

16. Enzymatic commercial sources

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16.1. Introduction

Biocatalysts are nowadays essential tools in the preparation of valuable compounds, particularly in the synthesis of pharmaceutical and fine chemical targets [1-3]. As highly selective catalysts, they offer a direct and simple way to synthesize complex achiral and chiral compounds. These biological catalysts also offer a high efficiency and are able to perform their activity under mild and environmentally friendly conditions. Depending on the reaction they catalyze, biocatalysts can be divided in seven main groups: oxidoreductases, transferases, hydrolases, lyases, isomerases, ligases and translocases, being the first three groups the most employed with synthetic purposes. Biocatalysts can be employed in different industrial sectors (see Chapter 15), being the most demanding food & beverages, cleaning reagents, biofuel production, agriculture and (bio)pharmaceuticals.

Enzymes can be extracted from any living organism. Most of the biocatalysts with industrial and laboratory applications are obtained from microorganisms, from eukaryotic systems as yeasts and fungi to prokaryotic bacteria from both the gram-positive and gram-negative families. Opposite, a small percentage of them can be obtained from plants and animals. In general, the microbial enzymes are preferred to plant and animal biocatalysts due to some advantages:

- Microbial enzymes are cheaper to obtain.
- Enzyme contents in microorganisms are more predictable and controllable.
- Plant and animal tissues can contain more potentially harmful materials than microbes.

There are several companies focused to the biocatalysts preparation, presenting different sizes. Some of them are only focused in the synthesis of enzymes, whereas others developed this activity as a part of their global business. Most of these companies produce enzyme formulations for large scale applications, including food and beverage production, household care and bioenergy or feed, but in the last few years there is an increasing production of biocatalysts for the pharmaceutical industry and biotechnology [4]. By this reason, carbohydrases, proteases, and lipases are the types of enzymes most widely employed on large scale applications.

In this chapter, we are going to describe some of the most important companies focusing mainly on the production of biocatalysts with applications in organic synthesis. These companies have been divided depending on the location of their headquarters between

Europe, North America and Asia. Apart from their portfolio of biocatalytic preparations, many of these companies are able to offer other types of services, which include:

- Screening of novel biocatalysts as well as improved variations of them.
- Production of the biocatalysts at high scale (fermentation procedures).
- Purification of the biocatalysts and preparation of enzymatic formulations ready to be employed.
- Development of novel chemoenzymatic procedures for the synthesis of highly valuable compounds.

Finally, it has to be taken into consideration that the biocatalysts suppliers market is very dynamic. Thus, the information showed herein is updated to July 2020.

16.2. European companies

16.2.1. AB Enzymes

German company located at Darmstadt which supplies enzymes for industrial applications, covering a huge range of sectors including baking, pulp and paper, grain and oilseed processing, detergents, protein modification, textiles and animal feed [5].

16.2.2. Almac

This company, located in Northern Ireland, was founded in 1968. Its initial activity was devoted to provide clinical services to the pharmaceutical industry. After some time of activity, the company expanded including a biocatalysis section which offers services to different clients worldwide [6].

Almac also offers services in process development for scaling-up reactions, employing as biocatalysts hydrolases, alcohol dehydrogenases (ADHs), ω -transaminases (ATAs), Baeyer-Villiger monooxygenases (BVMOs), nitrilases, cytochrome P450 and cyanide dihydratases. These biocatalysts can be acquired individually, but biocatalysts' libraries are also supplied in the selectAZymes™ kits, in which a number of enzymes with the same activity can be purchased.

Almac can offer to its customers the specific enzymes in different preparations including concentrated biomass (cell paste), cell free extracts or lyophilised enzyme powders. The company provides services as fermentation development and scaling-up from 1 liter to 63 m³ to deliver the desired biocatalysts. Enzymes can also be acquired as immobilized preparations, as this company presents a high expertise in immobilisation techniques for both whole cells and isolated enzymes.

16.2.3. Biocatalysts

This company was first registered in 1983, Cardiff (Great Britain), Biocatalysts develop and manufacture speciality enzymes from small to large scale quantities for a variety of industries [7]. The most important application of these biocatalysts are the food, flavour & fragrance and life sciences sectors, being also employed in pharma and fine chemicals. Some examples of the products offer by this supplier with applications in food sciences are shown in Table 16.1.

Table 16.1. Enzymes supplied by Biocatalysts with applications in food science [7].

