LCA Case Studies

Cradle-to-Gate Environmental Assessment of Enzyme Products Produced Industrially in Denmark by Novozymes A/S

Per H. Nielsen[1]*, Karen M. Oxenbøll[1] and Henrik Wenzel[2]

[1] Novozymes A/S, Krogshøjvej 36, 2880 Bagsværd, Denmark
[2] Department of Manufacturing Engineering and Management, Technical University of Denmark, 2800 Lyngby, Denmark

* **Corresponding author** (phgn@novozymes.com)

Preamble

1. Nielsen PH, Oxenbøll KM, Wenzel H (2006): Cradle-to-Gate Environmental Assessment of Enzyme Products Produced Industrially in Denmark by Novozymes A/S. Int J LCA, OnlineFirst (DOI: http://dx.doi.org/10.1065/lca2006.08.265.1)
2. Nielsen PH, Wenzel H (2006): Environmental Assessment of Ronozyme® P5000 CT Phytase as an Alternative to Inorganic Phosphate Supplementation to Pig Feed Used in Intensive Pig Production. Int J LCA, OnlineFirst (DOI: http://dx.doi.org/10.1065/lca2006.08.265.2)

The present paper is the first in a series of two, where environmental implications of enzyme technology are addressed. The second paper focuses on application of the enzyme product Ronozyme Phytase in pig production.

DOI: http://dx.doi.org/10.1065/lca2006.08.265.1

Please cite this paper as: Nielsen PH, Oxenbøll, Wenzel H (2007): Cradle-to-Gate Environmetnal Assessment of Enzyme Products Produced Industrially in Denmark by Novozymes A/S. Int J LCA 12 (6) 432–438

Abstract

Goal, Scope and Background. Enzymes are biological catalysts with an enormous capacity to increase the speed of a huge variety biochemical reactions. Industrially produced enzymes are used in a broad variety of sectors to increase quality, speed and yield of processes, and reduce energy consumption and use of hazardous chemicals. The present paper provides a methodological framework for analysing environmental impacts of enzyme products and environmental data for five characteristic enzyme products.

Methods. Life cycle assessment is used as an analytical tool and modelling of enzyme production is facilitated in SimaPro 6.0 software. Detailed data on enzyme production are derived from Novozymes' production facilities in Denmark. Data on ingredients are derived from the literature, publicly available databases and from Novozymes' suppliers.

Results and Conclusions. Cradle-to-gate environmental data for five representative enzyme products produced by Novozymes in Denmark have been determined, and a basis for further assessments of more of Novozymes' enzyme products has been established. Environmental impacts induced by producing the considered enzyme products vary by a factor 10 or more depending on the impact category considered. Contributions to global warming range, for example, between one and ten kg CO_2-equivalents per kg final product. The variation is explained by differences in fermentation time, formulation type, production yield and strength of the final product. The main sources of environmental impact are usually fermentation processes due to electricity and ingredient consumption. Enzyme production has been the subject of significant optimisation during the past decades by implementation of e.g. gene modified production strains, and the provided environmental data are only representative to enzyme products produced by Novozymes at the present optimisation stage.

Recommendations and Perspectives. Novozymes produces more than 600 enzyme products for use in a variety of sectors, and the established framework for environmental assessment will be used for assessing more products in order to provide a broad basis for environmental comparison of enzyme assisted technologies and conventional technologies.

Keywords: Amylase; environmental assessment; enzyme production; enzyme technology; Novamyl®; phytase; protease; Ronozyme®; Savinase®; Spirizyme®; Termamyl®; white biotechnology

Introduction

Enzymes are proteins that act as catalysts in all living organisms. Numerous enzymes exist and they are characterized by highly specific action and very fast reaction rates. Enzymes can be active outside the cell and, due to their biological origin, they work efficiently under mild conditions, i.e. ordinary temperatures and pressures. See Berg et al. (2002) and Olsen (2004).

Enzymes are produced industrially by growing bacteria or fungi in liquid culture (submerged fermentation). They are used in a broad range of industrial and non-industrial processes to increase quality, speed and yield of processes and to reduce energy consumption and use of chemicals (Arberer 2002, Kirk-Othmer 2004 and Ullmann's 2003).

Novozymes is the world's largest industrial producer of enzymes. The company would like to strengthen the understanding of enzyme production from an environmental perspective. Thus, the present paper explains some of the most important processes in enzyme production as seen from an environmental perspective, and provides environmental data on five characteristic products produced at the company's factories in Denmark. One enzyme product addressed in the present study (Ronozyme P5000 CT; phytase) is furthermore assessed in application by Nielsen and Wenzel (2006).

