Enzymatic bioprocessing of oils and fats

Determining the sustainability of enzyme processes with Life Cycle Assessment

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The industrial revolution, which started in Europe, has long since spread to much of the rest of the world and has raised living standards and brought prosperity to millions of people. However, these changes have not been without consequences, not the least of which is the coupling of increased industrialization to climate change. That this has occurred is now acknowledged by a majority of climate change researchers and by the wider community.

In recent years, biotechnological solutions have been introduced that can replace many chemical processes, resulting in reductions of chemical effluents and energy demand. In light of the impact industrial processes are having on environmental factors such as CO_2 emissions, can we be sure that these new processes are less environmentally damaging than the ones they replace?

Life Cycle Assessment (LCA) is an analytical tool that can be used to compare two or more processes in a product chain—from raw material extraction through production and use, to final disposal—to evaluate their relative environmental impact. In the case presented here, LCA is applied to three processes used within the oils and fats industry (ester synthesis, degumming, and interesterification) to compare the environmental impact of the conventional and enzymatic alternatives of each. In all the cases inputs and outputs have been quantified and the potential savings in terms of four environmental indicators have been calculated.

In this study the modeling is carried out in SimaPro 6.0 software (Amersfoort, the Netherlands), and characterizations of environmental impacts are based on Eco-indicator 95 v2 (SimaPro). The assessment covers four environmental indicators: global warming, acidification, nutrient enrichment, and photochemical ozone formation.

THREE CASES OF ENZYMATIC BIOPROCESSING

Three processes have been examined for this report:

- Enzymatic synthesis of oleochemical esters (myristyl myristate)
- Enzymatic degumming of vegetable oils (soybean oil)
- Enzymatic interesterification of oils for hard-stock production

We have completed the first two cases, and they have been subjected to peer review; the results of the third study have not yet been externally reviewed. External review and validation are an important quality check for the analysis, and plans have been made for them to be carried out.

In each case the enzymatic process has been compared with the corresponding chemical process. In the analysis, where parts of the process are identical in both cases, they are eliminated from the calculations. The purpose of the analysis is to find the differences between the two operations with regard to the four environmental indicators. Results are therefore expressed as a change in one of the parameters measured (global warming, acidification, nutrient enrichment, and photochemical ozone formation) when the enzymatic process replaces the chemical one.

Case 1: Enzymatic synthesis of oleochemical esters. This case evaluates the production of myristyl myristate, and emollient ester, frequently used in the production of various cosmetics, but the results obtained can be applied to similar cosmetic esters derived from fatty acids.

Two production procedures have been compared: a conventional, chemical process and an enzymatic production process using immobilized Lipase B from *Candida antarctica* under real industrial conditions as currently applied by Evonik Degussa AG (Essen, Germany).

Replacing the chemical catalyst (tin)-based process with an enzymatic one reduces energy use, production of by-products, and, as a result of the more specific enzymatic catalysis, the need for post-production cleanup. Comparison of the products made by the two routes shows that chemical catalysis produced a product with a gas chromatographic purity of 88.5% and a color value of 73 (measured at 50°C), whereas the product from the enzymatic process had a purity of 96.4% and a color value of only 28.

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When comparing the environmental impact of the two processes, the ecological advantages of the enzymatic process can be easily seen: Energy consumption is reduced by more than 60% and the emission of unwanted pollutants is reduced by up to 90%. In Figure 1 the environmental load of the enzymatic process is the "used" bar. The "saved" bar refers to the difference in environmental load between the consumption of the enzymatic and chemical processes.