Enzyme	Activity
Promod™ 950L	Protease preparation
Promod™ 192P	Microbial acid protease
Flavopro™ 954MDP	Microbial deaminase
Glucose oxidase 789L	Oxidase
Cellulase 13L/MDP	Degradation of cellulose
Beta Glucosidase 16L	Exo-carbohydrase
Amylase AD11MDP	Starch digestion

16.2.4. c-Lecta GmbH

This German biotechnological supplier, with headquarters in Leipzig, is a relatively young company. c-Lecta offers different types of biocatalysts including NuCLEANase, a cost-effective tech-grade endonuclease for industrial applications, able to catalyse the removal of nucleic acids from biotechnological products [8]. This company also commercialized ENARASE®, a genetically engineered endonuclease from *Serratia marcescens* expressed in *Bacillus* sp., which catalyse the cleavage of all forms of DNA and RNA very efficiently.

Lipase B from *Candida antarctica* (CAL-B) is one of the most employed biocatalysts for industrial applications, due to its usually high chemo-, regio- and/or selectivity, combined with its high stability, as this enzyme is able to work in a wide set of different non-conventional media [9]. CAL-B is commercialized under different preparations, being supplied by c-Lecta as CalB Immo Plus, a CAL-B immobilized onto a Purolite Corporation polymeric support.

Finally, c-Lecta supplies Customized Enzyme c-Lections, pools of industrially relevant and so far unavailable enzymes that are individually assorted upon request according to the custom specific needs. Different types of biocatalysts, including alcohol dehydrogenases, ω -transaminases, nitrilases and esterases, lipases and cytochrome P450s, are available in these screening kits at the quantities desired by the customers.

16.2.5. Enzymicals

Enzymicals is a German company (Greifswald), created in 2009, which offers a set of recombinant enzymes suitable for research and development [10]. This company also supplies chemicals as well as their expertise in process development, optimization and piloting of novel chemoenzymatic reactions for the production of fine chemicals. Enzymicals present a portfolio of several biocatalysts of different activity, including ω -transaminases, Baeyer-Villiger monooxygenases, imine reductases, halohydrin dehalogenases, phosphotransferases, aminoacylases, carboxyl esterases and lipases, as shown in Table 16.2. Apart from the individual enzymes, some types of biocatalysts can be acquired as enzyme kits on demand by the customers.

Table 16.2. Some selected examples of the biocatalysts supplied by Enzymicals [10].

Enzyme	Activity	Quantity
ATA-01 <i>Aspergillus fumigatus</i>	ω -Transaminase	On demand
ATA04 <i>Aspergillus oryzae</i>	ω -Transaminase	On demand
ATA07 <i>Mycobacterium vanbaalenii</i>	ω -Transaminase	On demand
BVMO 01 <i>Acinetobacter calcoaceticus</i>	Baeyer-Villiger monooxygenase	50 mg (0.5 mL) or 500 mg (500 mL)
BVMO 02 <i>Thermobifida fusca</i>	Baeyer-Villiger monooxygenase	0.5 mL or 5.0 mL
BVMO 04 <i>Pseudomonas putida</i>	Baeyer-Villiger monooxygenase	0.5 mL or 5.0 mL
IREDO1 <i>Streptomyces</i> sp. GF3587	Imine reductase	On demand
IREDO4 <i>Paenibacillus elgii</i> B69	Imine reductase	On demand
HHDH01 <i>Tistrella mobilis</i>	Halohydrin dehalogenase	50 mg or 500 mg
HHDH03 <i>Methylibium petroleiphilum</i>	Halohydrin dehalogenase	50 mg or 500 mg
PTF01 <i>Limulus polyphemus</i>	Phosphotransferase	50 mg or 500 mg
PTF02 <i>Brucella abortus</i>	Phosphotransferase	50 mg or 500 mg
PLE isozymes 1 to 6 from pig liver	Esterase	50 mg or 500 mg
Esterase 01 <i>Bacillus subtilis</i>	Esterase	50 mg or 500 mg
Esterase 04 <i>Pseudomonas fluorescens</i>	Esterase	50 mg or 500 mg
LIP01 <i>Candida antarctica</i>	Lipase	0.5 mL or 5.0 mL
LIP02 <i>Fusarium solai pisi</i>	Lipase	0.5 mL or 5.0 mL
LIP03 <i>Geobacillus thermoleovorans</i> IHI-91	Lipase	0.5 mL or 5.0 mL