1 Method

Life cycle assessment is used as an analytical tool (Wenzel et al. 1997) and modelling of enzyme production is facilitated in SimaPro 6.0 software. Characterisation of environmental impacts is based on Eco-indicator 95 v2.1. Detailed data on enzyme production are derived from the company's production facilities in Denmark in 2004. Data on ingredients are derived partly from public sources and partly from the records of Novozymes' suppliers.

It is acknowledged that the results are supposed to be used for comparative assessments of enzyme assisted processes and conventional processes without enzymes and the enzymes' environmental profiles are compiled by addressing changes induced by a change in demand for the company's products. Consequently, a marginal and market-oriented approach is taken and co-product issues are handled by system expansion, see Wenzel (1998), Weidema et al. (1999) and Ekvall and Weidema (2004).

2 Scope

The assessment addresses environmental impacts potentials associated with enzyme production in a 'cradle-to-gate' perspective, i.e. all processes from production of raw materials to the final enzyme product at Novozymes' gate. The assessment covers four environmental indicators: global warming, acidification, nutrient enrichment and photochemical ozone formation. Stratospheric ozone degradation is disregarded because no significant emissions of ozone degrading gasses appear in the system considered. Toxicity is disregarded because the available data basis presently is considered too incomplete. Enzyme production is to a large extent based on raw materials derived from agriculture and use of agricultural land ($m^2 \cdot$ years) has been addressed in the study. Use of land for other purposes (mines, infrastructure, production facilities, etc.) is not included because the available data are considered too inhomogeneous and incomplete. The production of enzymes is energy intensive, and energy consumption has been considered in terms of MJ primary energy carriers (low heat value).

Novozymes produces more than 600 different enzyme products with a wide range of characteristics. The present assessment covers five characteristic products that have been selected to represent the great majority: bacterial and fungal products in three main types of formulations; liquid, granulated/coated and granulated. See **Table 1**.

Production strains and production processes used to produce the considered products are at a mature state in process optimisation and products are produced in large scale at modern production facilities with much awareness of energy and resource optimisation.

3 Enzyme Production

3.1 Production at Novozymes

Production of enzyme products at Novozymes' factories involves four main processes: 1) fermentation: growth of pure culture micro-organisms in a liquid medium, 2) recovery: separation of extracellular enzymes from the biomass, 3) formulation: preservation and standardisation of enzyme products and, eventually, addition of formulation chemicals and 4) biomass treatment: inactivation of micro-organisms and drying the biomass for use as soil improver in agriculture (**Fig. 1**).

Table 1: Main characteristics of the five considered enzyme products

Enzyme	Product name	Type	Formulation type	Function	Industrial application
A	Termamyl 120 L	Bacterial alpha-amylase	Liquid	Liquefaction of starch	Production of high fructose syrup
B	Spirizyme plus FG	Fungal glucoamylase	Liquid	Saccharification of starch	Production of starch derived sugars
C	Ronozyme P5000 CT	Fungal phytase	Granulated and coated	Release of phytate bound phosphate	Additive to animal feed (pig, poultry, farmed fish)
D	Savinase 12 TXT	Bacterial protease	Granulated and coated	Removal of protein stains	Detergent additive
E	Novamyl 10,000 BG	Bacterial amylase	Granulated	Diminish crystallisation of starch	Industrial bread production (anti-staling)

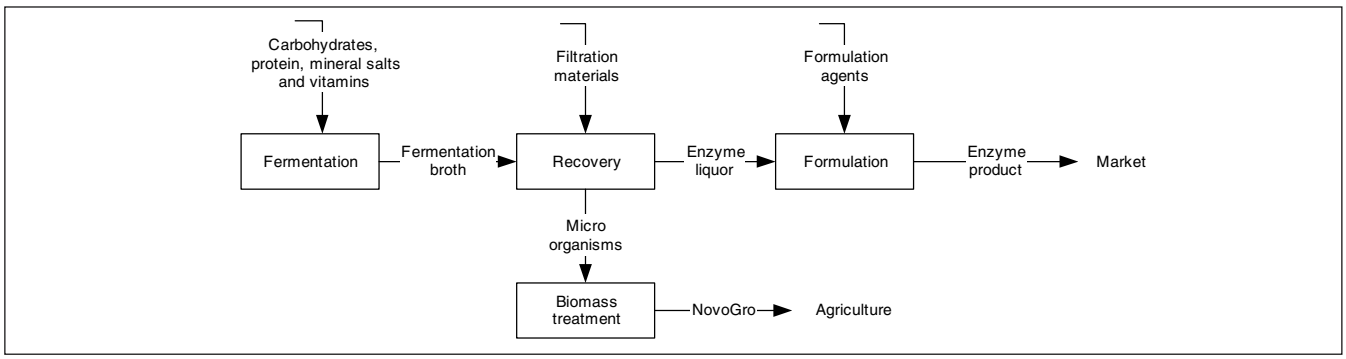

Fig. 1: Main processes in industrial enzyme production at Novozymes. Heat, electricity and water are used in any process and wastewater is generated in any process

