Life Cycle Assessment (LCA) and eco-balance

The extraction, processing and use of resources always has an impact on the environment, i.e. the soil, water and air. LCAs and life cycle assessments of products, companies, and services are prepared to measure and compare these environmental impacts starting from the extraction of raw materials, through manufacturing and processing operations, to distribution, sales and use. The results of an LCA can be used to optimize processes and reduce environmental impacts.

In order to be able to compare the data obtained, the preparation of the life cycle assessment of a product and / or service is carried out according to international standards [1]. A life cycle assessment begins by defining the scope of the assessment, i.e., the boundaries for the inputs and outputs to be included in the calculations. For example, a system might include the entire product life cycle, i.e., everything from the extraction of raw materials from the earth to their disposal in a landfill. This is referred to as a "cradle-to-grave" life cycle assessment ("LCA"). Alternatively, the system can be scaled down to include everything from the raw materials to the output of the production facility ("cradle-to-gate" LCA) or only the operations from the input to the output of the production facility ("gate-to-gate" LCA) itself. (-> See also Poster Quick guide to LCA)

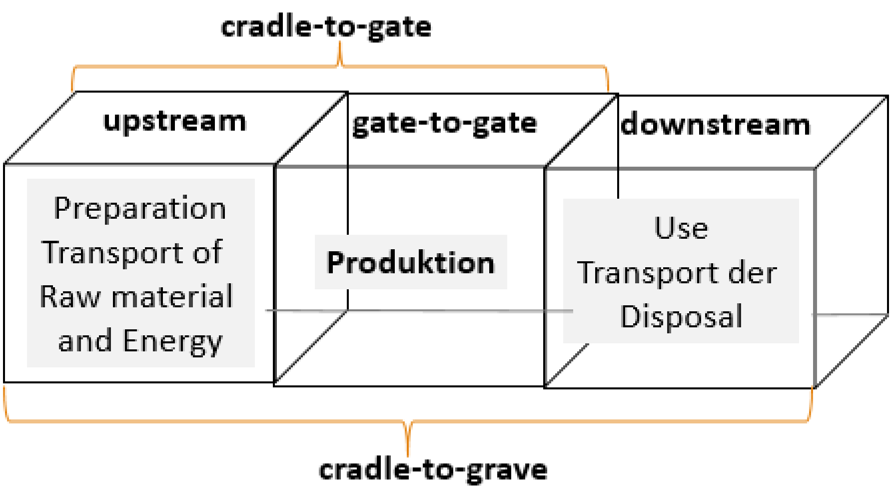

Figure 1: LCA studies to determine the ecological impact in production processes.

How large or small the system under consideration is directly affects the results. A larger scope leads to more comprehensive results, but also to a more complicated analysis. Conversely, a narrower scope is relatively easy to perform, but may result in significant ecological impacts not being captured.

The **synthesis of ethylene oxide from ethylene** will serve as an example. This reaction is one of the most important production processes in the chemical industry!

In the conventional process, about 15 % of the starting material ethylene is burned with air as oxidant at high operating temperatures, which makes this process one of the largest CO_2 emitters in the industry. The new liquid-phase process of Ghanta et al. (2013) eliminates the combustion and thus the emission of CO_2 by reacting at mild temperatures with liquid hydrogen peroxide as oxidant and methyltrioxorhenium (MTO) as catalyst.

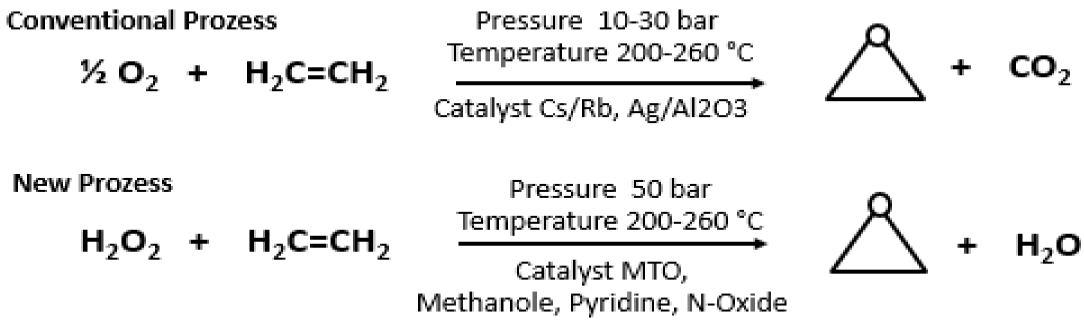

Figure 2: Comparison of two syntheses of ethylene oxide from ethylene and an oxidizing agent.
(according to Bode et al., J. Chem. Educ. 2017, 94, 11, 1798-1801)

The elimination of energy-intensive combustion could lead to the assumption that the LCA figures are more favorable in terms of greenhouse gas emissions. However, this is not the case!

This assumption is too narrow because it ignores the upstream impacts of energy production and raw material processing.

If the scope of the LCA is expanded to include both on-site and upstream ecological impacts, a very different picture emerges. The LCA by Ghanta et al. quantifies these upstream impacts and predicts that the new process produces slightly higher greenhouse gas emissions than the conventional process (about 100 million kg of CO_2 equivalents per year and 200,000 tons of ethylene oxide production).

Why is that? If the new process eliminates the CO_2 byproduct, how can it emit more CO_2?

The answer lies in the hydrogen peroxide manufacturing process, which gets its hydrogen from steam reforming of methane. This offsets the CO_2 savings in the new process because for every mole of methane reformed, 4 moles of H2 and 1 mole of CO_2 are produced.

This example illustrates the importance of thinking in larger contexts. LCAs need to assess the impacts that occur upstream from the factory to the factory exit gate ("cradle-to-gate" LCA) and downstream from the factory ("cradle-to-grave" LCA) to fully capture the ecological impacts.

It is important to perform LCAs early in the design process to ensure that impacts are actually mitigated and not just displaced!

Sources:

[1] DIN ISO 14040/14044 Ökobilanz: https://www.ressource-deutschland.de/fileadmin/user_upload/3_Werkzeuge/a_Basis-Werkzeuge/i_Leitfaden_Ressourceneffizienz/OEkobilanz_DIN_EN_ISO_14040.pdf
[2] Bode, C. et al (2017): Developing Students' Understanding of Industrially Relevant Economic and Life Cycle Assessments. *J. Chem. Educ.* 2017, 94, 11, 1798–1801 https://doi.org/10.1021/acs.jchemed.6b00548
[3] Curan, M A.: *Life Cycle Assessment: Principles and Practice*; U.S. Environmental Protection Agency: Cincinnati, OH, 2006.
[4] Ghanta et al. (2013): Is the Liquid-Phase H2O2-Based Ethylene Oxide Process More Economical and Greener Than the Gas-Phase O2-Based Silver-Catalyzed Process? Ind. Eng. Chem. Res. 2013, 52 (1), 18–29.
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