16.2.6. Evoxx Technologies GmbH

Evoxx Technologies GmbH is a company located at Monheim am Rhein (Germany), being the European Headquarter of the global enzyme manufacturer AETL group, which supplies different types of biocatalysts and probiotics [11]. Evoxx Tehcnologies presents a broad range of enzymes employed in food applications, as in fruit and vegetables processing, baking, brewing and malting, starch and grain processing, oil and fats treatments and dairy and cheese processing. But apart from this line of business, this company also supplies several biocatalysts to be employed in chemical synthesis and in pharmaceutical technology, focusing mainly in three types of enzymes: ω -transaminases, alcohol dehydrogenases and lipases. Regarding the first enzymes, Evoxx supplies two screening kits, one with nine lyophilized (*R*)-transaminases from different microorganisms, and one with 10 lyophilized (*S*)-selective transaminases. It is also possible to acquire the comprehensive screening kit including the 19 enzymes. Table 16.3 shows some of the alcohol dehydrogenases and lipases that can be purchased on demand, takin into account that ADHs can be also supplied as screening kit, whereas the lipases can be obtained as different preparations, including immobilized forms, powders or liquid preparations.

Table 16.3. ADHs and lipases supplied by Evoxx Technologies [11].

Enzyme	Activity
ADH 030, lyophilized powder, NAD-dependent enzyme	(S)-Alcohol dehydrogenase
ADH 040, lyophilized powder, NAD-dependent enzyme	(S)-Alcohol dehydrogenase
ADH 200, lyophilized powder, NAD-dependent enzyme	(R)-Alcohol dehydrogenase
ADH 270, lyophilized powder, NADP-dependent enzyme	(R)-Alcohol dehydrogenase
ADH 440, lyophilized powder, NADP-dependent enzyme	(S)-Alcohol dehydrogenase
Addzyme CalB 165G, immobilized <i>Candida antarctica</i> B	Lipase
Addzyme TL 165G, immobilized <i>Thermomyces lanuginosus</i>	Lipase
Addzyme RD 165G, immobilized <i>Rhizopus delemar</i>	Lipase
Addzyme CalB 5L, <i>Candida antarctica</i> B liquid preparation	Lipase
Addzyme TL 100P, <i>Thermomyces lanuginosus</i> powder	Lipase
Addzyme RD 50P, <i>Rhizopus delemar</i> powder	Lipase

16.2.7. GECCO

The Groningen Enzyme and Coenzymes Company is a dynamic Dutch spin-off company born from the University of Groningen [12]. GECCO was created in 2018, and presents a wide selection of valuable enzymes to be employed with synthetic purposes. The main portfolio consists in redox enzymes, including alcohol dehydrogenases (ADHs) and oxidative biocatalysts as copper-dependent oxidases (laccases), flavin-containing monooxygenases (FMOs), Baeyer-Villiger monooxygenases (BVMOs), and dye-decolorizing peroxidases (DyP), as indicated in Table 16.4. GECCO also provides other types of enzymes as dehalogenases or epoxide hydrolases (EHs). Finally, this company offers various cofactors and cofactor analogues, as deazaflavin cofactors F0 and F420.

Table 16.4. Some of the enzymes commercialized by GECCO [11].

Enzyme	Activity
ADH A <i>Pyrococcus furiosus</i>	Alcohol dehydrogenase
RjADH <i>Rhodococcus jostii</i>	Alcohol dehydrogenase
LbADH <i>Lactobacillus brevis</i>	Alcohol dehydrogenase
<i>Bacillus licheniformis</i> ATCC 9945a	Laccase
Human FMO5	Flavin-containing monooxygenase
MeFMO <i>Methylophaga aminisulfidivorans</i>	Flavin-containing monooxygenase
FMOs <i>Rhodococcus josti</i> RHA1 (8 enzymes)	Flavin-containing monooxygenases
STMO <i>Rhodococcus rhodochrous</i>	Baeyer-Villiger monooxygenase
PAMO <i>Thermobifida fusca</i>	Baeyer-Villiger monooxygenase
CPMO <i>Comamonas</i> sp. NCIMB 9871	Baeyer-Villiger monooxygenase
TmCHMO <i>Thermocrispum municipale</i>	Baeyer-Villiger monooxygenase
TfuDyP <i>Thermobifida fusca</i>	Dye-decolorizing peroxidase
PfDyP <i>Pseudomonas fluorescens</i>	Dye-decolorizing peroxidase

16.2.8. Inofea AG

This Swiss company founded in 2014 is an enzyme producer for different applications including biocatalysis, bioconjugation processes in order to obtain antibody-drug conjugates and bioanalysis [13]. Inofea offers the Enzzen[®] Technology, a system capable of immobilizing almost all type of biocatalysts or enzyme cocktails onto safe silica particles. This immobilization procedure is able to protect the biocatalyst(s) by growing a structured shield on the outer surface of the particle, improving the properties and the reusability of the enzymatic systems.