Enzymes are produced in fermentation tanks by micro-organisms supplied with carbohydrates (sugar and starch), protein, mineral salts and vitamins. The process typically takes three to ten days and electricity is used for aeration and mixing. The fermentation broth contains the micro-organisms and extracellular enzymes. The enzymes are recovered by centrifugation and filtration. The recovered enzyme liquor is transferred to formulation processes and the remaining biomass is transferred to biomass treatment. The recovery process uses filtration materials and electricity for pumping, etc. The concentration of enzyme in the enzyme liquor is standardised and some products are furthermore fixed on a solid material (granulation) and coated in the formulation process. The formulation process uses water for dilution, heat and electricity for spray driers and vacuum evaporators and granulation materials for the granulation process (kaolin, sodium sulphate, etc. depending on the specific product). The final products are packed and stored for delivery. The biomass generated in the recovery process is heat treated (90°C) and burnt chalk (CaO) is added (to pH = 11) to kill the micro-organisms. The sterilised biomass is dewatered by centrifugation and delivered to local farmers as NovoGro® (30% dry matter). NovoGro serves as a soil improver in agriculture due to its content of organic matter, N, P and Ca. Efficiency of the applied inactivation of microbial biomass is addressed by Andersen et al. (2001). Wastewater is subject to significant treatment in the company's own wastewater treatment plant before it is diverted to the sewer system for further municipal wastewater treatment. Treated wastewater is diverted to the sea. The total treatment of wastewater includes activated sludge treatment, denitrification, phosphorus removal and ozone treatment. Data on public wastewater treatment are derived from Nielsen et al. (2003). Transport of NovoGro from production sites to local farmers (about 60 km on average) is included.

The enzymes considered in the present study are produced at Novozymes' factories in Kalundborg, Bagsværd and Fuglebakken, either entirely or in combination.

All significant consumptions of electricity, steam, ingredients, and water in all production and waste treatment processes are included in the assessment, based on enzyme specific production records from 2004. Enzyme production is an energy intensive process and heat and electricity consumptions for administration, etc. are ignored because they are considered insignificant. Ingredients are mostly delivered in bulk or big bags and final products are sold in a broad spectrum of cardboard/plastic packaging. Packaging is ignored because it is insignificant in most cases and specific for specific applications and costumers. Displacement of alternative sources of N and P fertilisers (Patyk and Reinhardt, 1997) and limestone (Ecoinvent, 2003) as a result of NovoGro application in agriculture is included in the assessment.

Most of Novozymes' enzyme products are produced by gene modified micro-organisms (GMMs). Production is approved according to EU directive 90/219/EEC on the contained use of genetically modified micro-organisms. Novozymes has used GMMs in enzyme production for more than 20 years, and has continuously evaluated possible risks of GMM application in laboratory tests and field re-finding programmes. The results are reported to the local authorities and the Danish Ministry of the Environment on a regular basis, and so far there have been no indications of any risks at any stage, from enzyme production to final product and waste. See e.g. Aberer et al. (2002), AMFEP (2006) and Ullmann's (2003) for further reference.

3.1.1 Energy supply

Electricity is drawn from the national grid, and following Weidema (2003), natural gas fired power plants have been identified as the marginal sources of electricity. Data are derived from (ETH, 1996).

Steam is produced in different ways at Novozymes' factories in Kalundborg, Bagsværd and Fuglebakken. The factory in Kalundborg is integrated in the 'Industrial Symbioses' network (www.symbiosis.dk) and steam is usually delivered as excess steam from Asnæs combined heat and power plant. Quantities of heat and power produced at Asnæs power plant is determined by the electricity demand in the society, and a demand for steam for enzyme production does usually not induce any extra production at the plant (discharge of excess heat is reduced instead). However, six to seven weeks of the year, steam production at Asnæs power plant is insufficient for industrial application and the steam applied by Novozymes and other factories in the network is produced at a fuel oil-based boiler located at the power plant (Larsen 2003). During this period, steam production is determined by the demand in enzyme production processes and steam production from the oil furnace (ETH, 1996) is included accordingly.

The factory in Bagsværd primarily uses steam from a natural gas turbine which produces electricity and steam in combination. The steam consumption determines the production, and the co-produced electricity is delivered to the public power grid. Displacement of publicly-produced electricity by co-produced electricity in Bagsværd is included in the assessment by crediting the avoided impacts from public electricity production to the enzyme products. Data on natural gas consumption and heat/power production are derived from the factory's 2003 production records. Data on natural gas extraction are derived from ETH (1996). Emission factors related to combustion process are derived from NERI (2004).

The factory at Fuglebakken uses steam from an oil based boiler and no co-product issues are related to the production. Data on fuel oil production are derived from ETH (1996) and emission factors related to combustion process are derived from NERI (2004).