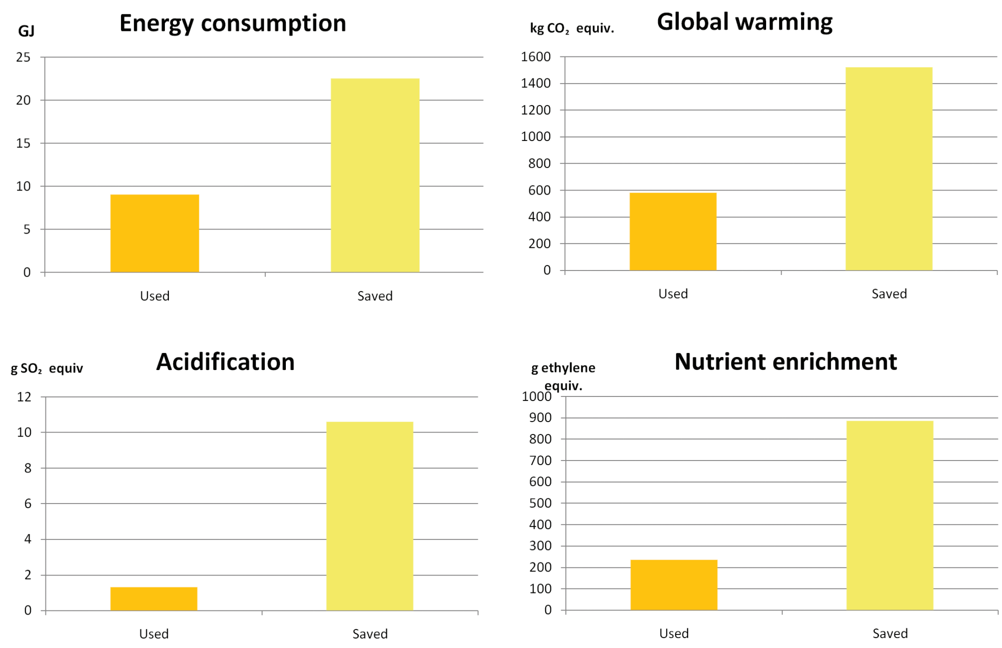

FIG. 1. *Environmental savings when using an enzymatic process for synthesis of oleochemical esters (per 5 metric tons of myristyl myristate).*

Case 2: Enzymatic degumming of vegetable oils. This case assesses the environmental changes when soybean oil is degummed by an enzymatic method as an alternative to the conventional method of alkaline degumming.

This process is used in oils and fats production to remove phosphatide gums from oil, which have an adverse effect on oil quality and stability. Further details on this and all of the enzyme processes described can be found at www.novozymes.com.

In this case, analysis shows that the major environmental benefit is the reduction of oil losses during processing (Fig. 2; Table 1).

Case 3: Enzymatic interesterification. In this case an enzymatic catalyst is used for the interesterification of vegetable oils in margarine hard-stock production. This analysis compares chemical and enzymatic interesterification of soybean oil and fully hydrogenated soybean oil to produce a hard stock for margarine production. It is based on margarine production in the United States using local