16.2.9. Johnson-Matthey

This British company with headquarters at London is a multinational speciality chemicals and sustainable technologies supplier [14]. Its biocatalytic section offers different enzymatic products to be employed in organic synthesis (Table 16.5).

Johnson-Matthey supplies a wide set of alcohol dehydrogenases, as well as other dehydrogenases as alanine dehydrogenase, able to catalyse the conversion of pyruvate to L-alanine, amine dehydrogenases for the synthesis of primary amines and lactate dehydrogenases which catalyse the reduction of pyruvate to lactate. This company also offers a set of ene-reductases with different activity for the reduction of double bonds, as well as (*R*)- and (*S*)-selective ω -transaminases for the synthesis of aromatic and aliphatic primary amines. These biocatalysts can be supplied individually or as biocatalysts kits. Thus, a C=C bond reduction kit, containing seven ene-reductases and a ketoreductase kit consisting in 17 different alcohol dehydrogenases, are available. Finally, the company offers a chiral amine kit, containing different enzymes able to catalysed the synthesis primary, secondary and tertiary amines.

Table 16.5. Enzymes supplied by Johnson-Matthey [14].

Enzymes	Activity
ADH-105, ADH-110, ADH-150, ADH-153, ADH-159, ADH-160, ADH-171, ADH-19, ADH-20, ADH-220, ADH-230, ADH-244, ADH-27, ADH-61, ADH-62	Alcohol dehydrogenases
AlaDH-6,	Alanine dehydrogenase
AmDH-1, AmDH-2, AmDH-3, AmDH-4, Am-DH-8	Amine dehydrogenases
LDH-4, LDH-12	Lactate dehydrogenases
ENE-101, ENE-102, ENE-103, ENE-105, ENE-107, ENE-108, ENE-109	Ene-reductases
RTA-102, RTA-103, RTA-104, RTA-105, RTA-25, RTA-40, RTA-45, RTA-57, RTA-58, STA-1, STA-113, STA-118, STA-120, STA-121, STA-13, STA-14, STA-2	ω -Transaminases

16.2.10. Metgen Oy

Metgen Oy is a Finnish company with headquarters in Kaarina founded in 2008, which performs its activity in the development and production of industrial enzymes [15]. MetGen offers a range of biocatalysts to solve critical industrial issues that address needs in the markets of pulp and paper, biofuels and wastewater treatment. Thus, since its origin,

this company has been mainly focused on the development of enzymes useful for biomass treatment in pulp & paper industry. Some of the products that Metgen commercializes are summarized in Table 16.6.

Table 16.6. Examples of the enzymatic products supplied by Metgen Oy in the fields of paper and pulps and wastewater treatments [15].

Products	Application
MetZyme® Brila™ Enzyme product family	Recycle fiber applications
MetZyme® Ligno™ Enzyme product family	Mechanical pulping processes
MetZyme® Povon™ Enzyme product family	Chemical pulp bleaching and extracts control
MetZyme® Forico™ Enzyme product family	Industrial water treatment and effluent control
MetZyme® Sekalo™ (α -amylase)	Starch conversion solutions
MetZyme® Plata™ Enzyme product family	Recycled fiber deinking and wood pitch removal
MetZyme® Suno™ Enzyme product family	Lignocellulosic chemicals production

16.2.11. Novozymes

This Danish biotechnological company, with headquarters close to Copenhagen, has been expanded to the rest of Europe, Asia and America, representing nowadays one of the most important enzyme suppliers worldwide [16]. Novozymes offers biocatalysts for several applications, including pharma, organic synthesis, food processing, laundry, flavours and fragrance, etc.

Regarding their use in organic synthesis and pharma, most of the enzymes commercialized by this company are lipases and other type of hydrolases, being widely employed in several hydrolytic and synthetic procedures. Table 16.7 shows some examples of the enzymes from Novozymes with synthetically valuable purposes, including Novozym® 435, an immobilized *Candida antarctica* B preparation that has been extensively employed in organic synthesis.

Table 16.7. Some hydrolytic enzymes commercialized by Novozymes [16].