3.1.2 Ingredients and materials

A broad variety of ingredients and materials are used for production of enzymes and the dominating ingredients and materials used to produce Enzyme A to E are shown in

Table 2: Ingredients and materials included in the study

Process	Substance	Data source
Fermentation	Corn starch	Würdinger et al. (2003)
	Sucrose	Nielsen et al. (2003)
	Glucose/maltose	Supplier / Int. Starch Inst., Denmark
	Corn steep powder	Supplier
	Soy bean meal	Nielsen et al. (2003)
	Potato protein	Supplier
	Phosphoric acid	Ecoinvent (2003)
	Glucose syrup	Supplier / Int. Starch Inst., Denmark
	Ammonia	Ecoinvent (2003)
Recovery	Kiselgur	Supplier (mined from the ground)
	Perlite	Supplier (mined from the ground)
	Sodium chloride	Ecoinvent (2003)
Formulation	Sodium sulphate	Supplier (mined from the ground)
	Cellulose powder	Supplier
	Palm oil	Ecoinvent (2003)
	Wheat starch	Würdinger et al. (2003)
	Kaolin	Ecoinvent (2003)
	Calcium carbonate	Ecoinvent (2003)
	Titanium dioxide	Ecoinvent (2003)
	Sodium chloride	Ecoinvent (2003)
	Sucrose	Nielsen et al. (2003)
	Calcium chloride	Weidema (2003)
	Acetic acid	Ecoinvent (2003)

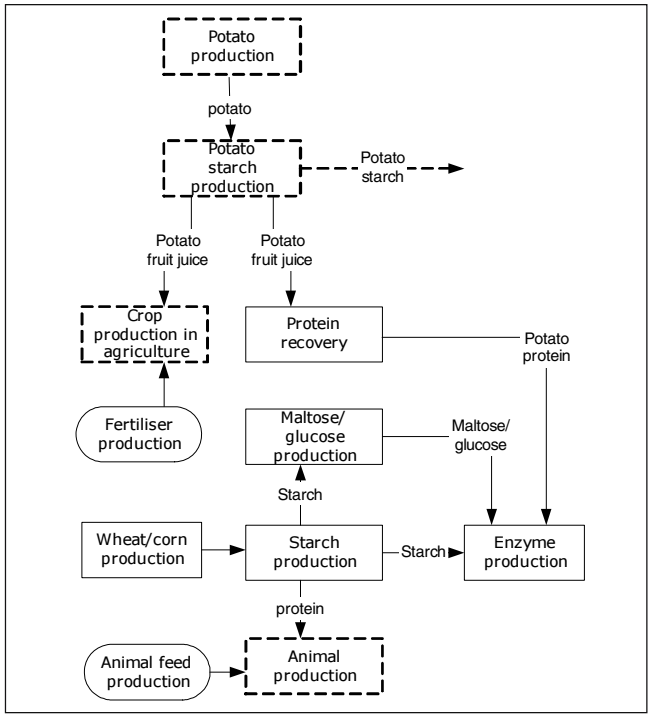

Fig. 2: System expansions related to potato protein, starch and maltose/ glucose production. Boxes refer to production processes and arrows refer to material streams. Processes indicated with dotted boxes are not included in the assessment because they are independent of demand for enzyme products. Rounded boxes refer to displaced processes

Table 2. Data are mostly based on publicly available sources and data which were not available from public sources have been collected from Novozymes' suppliers. Data from suppliers are collected in 2004 and refer to the most recent production records. Supplier's names and quantities of ingredients applied in production are confidential.

The ingredients listed in Table 2 constitute the majority of ingredients used to produce the considered enzymes. The remaining ingredients comprise a relatively long list of individual substances such as vitamins, cleaning agents, micronutrients, flocculation agents, product stabilisers, etc. used in relatively small amounts. Their names and applications cannot be further detailed here for confidentiality reasons. In total, however, more than 95% (w/w) of ingredients are included in the assessment of any of the five enzyme products.

Many of the agricultural inputs to enzyme production (starch, protein and sugar) are co-produced with other agricultural products and important system expansions applied are shown in **Fig. 2**.

The applied potato protein is produced from potato fruit juice, an excess product from potato starch production which would otherwise be spread on agricultural land, (displacing artificial fertilisers due to it's N and P content). Thus, a demand for potato protein production for enzyme production does not induce any potato or potato starch production and these processes are disregarded. It instead induces protein recovery from potato fruit juice (concentration and drying) and corresponding fertiliser production as compensation for the missing N and P input to agriculture. Starch applied in enzyme production is produced from wheat or corn, and protein (gluten) is a co-product from starch production. Proteins have many uses of which animal feed is among the least lucrative. Thus, it is assumed that the marginal protein displaces other types of protein for animal feed. Animal feed displacements are determined from the Danish Feed Table (Møller et al. 2000) in dialogue with relevant animal feed producers. Maltose and glucose is produced from starch and the same system expansions have been applied for theses ingredients.

