider of science-based sustainable development, innovation, consulting and education programmes. As a nonprofit organisation, The Natural Step helps organisations and individuals create value within the planetary boundaries. Since its inception in Stockholm in 1989, The Natural Step's science-based framework has been successfully employed in thousands of forward-thinking organisations around the world. Based on systems thinking, we help organisations and individuals understand and accelerate change towards sustainability and a flourishing future. Link to page: https://www.thenaturalstep.de/

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