Enzyme	Activity	Specific activity
Novozym® 435, immobilized	Non-specific lipase	10,000 PLU/g
Lypozime® CalB L, liquid	Non-specific lipase	5 KLU/g
Resinase® HT from <i>Aspergillus oryzae</i> , liquid	Lipase	50 KLU/g
Alcalase® 2.4LFG from <i>Bacillus licheniformis</i> , liquid	Endo-peptidase	2.4 AU/g
Esperase® 8.0L from <i>Bacillus licheniformis</i> , liquid	Endo-peptidase	8 KNPU/g
rTrypsin® 8.0L from <i>Fusarium venenatum</i> , granulate	Serinprotease	800 USP/mg

16.2.12. Prozomix

This British biotechnological company is located at Haltwhistle [17]. Since its creation, Prozomix develops, produces and supplies a huge range of biocatalysts with several applications in organic chemistry. Thus, this company offers hydrolases, alcohol dehydrogenases, aldolases, alkyl transferases, Baeyer-Villiger monooxygenases, decarboxylases, enoate-reductases, epoxide hydrolases, glycosyl transferases, halogenases, halohydrin dehalogenases, imine reductases, nitroreductases, nitrile hydratases, cytochrome P450s, ammonia lyases, monoamine oxidases and transaminases, being shown some examples at Table 16.8. Most of the enzymes can be purchased in Screening Kits, whereas other enzymes can be obtained individually. Prozomix also supplies different cofactors required for the activity of certain enzymes, as well as enzymes for the regeneration of these cofactors, as for instance formate- or glucose-dehydrogenases and NADPH-oxidases. Finally, this company has an extensive portfolio of enzymes with industrial application in different sectors, including amylases, catalases, pectinases and different proteases.

Table 16.8. Some of the biocatalysts supplied by Prozomix [17].

Biocatalysts	Quantity
PRO-AKR(001-203) Aldo-ketoreductases from different sources	50 mg-Bulk enquires
PRO-450(001-010) Cytochrome P450s from different sources	100 mg crude
PRO-ERED(001-0040) Enoate reductases from different sources	50 mg-Bulk enquires
Nitroreductase <i>Escherichia coli</i> K12	1-1,000 mg
PRO-E0260 Nitrilase from <i>Bradyrhizobium japonicum</i>	1-1,000 mg
PRO-NITR(001-018) Nitrilases from different sources	50 mg-Bulk enquires
PRO-AldP, Aldolases Screening Kit	100-200 mg
PRO-CoE-BVMOs Screening Kit	1 mg or 1-10 g
PRO-DACARBP, Decarboxylases Screening Kit	100-200 mg
PRO-GHP(MTP), Glycosyl hydrolases Screening Kit	1 mg
PRO-CoE-IREDs, Imine reductases Screening Kit	1 mg or 1-10 g
PRO-NHASEP, Nitrile hydratases Screening Kit	2 mL
PRO-CoE-AMLp, Ammonia lyases Screening Kit	1 mg or 1-10 g
PRO-CoE-RAMO, Monoamine oxidases Screening Kit	10 mg or 2-20 g

16.2.13. Royal DSM

This Dutch multinational is involved in the manufacturing and supplying of food and dietary supplements, personal care products, bio-based materials, as well as yeast and enzymes [18]. DSM is one of the major suppliers of enzymes and yeasts in the world, producing enzymes with different applications in foods and beverages production, from boosting baking and brewing, to empowering egg and fruit processors, to optimizing dairy, oils and fats.

16.3. American companies

16.3.1. Codexis Inc.

Codexis, Inc. is a leading protein engineering company applying technologies to use enzymes at laboratory and industrial scale [19]. Their headquarters are located in Redwood City (USA), and since 2002, they are focused on the development of new proteins through molecular biology tools and also to their production, in order to find applications in the pharmaceuticals and fine chemicals, biotherapeutics, food & beverage, and agriculture fields.

Guided by proprietary software and bioinformatic systems, Codexis powers existing knowledge and expertise to improve protein stability, activity, specificity and other properties to enhance clinical function or process performance. With this approach to protein engineering starts with an understanding of the desired performance specifications and optimizes a protein specifically to fit the desired requirements.

Enzymes can be produced from grams to kilos to tons, developing optimized proteins for specific applications in weeks and can scale up to full commercial production in short periods as three months. Codexis can provide screening kits (Table 16.9) to rapidly determine the feasibility of using the engineered enzymes. Each kit contains a selected set of enzymes that have been engineered for enhanced activity, selectivity, substrate range, solvent and temperature stability. Conveniently packaged in individual vials and with enough enzyme for several screens and hit verification, kits include protocols and co-reagents for use. Follow-on quantities of all kit enzymes are stocked in 50–100 g quantities to enable rapid delivery.

