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Looking for sustainable transformations of bio-based feedstock, a LCA case: hydrogenation of glucose to sorbitol.

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PURPOSE OF THE ABSTRACT

Sorbitol is the largest-volume sugar alcohol worldwide produced. It is used for many industrial applications such as food additives, cosmetics, or drug preparations [1]. This versatility has prompted its inclusion in the top-ten list of biomass-derived building blocks to be converted into high-value bio-based products [2]. Usually, sorbitol is produced at industrial scale by catalytic hydrogenation of glucose over Raney Ni catalysts, a quite active and cheap catalyst that requires high hydrogen pressure conditions (40-80 bar) to promote hydrogenation reactions in high extension. Despite this hydrogenation process is well-known and totally implemented at industrial scale [3], not too many works focused on quantifying its environmental impacts can be found in existing literature. In this context, LCA methodology could be a very useful tool to determine system strengths and weaknesses, showing the adequate way for designing truly sustainable transformations. In this work, we applied the LCA methodology to determine the environmental impacts and energy consumption of sorbitol production by conventional glucose hydrogenation. The assessment was carried out with Gabi 6.0 software by using the database Ecoinvent 2.2. The functional unit (FU) was 1 ton of sorbitol. Selected system boundaries correspond to a ?cradle to gate? approach: from raw materials to final sorbitol at hydrogenation plant. Data for inventory were obtained by combining literature information [3] and simulations of the process units. The evaluation of environmental impacts was performed by using the ReCiPe (Midpoint) method taking into account the following categories: climate change (CC), ozone depletion (OD), human toxicity (HT), particulate matter formation (PMF), terrestrial acidification (TA) and fossil depletion (FD). LCA results indicate that glucose origin has a clear influence on sorbitol environmental profile. Thus, glucose coming from conventional processes (hydrolysis of starch) leads to higher environmental damages than glucose produced from residual biomass due to the quantification of avoided impacts. Since LCA results are strongly affected when including avoided impacts related to reusing residual materials, the quantification of these damage savings should be properly justified. On the contrary, it is problematic comparing LCA conclusions of different authors. Regarding to sorbitol production process (excluding glucose), the FU contributes as follows to the evaluated impact categories: 680 kg CO_2 eq (CC), 6.2E-5 kg CFC-11 eq (OD), 64 kg 1,4-DB eq (human toxicity), 1.3 kg PM10 eq (PMF), 4.2 kg SO_2 eq (TA) and 231 kg oil eq (FD). Figure 1 shows the relative contribution of the different process stages to each impact category. As observed, energy requirements of the system (heating and electricity) involve a relative contribution higher than 85 % for almost all the environmental categories. Thus, the largest contributor is the electricity consumption, mainly coming from compression stages necessary for reaching hydrogenation conditions (88 bar and 150 ºC for the reaction simulated here) and using vacuum pump for sorbitol purification (water removing). Heating requirements for raw materials preparation and sorbitol purification involve the second relative contribution. Apart from energy use, Raney Ni catalyst has also a remarkable influence on some impact categories (such as PMF and TA). Finally, the use of hydrogen (produced by steam reforming of methane) leads to a notable contribution to CC, PMF and FD.

These results clearly point to main process drawbacks that must be overcame to improve the energy and environmental profile. In this sense, the use of alternative catalytic systems that will allow working under milder conditions (especially at lower pressure) and the increase of glucose concentration (making easier sorbitol purification) would probably be the most efficient ways for reducing environmental impacts.

FIGURES

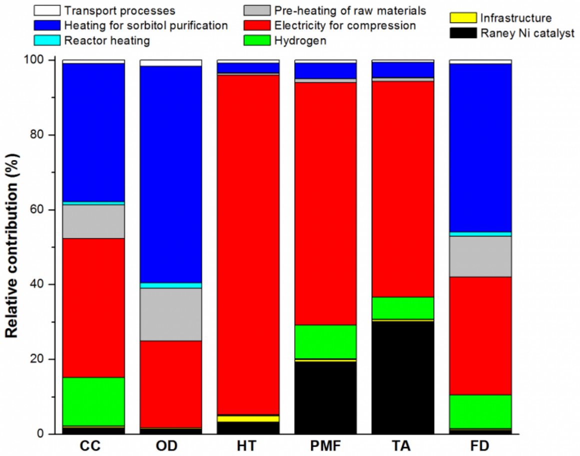

FIGURE 1

Figure 1

Relative contribution of process stages to environmental impacts

FIGURE 2

KEYWORDS

LCA | sorbitol | glucose hydrogenation | process sustainability

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