The most important ingredient transportation processes (long distance and/or large quantity) are included in the study. Transportation distances and dominating modes of transportation refer for simplicity to the largest single suppliers.

3.1.3 Data quality assessment

Modelling of the enzyme production at Novozymes is based on very detailed and accurate information reflecting true production conditions in 2004. Data from suppliers are also very recent, but mostly somewhat more approximate. Significant data from the literature have to a large extent been verified by producers and vice versa. All significant data are based on the market-oriented approach taken in the study. Allocations applied in some data from Ecoinvent (2003) are not influencing results significantly because quantities of materials and/or significance of allocations are small. Though data represent a mix of generic and specific data from the past decade, data quality is considered high, because signifi-

cant data are mostly quite uniform and updated. The only exception is data from ETH (1996) on energy supply, which are somewhat older. Energy input to enzyme production turn out to be quite important for the overall assessment (see next section) suggesting that estimated impacts of enzyme products and impacts of energy use in particular may be slightly overestimated.

4 Environmental Impact Assessment

4.1 Environmental impacts induced by enzymes

Environmental impacts associated with production of enzyme A to E in all processes from 'cradle to gate' are shown in **Fig. 3**. The figure shows a variation of environmental impacts between the five considered enzymes in the order of a factor ten for contributions to global warming, acidification, photochemical ozone formation and for primary energy consumption. Variation in terms of agricultural land use and contributions to nutrient enrichment are generally higher.

Analysis of the model behind the results reveals that the differences in environmental impacts can be explained by 1) differences in concentrations of enzyme in the final products, 2) differences in energy consumption per produced unit (particularly electricity consumption which is in turn related to fermentation time) and 3) differences in quantities and types of ingredients, particularly major ingredients such as carbohydrates and formulation chemicals. Differences in contributions to nutrient enrichment and use of agricultural land can, furthermore, to a large extent be explained by differences in crops applied to produce the most important carbohydrates.

4.2 Identification of main sources of environmental impact

A break-down of a selected enzyme product's contribution to global warming is shown in **Fig. 4**. The figure shows that fermentation is the most important process, responsible for about half of the products' total contribution to global warming. Formulation is the second most important process (about one fourth of contribution) and recovery and waste management are about equal, representing around 1/8 of the total contribution. Avoided impacts due to displacement of artificial fertiliser resulting from NovoGro application on agricultural land are insignificant. Relative contributions from transportation of ingredients and final products are generally very small.

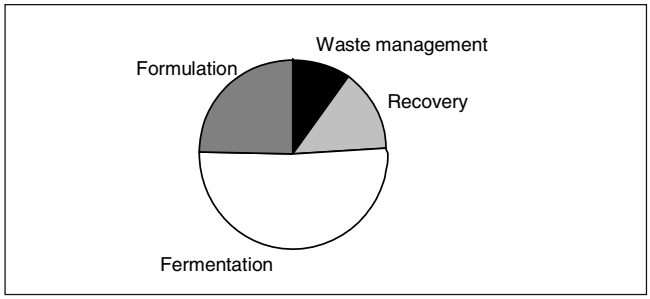

Fig. 4: Break-down of a selected enzyme product's main sources of global warming

The result of the breakdown varies with first and foremost fermentation time, fermentation ingredients and type of formulation of individual products and the result in Fig. 4 should only be seen as an example.

Contributions to global warming are to a large extent driven by energy consumption, and other energy related impact categories (acidification and photochemical ozone formation) follow the same overall pattern (data not shown). Enzymes' contributions to nutrient enrichment are to a large extent driven by carbohydrate consumption (sugar and starch) and protein consumption, and use of ingredients is the most important factor for this impact category (data not shown).