Table 16.9. Screening kits provided by Codexis Inc. [19]

Screening kits	Quantity
Codex® Ketoreductase (KRED) Screening Kit	24 enzymes x 250 mg
Codex® Amine Transaminase (ATA) Screening Kit	24 enzymes x 250 mg
Codex® Nitrilase (NIT) Screening Kit	12 enzymes x 250 mg
Codex® Ene Reductase (ERED) Screening Kit	7 enzymes x 250 mg
Codex® Standard MicroCyp® Screening Kit	23 enzymes (1 screen per kit)

Furthermore, other available enzyme kits are: Baeyer-Villiger monooxygenases, imine reductases, monoamine oxidases, halohydrin dehalogenases, and acylases.

16.3.2. Dupont Nutrition & Biosciences

This transnational company is a world leader of innovative and sustainable solutions across food, health, pharma and biotech industries [20]. Among the different products that are provided by this company, antimicrobials, antioxidants, dairy cultures, emulsifiers, probiotics, and food enzymes. DuPont™ Danisco® food enzymes can help to improve food freshness, optimize production, add texture, ensure consistent quality, and therefore reduce costs.

Among the different enzymes that are available from this company, lipases to modify the flavour of cheeses, lactases for reducing the lactose content in milk, chymosin and/or pepsin coagulants for traditional cheese making, alkaline proteases for enhancing the quality of fish-processing by-products, or α -amylases, β -glucanases and xylanases for brewing applications, can be mentioned.

16.3.3. IBEX Technologies

This company is based in Montreal (Canada) manufactures and markets reagents for biomedical use through its wholly owned subsidiary IBEX Pharmaceuticals Inc. The company product lines comprise high purity enzymes for in-vitro diagnostics and research, as well ELISA kits for osteoarthritis research. IBEX also provides custom production services for *in vitro* diagnostic market, including custom fermentation as well as filling and lyophilization for disposable diagnostic components.

Among the different enzymes they trade, several heparinases, chondroitinases, collagen antibodies, and a diamine oxidase can be mentioned. They can be acquired from few enzymatic units to bulk quantities [21].

16.3.4. MP Biomedical

MP Biomedicals is a worldwide corporation developing, manufacturing and distributing products for the life science, *in vitro* diagnostics (IVD), fine chemicals and dosimetry markets from small scale research to large scale manufacturing. They are located in Irvine (USA), having more than 50 years of experience in research products, also introducing innovative new products of high quality [22]. Apart from many diagnostics reagents, they can also provide with many different fine chemicals for organic synthesis. Among these, several cofactors and enzymes (Table 16.10) can be found in their catalogue.

Table 16.10. Selection of biocatalysts supplied by MP Biomedical [22].

Enzyme	Activity	Quantity
Lyticase from <i>Arthrobacter luteus</i>	Protease	Up to 50 kU
Trypsin	Peptidase	Up to 500 mg
Leucine aminopeptidase from porcine kidney	Peptidase	Up to 100 U
Lipase from porcine pancreas	Lipase	Up to 500 g
Lipase from <i>Candida rugosa</i>	Lipase	100 g
Cholesterol esterase from <i>Pseudomonas</i> sp.	Esterase	Up to 200 kU
Amylase from <i>Aspergillus oryzae</i>	Amylase	Up to 5 MU
β -Glucuronidase from <i>Helix pomatia</i>	Glycosidase	Up to 50 mL
β -Galactosidase from <i>Escherichia coli</i>	Glycosidase	Up to 3 kU
Alcohol oxidase from <i>Pichia pastoris</i>	Oxidase	Up to 5 kU
Horseradish peroxidase	Peroxidase	Up to 25 kU
Glucose oxidase from <i>Aspergillus niger</i>	Oxidase	Up to 500 kU
Alcohol dehydrogenase from yeast	Dehydrogenase	Up to 150 kU
Glucose-6-P dehydrogenase from <i>Leuconostoc mesenteroides</i>	Dehydrogenase	Up to 1 kU
Lactate dehydrogenase from bovine heart	Dehydrogenase	10 kU

16.3.5. Sigma-Aldrich

This transnational chemical company was created in 1975 and is headquartered in St. Louis (USA). In 2014 was acquired by Merck KGaA and it is located all over the world. In the last decades this chemical company has significantly expanded their business lines, serving customers focused on identifying and developing medicines, delivering end-to-end products and expertise to customers who take what is developed in labs and manufacture it, and applying analytical tools to ensure that drugs, food and beverages are safe for consumption.

