Biocatalysis in Sustainable Development

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Background

Biocatalysis is the use of biological catalysts, such as enzymes, to perform chemical transformations on organic compounds. A catalyst accelerates (bio)-chemical reactions. Enzymes that are used in these biochemical transformations can be purified enzymes or those that still reside within living cells (using a whole-cell culture) (Anthonsen et al., 2000).

The brewing of beer is an example of classical chemical transformation. Enzymes and whole cells (such as yeasts) are used in the production of wine, beer and cheese which means their preparation is dependent on enzymes (bio-catalysts) from microorganisms. Although the techniques in these processes have been reproducibly worked out, their mechanism of action was not understood. In the last thirty years biocatalysis has been used to produce fine chemicals, such as drugs in the pharmaceutical industry (Liese et al., 2006).

Biocatalysis makes use of green chemistry to provide an overall, more sustainable chemical product. An example of biocatalysis that is already being largely applied is the utilization of biomass for sustainable fuels and chemicals. First generation of biofuels derived from starch, sucrose and vegetable oils are more sustainable than fossil fuels but only in the short term. This is because their availability is limited and competes with food production. A next generation of biofuels will utilize lingo-cellulosic biomass and inedible oilseed crops, which is, at the moment, more difficult to degrade than first generation biomass (Sheldon, 2008). Various products will be available such as biodegradable plastics and specialty chemicals. Application of 2nd generation biomass will radically change the chemical industry in terms of structure of supply chains, creating the need for innovative, sustainable chemicals based on green catalytic methodologies (Sheldon, 2008).

Green chemistry is defined as follows: green chemistry efficiently uses raw materials (preferably renewable), eliminates waste and avoids the use of toxic and/or hazardous reagents and solvents in the manufacture and application of chemical products (Sheldon, 2008). Green chemistry is part of the environmental movement in which the problem has been identified whereas in the sustainability movement the common goal has been defined. Sustainability chemistry aims 1) to use natural resources at rates that do not unacceptably deplete supplies over the long term and 2) to generate and dissipate residues at rates no higher than can be assimilated by the natural environment. The environmental movement did not have a broad industrial or societal impact because emphasis was placed on the environmental problems instead of devising technological solutions. Green chemistry is responsible for the products that are made and the process by which they are manufactured. It utilizes raw materials efficiently and takes care of the elimination waste, health, safety and environmental aspects of chemicals and their manufacturing process (Sheldon, 2008).

Roger A. Sheldon introduced the E factor in 1992. The E factor measures the ratio of waste over product. Sheldon postulated these E factor ranges over the different branches in the chemical industry as shown in table 1.

Industry segment	Volume/tonnes per year	*E* factor
Bulk chemicals	10^4-10^6	<1 - 5
Fine chemicals industry	10^2-10^4	5 - 20
Pharmaceutical industry	10-10^3	25 - 100

Table 1: An overview of the *E* factors in different industry segments. Adapted from Dunn *et al.*, 2012

Table 1 shows that a lot of pharmaceutical companies produce a lot more waste than the bulk chemicals industry. Pharmaceutical companies produce small, specific commodity chemicals that have to be made from large, raw materials. Therefore, much is thrown away during the process of purification. Certain

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reactions produce many different by-products that are not used after the reaction has been carried out also resulting in waste. An attractive alternative is the application of biocatalysts which produce far less by-products or recycle them in other reactions (Dunn et al., 2012). Owing to the fact that biocatalysts are extracted from natural organisms, it is quite logical that barely any waste is produced that is unhealthy for the environment.

Scientific Debate

The impact of biocatalysts on the chemical industry resulted in more efficient production and less waste. Since biocatalysts are extracted from natural organisms, very little waste is environmentally toxic. Although the chemical, social and economic advantages of biocatalysts over chemical approaches have already been realized, they have not been largely applied in industrial production processes and have been neglected (Franssen, 2013). Recent breakthroughs in modern biotechnology expand the utility of enzymes in chemical industries. If designed properly, using biocatalysts in chemical production provides businesses with a myriad of benefits such as lower costs, timesaving, and less waste generation. The greater focus on sustainable manufacturing processes places (bio)-catalysis at the top of the green chemistry movement (Bussaca et al., 2011).

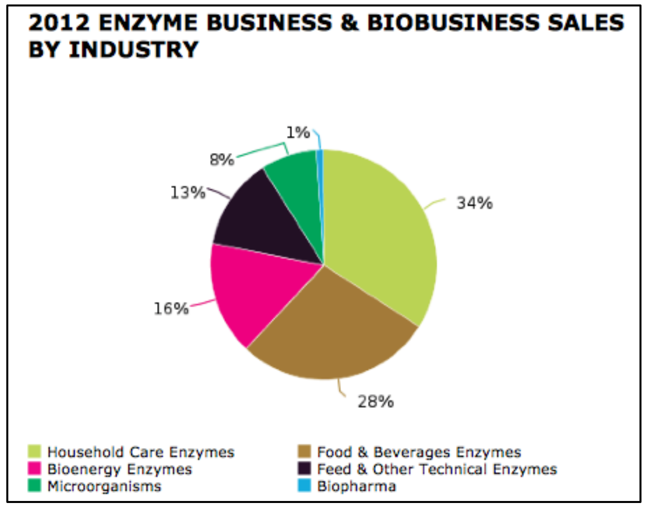
Food for Thought

- Biocatalytic processes can potentially be more efficient in producing the same chemical product as organic synthesis because of their specificity for certain reactions
- 2-step biocatalytic conversions result in a lot less waste than a 10-step organic reactions since less additives have to be incorporated in the reaction

One concern with the incorporation of biocatalysts stems from the idea that biocatalyzed processes take longer to complete. Much is unknown about biotechnological processes in general, especially in the field of specialty chemicals where organic chemists prefer traditional methods of organic synthesis. Also, new materials and equipment will need to be purchased in order to switch over from the chemical synthesis of a certain product to the biochemical synthesis. Familiarity with the old process can also rule out the incorporation of biocatalysts.

Another disadvantage of using enzymes (biocatalysts) is that they are expensive for companies who do not produce them themselves. Many enzymes have to be modified in order to be able to use them on an industrial scale. The costs of such a modified enzyme are much higher than buying organic reagents for performing certain reactions (Franssen, 2013). It would be difficult to incorporate the bio-catalytic industry in developing countries due to these high costs, but perhaps private companies can set up local factories to improve employment there.

The waste problem in the chemical industry can be largely eliminated through the use of catalysis and alternative reaction media. There are many more advantages to using biocatalysis than disadvantages.



Although these enzymes have to be upgraded from their original, natural form, their stability and reaction rate is largely improved through directed evolution and rational redesign (Carvalho et al., 2011). Enzymes are very specific and can act under mild conditions, meaning low temperatures and optimal pH conditions. This makes them more environmentally friendly along with the fact that they produce less to no waste and can also be biologically degraded (Leggewie et al., 2012).

Further issues for consideration

The following issues are suggested for consideration by policy makers:

- Certain chemical catalysts such as rhodium, iridium, palladium and platinum will become scarce long before petroleum does (Dunn et al., 2012). An alternative is not only preferable but also necessary in the long run. Finding new chemical methodologies using more abundant metals or, even better, enzymatic catalysts has a high value for society.
- Increase efficiency of biological catalysts so that their reaction rates and substrate loadings are improved.
- Transition from chemical catalysis to biological, enzyme-based catalysis in order to significantly

reduce the effect of waste within the chemical industry

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