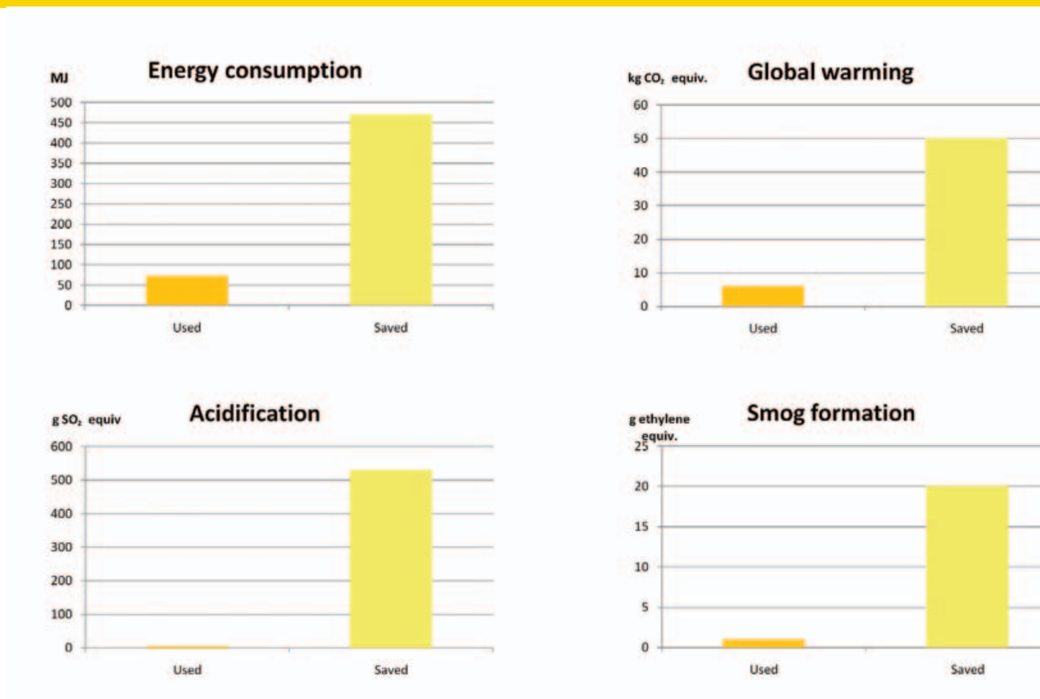

FIG. 2. *Environmental savings when using an enzymatic process for degumming of vegetable oil (per metric ton of refined soybean oil).*

figures for energy and other costs at the time of the analysis.

The preliminary results show that major savings are possible in terms of energy because the process runs at a lower temperature. Another, lesser, benefit is that, as a result of reduced losses, vegetable oil consumption per metric ton of produced margarine is lower.

CONCLUSIONS

Enzymatic processing of oils and fats is an innovative, more sustainable way of processing than using chemical agents, but the true potential of the benefits needs to be quantified. LCA allowed us to determine which methods of enzymatic processing of oils and fats are less detrimental to the environment. We found that significant savings can be achieved by switching to an enzyme-catalyzed alternative.

An example of how to view some of the potential savings is as follows: World use of fatty acid esters for cosmetics (Case 1) is about 120,000 metric tons per year. If all fatty acid esters used for cosmetics were produced by enzyme technology, this would reduce CO_2 emissions by 20,000 metric tons per year. This corresponds to the annual load of 2,300 average persons, or the annual load of 5,000 cars. The larger the production, the greater the potential savings.

In Case 2, if all soybean oil in the world were refined using enzyme technology, the CO_2 emission savings would be equivalent to the amount emitted by over 150,000 people carrying out their usual activities, and fuel savings would be equivalent to over 2 million barrels of refined gasoline per year.

Enzymatic bioprocessing of oils and fats offers the industry a means to considerably reduce the environmental impact of their operations, and as more of these processes are introduced, the possibilities will continue to increase.

information

Further reading:

- Thum, O., and K. Oxenbøll, in *Proceedings of the 24th International Federation of the Society of Cosmetic Chemists*, Osaka, Japan, October 16–19, 2006.
- Wenzel, H., M.Z. Hauschild, and L. Alting, *Environmental Assessment of Products: Volume 1: Methodology, Tools and Case Studies in Product Development*, Chapman and Hall (1997).

Netlinks:

- www.pre.nl/default.htm [Product Ecology Consultants]
- www.springer.com/environment/journal/11367 [*The International Journal of Life Cycle Assessment*]
- www.degussa.com/degussa/en [Evonik, formerly Degussa]
- www.novozymes.com

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TABLE 1. Identification of savings in enzymatic degumming

	Global warming	Acidification	Nutrient enrichment	Smog formation	Fossil energy
Vegetable oil savings	50%	50%	90%	80%	35%
NaOH savings	20%	10%	—	10%	25%
Phosphoric acid savings	—	10%	10%	—	5%
Byprod. treatment (incl. heat production)	20%	30%	—	10%	35%