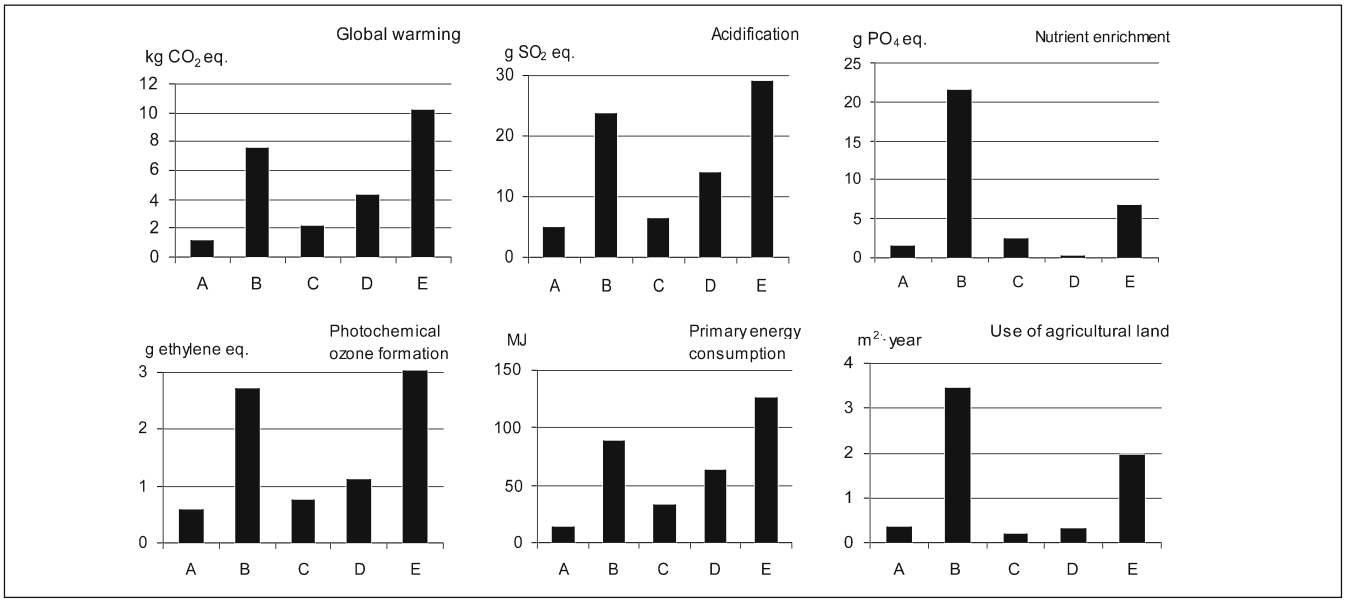

Fig. 3: Potential environmental impacts and resource consumptions induced by production of enzyme A to E. All data are provided per kg final product at the gate of the factory

Contributions to global warming have been broken further down for a selected enzyme product in **Fig. 5**. The figure shows that electricity and ingredient consumption are by far the most important sources of global warming, while contributions from steam are more limited. The limited contribution from steam can to some extent be explained by the fact that steam for the particular product is derived from Asnæs combined heat and power plant with a relatively small environmental impact per GJ (see 3.1.1). Steams' significance is thus somewhat higher for enzymes produced at the factories in Bagsværd and Fuglebakken.

The breakdown of contribution to global warming and other impact categories on specific processes at Novozymes varies and the pattern in Fig. 5 should again only be seen as an example.

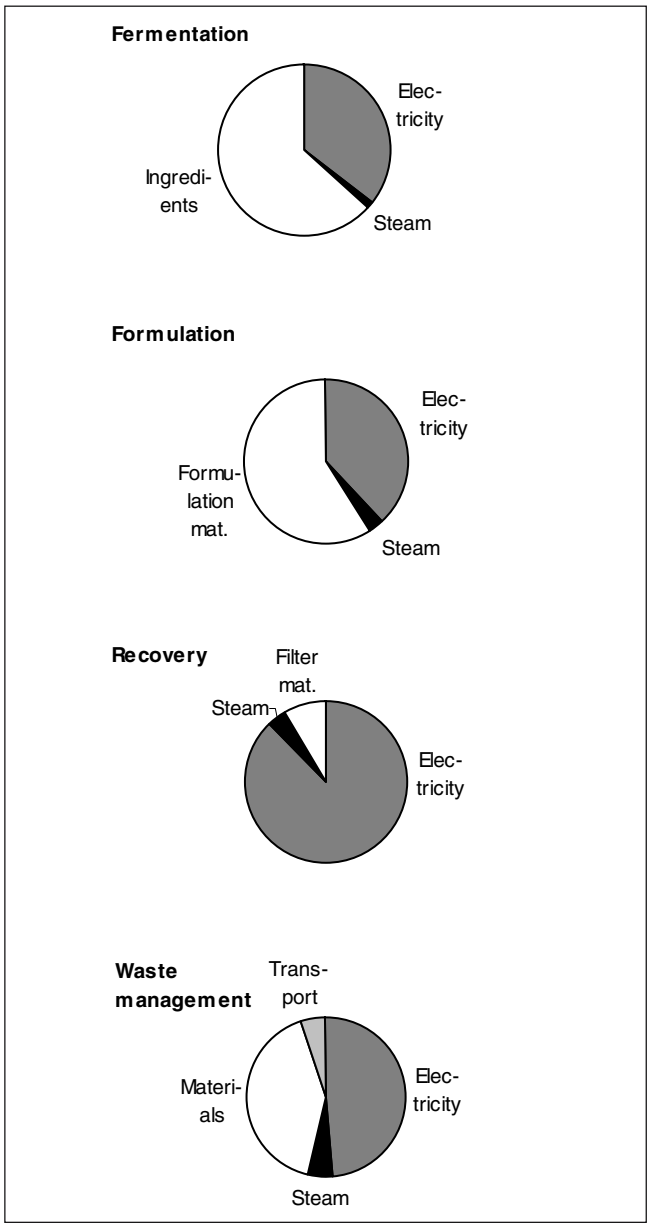

Fig. 5: Break-down of a selected enzyme product's main sources of global warming on fermentation, recovery, formulation and waste management processes