Among the many different chemical products they can provide, an important number of reagents, catalysts, inhibitors and cofactors related to enzyme catalysis can be mentioned. For instance, a summary of the different biocatalysts that are accessible through its webpage [23] is displayed in Table 16.11.

Table 16.11. Selection of biocatalysts provided by Sigma-Aldrich divided by enzyme class [23].

Enzyme class	Total number
Oxidoreductases (EC 1.x.x.x): alcohol dehydrogenases, alcohol oxidases, amino acid oxidases, monoamine oxidases, cytochrome P450s, laccases, catalases, peroxidases, dioxygenases, monooxygenases, superoxide dismutases	177
Transferases (EC 2.x.x.x): transaldolase, acyltransferases, phosphorylases, transaminases, kinases,	79
Hydrolases (EC 3.x.x.x): esterases, lipases, (deoxy)ribonucleases, phosphatases, sulfatases, glycosidases, epoxide hydrolase, peptidases, proteases, acylases, amidases, β -lactamases, deaminases	542
Lyases (EC 4.x.x.x): decarboxylases, cyanohydrin lyases, aldolases, carbonic anhydrases, phenylalanine ammonia lyase, phospholipases	46
Isomerases (EC 5.x.x.x): sugar-converting isomerases, topoisomerases	18
Ligases (EC 6.x.x.x): synthetases, carboxylases	8

16.3.6. Strem Chemicals, Inc.

This chemical company was established in 1964, located in Newburyport (USA), manufactures and markets specialty chemicals of high purity. Its clients include academic, industrial and government research and development laboratories as well as commercial scale businesses in the pharmaceutical, microelectronic and chemical or petrochemical industries. Strem also provides custom synthesis (including high pressure synthesis) and cGMP manufacturing services.

Strem offers over 5,000 specialty products in the area of metals, inorganics, organometallics and nanomaterials. Its first commercial product was cobalt carbonyl, manufactured in Strem's high pressure autoclaves. The first catalog also contained (pre)catalysts and phosphorus ligands, which continue to be important classes of products offered by Strem.

More recently, they are focused on the commercialization of biocatalysts, mainly on lipases. In its catalog different immobilization forms from *Candida antarctica* lipase B (CAL-B) and also a number of immobilized proteases are accessible. Also, various

enzyme kits including different lipases, immobilized forms of CAL-B and proteases can be found through its webpage [24].

16.3.8. Worthington Biochemical Corp.

This biotech company was founded in 1947, it is located in New Jersey (USA), and manufactures enzymes as the main products [25]. Worthington does not actually make enzymes: they extract them from various animal and plant tissues and various microbial sources such as bacteria, fungi, and molds. A starting material for a particular enzyme is selected according to the prevalence of that enzyme in the material.

Some of the animal tissues used at Worthington include beef pancreas, hog kidney, cow eyes, horse liver, rabbit muscle, beef liver, pig heart, horse blood, and calf intestine. Various proteins are also extracted from horseradish roots, sweet potatoes, almonds, and pokeweed. Some products are isolated from the bacteria *E. coli*, different species of *Clostridia*, and various other bacteria. Yeast, mushrooms, whole milk, and eggs are also used for this purpose. All enzymatic products are materials extracted from living cells. Table 16.12 show a selection of enzymes that are accessible at this company.

Table 16.12. Selection of biocatalysts that are provided by Worthington Biochemical Corp. [24]

Enzyme	Activity
Alcohol dehydrogenase from yeast	>300 U/mg
Lactate dehydrogenase from rabbit muscle	>250 U/mg
Glucose-6-phosphate dehydrogenase from <i>Leuconostoc mesenteroides</i>	>600 U/mg
Galactose oxidase from <i>Dactylium dendroides</i>	>30 U/mg
Catalase from bovine liver	>40,000 U/mg
Peroxidase from horseradish	>500 U/mg
L-Amino acid oxidase from <i>Crotalus adamanteus</i> venom	>4 U/mg
Hexokinase from yeast	>150 U/mg
Cholesterol esterase from porcine pancreas	>300 U/g
Deoxyribonuclease I from bovine pancreas	>2,000 U/mg
Alkaline phosphatase from calf intestine	>3,000 U/mg
β -Galactosidase from <i>Escherichia coli</i>	>300 U/mg
Cellulase from <i>Trichoderma reesei</i>	>45 U/mg
α -Chimotrypsin from bovine pancreas	>45 U/mg
Trypsin from bovine pancreas	>180 U/mg
Pepsin A from porcine stomach	>2,500 U/mg
Collagenase from <i>Clostridium histolyticum</i>	>500 U/mg
Adenosine deaminase from calf spleen	>15 U/mg
Tyrosine decarboxylase from <i>Streptococcus faecalis</i>	>0.2 U/mg
Aldolase from rabbit muscle	>10 U/mg

16.4. Asian enzyme suppliers

16.4.1. Advanced Enzymes Technologies, Ltd.

Indian company located at Louiswadi Thane is a research driven company manufacturing enzymes and probiotics, marketing of more than 400 proprietary products developed from over 65 indigenous enzymes and probiotics [26]. They commercialize different biocatalysts for human nutrition (e.g. peptidases, lipases, and proteases), and food processing (e.g. pectinases, amylases, and esterases), among others.

