MATERIAL SELECTION IN PRODUCT DESIGN BASED ON CLOSED LOOP RECYCLING EFFICIENCY

Desing, Harald*; Bill, Andreas*; Böni, Heinz*; Hischier, Roland*; Wäger, Patrick*

**Empa, Technology and Society Laboratory, Lerchenfeldstrasse 5, CH-9014 St.Gallen*

Selecting a suitable material for a specific function in a product stands at the beginning of the product design process. Functional requirements limit the choice of materials (e.g. required strength) and demand a specific material quality. Primary material can satisfy almost any quality requirement. On spaceship Earth [1], however, primary resources are limited in quantity and their exploitation is associated with major detrimental environmental effects [2]. In order to stay within the Planetary Boundaries [3], primary resource extraction would need to be limited to sustainable levels. Closing material cycles, as targeted by the concept of circular economy (CE) [4], is seen as one possible strategy to become more independent from primary resource supply and avoid the environmental consequences of their extraction. In theory, fully closed cycles are only possible as long as sufficient useful energy is available [5]. However, in practice recycling is limited by losses and, in some cases, thermodynamic constraints [6-8]. Consequently, primary material production and disposal in safe final sinks will still be necessary as part of a CE [9]. Within the socio-economic metabolism, the primary material input is utilized most intensely in durable products, circulation of materials as much as possible at the same quality level, i.e. closed loop recycling, and using unavoidable losses from higher quality levels as input to lower quality cycles, i.e. open loop recycling or cascading.

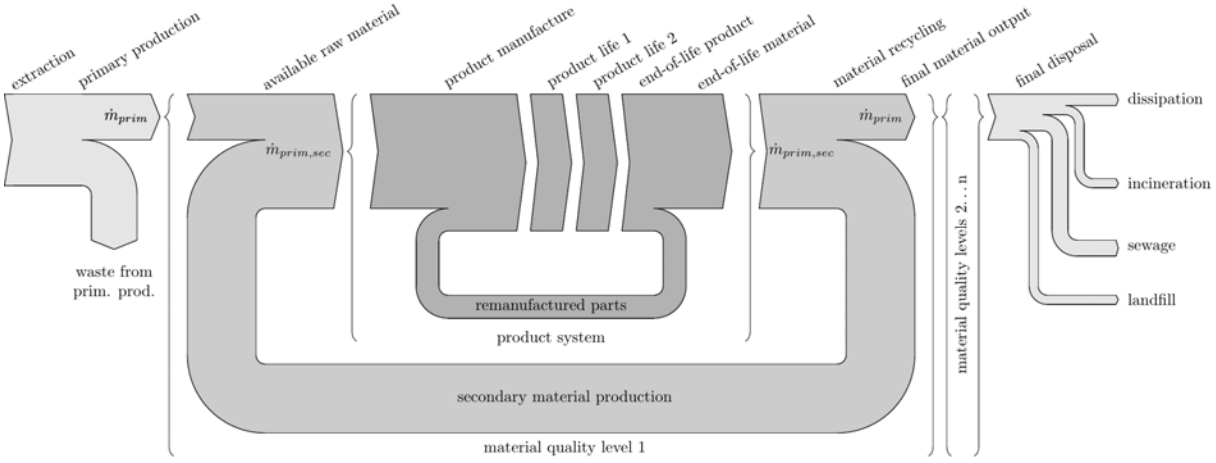

Figure 1: Material flow from primary resource extraction through the socio-economic system to final disposal in a steady state

The design of the product as well as the choice of materials crucially influence the recoverability of all the materials at end-of-life. Technical and economic constraints on the separation of materials from end-of-life products are often the most inhibiting

factors concerning material quality conservation in the recycling process. Product designers consequently have a significant influence on the recoverability in the recycling chain and as such require tools to assess their choices regarding closing material cycles. With this contribution, we will present a new methodology that allows considering key aspects of resource utilization within the product system in product design based on a simplified material flow model (see fig.1). The material flows in the socio-economic system are modelled as being in a steady state, i.e. it is assumed that primary material entering the socio-economic system will eventually leave the system into final sinks. Up to a certain quality level, secondary material, which can be kept at this level, enlarges the primary inflow. The remaining material leaves the quality level and enters the next lower level. This procedure can be repeated multiple times while gradually reducing quality levels (cascading). Maximizing the amount of material that can be kept at the same quality level over multiple product cycles reduces the need for primary input and final disposal. Therefore, our here proposed methodology considers closed loop recycling efficiency as primary decision criterion for product design. Multiple design aspects of the product system influence the technically feasible recycling efficiency for the same quality level, e.g. coatings, quality requirements, material composition and arrangement, take back and sorting or disassembly to material level. A flow chart shall guide the designer in choosing appropriate strategies and estimate possible efficiencies for closed loop recycling.

First results from a case study on the selection of materials for a heat exchanger in a household appliance will be presented in this contribution in order to exemplify the applicability of the here proposed methodology. We will conclude the presentation with indicators to measure the contribution of recycling to the reduction of primary resource depletion towards sustainable levels.

References:

1. Boulding, K.E., *The economics of the coming spaceship earth.* Environmental Quality Issues in a Growing Economy (ed. H. Jarrett), 1966(3-14).
2. International Resource Panel, *Global resources outlook*, B. Oberle, et al., Editors. 2019, UNEP: Nairobi, Kenya.
3. Rockström, J., et al., *Planetary Boundaries: Exploring the Safe Operating Space for Humanity.* Ecology and Society, 2009. **14**(2).
4. Ellen MacArthur Foundation, *Towards the circular economy*. 2013.
5. Ayres, R., *The second law, the fourth law, recycling and limits to growth.* Ecological Economics, 1999. **29**: p. 473-483.
6. Nakajima, K., et al., *Thermodynamic analysis of contamination by alloying elements in Aluminum recycling.* Environmental Science and Technology, 2009. **44**: p. 5594-5600.
7. Nakajima, K., et al., *Evaluation Method of Metal Resource Recyclability Based on Thermodynamic Analysis.* Materials Transactions, 2009. **50**(3): p. 453-460.
8. Nakajima, K., et al., *Thermodynamic analysis for the controllability of elements in the recycling process of metals.* Environ Sci Technol, 2011. **45**(11): p. 4929-36.
9. Kral, U., K. Kellner, and P.H. Brunner, *Sustainable resource use requires "clean cycles" and safe "final sinks".* Science of the Total Environment, 2013. **461-462**: p. 819-22.