4.3 The considered enzyme products are highly optimised

Novozymes' enzyme production has been the subject of intensive optimisation efforts over the past decades. Earlier, the efforts were mainly based on mutation of the production strains and on optimisation of the fermentation conditions. Today, these disciplines have been supplemented with gene technology (gene modified micro-organisms, GMM), which has provided additive increases of the out-put of enzyme per input unit of ingredients and energy (Novozymes 2005). The environmental achievement of this development has been addressed by analysing various enzyme products produced with conventionally optimised micro-organisms (non-GMM) and with GMM. The results for a selected enzyme product are shown in **Fig. 6** for comparison.

Fig. 6 shows that considerable environmental improvements have been achieved by implementing gene-modified micro-organisms in enzyme production, and emphasises that data provided in the present paper are only representative to Novozymes' products at their present optimisation state.

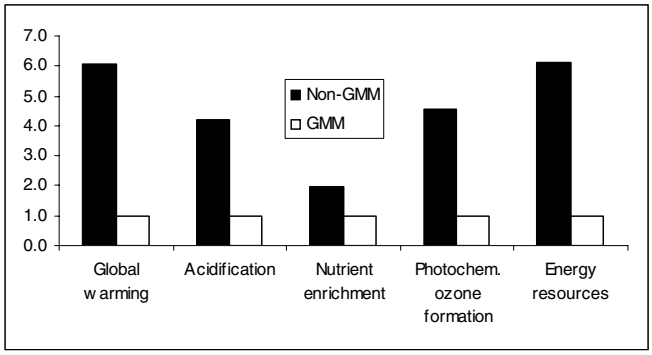

Fig. 6: Relative environmental impacts induced by a selected enzyme product produced with a non-gene modified production strain (non-GMM) and with a gene modified production strain (GMM). All impacts are normalised to the present product produced with GMM

5 Conclusions and Perspectives

Cradle-to-gate environmental data for five characteristic enzyme products produced by Novozymes in Denmark have been determined, and a basis for further assessments of more of Novozymes' products has been established.

The main sources of impacts are the fermentation processes and production of ingredients for fermentation. Environmental impacts of the considered enzyme products vary by a factor of about ten due to differences in use of carbohydrates, applied fermentation time, formulation type, yield and final product strength.

The study provides environmental data on five characteristic enzyme products and an indication of the range of environmental impacts induced by mature enzyme products produced in large scale by Novozymes. This information can be used to address the environmental implications of using enzymes in todays production processes and compare conventional processes with enzyme-assisted processes. An example where Ronozyme P 5000CT (Enzyme C) is used as an additive to pig feed in order to release natural phosphate in grains as an alternative to supplementing inorganic phosphate from external sources, is provided by Nielsen and Wenzel (2006).

Novozymes' production has been the subject of significant optimisation over the years, and environmental impacts per produced unit have in some cases dropped substantially, primarily due to yield improvements enabled by efficient production strains created by gene modification. The study indicates that continued improvement of yields through production strain optimisation is probably the most effective single means to further environmental improvements, but it also points to interesting points in production which will be addressed in the continuous efforts to reduce environmental impacts per produced unit of enzyme products.

Acknowledgements. The authors are grateful to all colleagues and partners in and out of Novozymes who supported the study with data and information. The study was financed by Novozymes.

References

Aberer W, Hahn M, Klade M, Seebacher U, Spök A, Wallner K, Witzani H (2002): Collection of information on enzymes. Final report. European Communities, ISBN 92-894-4218-2

AMFEP (2006): Association of Manufacturers and Formulators of Enzyme Products. <www.amfep.org>

Andersen JT, Schäfer T, Jørgensen PL, Møller S (2001): Using inactivated microbial biomass as fertilizer: The fate of antibiotic resistance genes in the environment. Res Microbiol 152, 823–833

Berg JM, Tymoczko JL, Stryer L (2002): Biochemistry. Fifth edition, W.H. Freeman and Company

Ecoinvent (2003): The life cycle inventory data version 1.01. <www.ecoinvent.com>

Ekvall T, Weidema BP (2004): System boundaries and input data in consequential life cycle inventory analysis. Int J LCA 9, 161–171

ETH (1996): Ökoinventare für Energiesysteme (Teil I-VII). ETH Zürich

Kirk-Othmer Encyclopedia of Chemical Technology (2004): Enzyme Applications. Industrial, John Wiley & Sons, Inc.

Larsen N (2003): Telephone communication with Niels Larsen, Kalundborg Erhvervsråd

Møller J, Thøgersen R, Kjeldsen AM, Weisbjerg MR, Søegaard K, Hvelplund T, Børsting CF (2000): Feed table – Composition and feed value of feed for cattle. Report no 91, Danish Agricultural Advisory Service (in Danish)

NERI (2004): Emission factors, stationary combustion main for the year 2003. National Environmental Research Institute, Denmark

Nielsen PH, Nielsen AM, Weidema BP, Dalgaard R, Halberg N (2003): LCA food data base. <www.lcafood.dk>

Nielsen PH, Wenzel H (2006): Environmental assessment of Ronozyme® phytase as an alternative to inorganic phosphate supplementation to pig feed used in intensive pig production. Int J LCA, OnlineFirst <DOI: http://dx.doi.org/10.1065/lca2006.08.265.2>

Novozymes (2005): The Novozymes report 2004: Efficient production also benefits the environment (p 35). Novozymes A/S, <www.novozymes.com>

Olsen HS (2004): Enzymes at work. Novozymes A/S, <www.novozymes.com>

Patyk A, Reinhardt G (1997): Fertiliser – Energy and mass balance. Friedr. Vieweg & Sohn Publishers, ISBN: 3-528-06885-X (in German)

Ullmann's Encyclopedia of Industrial Chemistry (2003): Enzymes. Wiley-VCH Verlag GmbH & Co

Weidema BP, Frees N, Nielsen AM (1999): Marginal production technologies for life cycle inventories. Int J LCA 4, 48–56

Weidema B (2003): Market information in life cycle assessments. Environmental project no. 863, Danish Environmental Protection Agency

Wenzel H, Hauschild M, Alting L (1997): Environmental assessment of products. Volume 1: Methodology, tools and case studies in product development. Chapman and Hall

Wenzel H (1998): Application dependency of LCA methodology – Key variables and their mode of influencing the method. Int J LCA 3, 281–288

Würdinger E, Roth U, Wegener A, Peche R (2003): Kunststoffe aus nachwachsenden Rohstoffen: Vergleichende Ökobilanz für Loose-fill-Packmittel aus Stärke bzw. aus Polystyrol. Final report. BIfA, IFEU, Flo-Pak (eds), Projektförderung: Deutsche Bundesstiftung Umwelt, Augsburg, März 2003 (in German)

Received: September 22nd, 2005
Accepted: August 11th, 2006
OnlineFirst: August 12th, 2006

Environmental Assessment of Ronozyme® P5000 CT Phytase as an Alternative to Inorganic Phosphate Supplementation to Pig Feed Used in Intensive Pig Production

Per H. Nielsen[1]* and Henrik Wenzel[2]

[1] Novozymes A/S, Krogshøjvej 36, 2880 Bagsværd, Denmark
[2] Department of Manufacturing Engineering and Management, Technical University of Denmark, 2800 Lyngby, Denmark

* **Corresponding author** (phgn@novozymes.com)

DOI: http://dx.doi.org/10.1065/lca2006.08.265.2

Abstract

Goal, Scope and Background. Ronozyme® P5000 CT is an industrially produced enzyme product (phytase) which is able to degrade naturally occurring phytate in animal feed and release the phytate's content of phosphorus for pig's growth. Ronozyme P5000 CT (hereafter called Ronozyme Phytase) can be used as an alternative to inorganic phosphorus supplementation to feed and the study addresses the environmental implications of substituting inorganic phosphorus with Ronozyme Phytase in intensive pig production in Denmark.

Methods. Life cycle assessment is used as an analytical tool, and modelling of the two considered systems is facilitated in SimaPro 6.0 software. The study addresses changes induced by switching from the one alternative to the other, and all significant processes influenced by the change are included in the study.

Results and Conclusions. Application of Ronozyme Phytase in intensive pig production is justified by major advantages in terms of avoided contributions to global warming, acidification, photochemical ozone formation and particularly nutrient enrichment and by significant energy savings and particularly phosphate savings. A single trade-off in terms of agricultural land use for enzyme production is small and unimportant unless use of agricultural land is given very large relative weight.

Recommendations and Perspectives. Hundreds of enzyme products are commercially available on the market today, each with a range of different applications. There are several indications that enzymes like Ronozyme Phytase can play an important role in a transition to a more sustainable society, and more focus should be addressed to the evolving enzyme technology in environmental research.

Keywords: Environmental assessment; enzyme technology; eutrophication; monocalcium phosphate; nutrient enrichment; phosphorus; phytase; pig production; white biotechnology