16.4.2. Amano Enzyme Co., Ltd.

This company was created in 1899 in Japan as a pharmaceutical business. In 1948, this business expanded to use the process of koji fermentation (traditionally used to create soy sauce, miso, and sake) to produce specialty enzymes, beginning with Malt Diastase. This company, with headquarters in Nagoya (Japan), is also located in Elgin (USA), and supplies high-quality, microbial enzymes for the food, dietary supplement, industrial, diagnostic, and regenerative medical industries [27]. They feature multi-ton manufacturing capabilities, SQF Level 2 certification, and technical expertise to provide service along with guaranteed quality products. Some of the products that Amano commercializes are summarized in Table 16.13.

Table 16.13. Examples of the enzymes supplied by Amano and their possible applications [27].

Enzymes	Application
KLEISTASE E5NC, KLEISTASE SD80, KLEISTASE T10S, KLEISTASE PLF3	Starch processing
Protease A “Amano” 2 SD, Protease M “Amano” SD, Protease P “Amano” 6 SD, ProteAX, Peptidase R, THERMOASE PC10F, THERMOASE GL30, PROTIN SD-AY10, PROTIN SD-NY10	Flavour enhancement
Lipase A “Amano” 12, Lipase AY “Amano” 30SD, Lipase G “Amano” 50, Lipase R “Amano”, Lipase MH “Amano” 10SD, Lipase DF “Amano” 15, Lipase MER “Amano”	Oils and fats refining
Glucose dehydrogenase “Amano” 8 [GDH-8], Glucose dehydrogenase “Amano” 2A [GDH-2A], Glucose dehydrogenase “Amano” NA [GDH-NA], Glucose oxidase “Amano” AM [GO-AM], Glucose oxidase “Amano” NA [GO-NA], Glucose oxidase “Amano” M [GO-M], Glucose oxidase “Amano”2 [GO-2]	Glucose sensor
Cholesterol dehydrogenase “Amano” 6 [CHDH-6], Cholesterol oxidase “Amano”6E [CHO-6E], Cholesterol oxidase “Amano” 7 [CHO-7], Cholesterol esterase “Amano”2A [CHE-2A], EST “Amano” 2 [EST-2]	Cholesterol determination
Lipase PS “Amano” SD, Lipase PS “Amano” IM, Lipase AK “Amano”, Lipase AH “Amano” SD, Lipase AYS “Amano”, Lipase AS “Amano”, Acylase H “Amano”, D-aminoacylase “Amano”	Chiral resolution / Synthesis

16.4.3. Aumgene Biosciences

This biotech company is based in Surat, India. Founded in 2004, the company undertakes development, manufacturing and marketing of enzymes, probiotics and agribiotech products [28]. The company has state of the art research and development facilities for high throughput screening of microbial strains, fermentation process development, and purification of enzymes and biologics. Among the different enzymes they commercialize, laccases, cellulases and amylases for large-scale production can be mentioned.

16.4.4. EnzymeWorks

EnzymeWorks is a company supplier of enzymes, cofactors and biochemicals in addition to provide contract manufacturing (CMO) services. The company is located in Jiangsu (China). EnzymeWorks develop bio-based green processes for chemical manufacturing through retrosynthetic integration of chemical and biological transformation toolboxes [29]. They are focused on biosynthesis, enzyme development, protein engineering, high throughput screening, metabolic engineering and fermentation from the lab to pilot scale, manufacturing enzymes and fermented chemicals from 3,000-L to 10,000-L scale.

They provide different enzyme family kits such: ketoreductases, transaminases, cytochrome P450s, hydrolases, nitrilases, ene-reductases, monoamine oxidases, nitrile hydratases, epoxide hydrolases, imine reductases, glycosyltransferases, Baeyer-Villiger monooxygenases, aldolases, nitroreductases, decarboxylases, and dehydrogenases.

16.4.5. Meito Sangyo Co., Ltd.

This biotech company is located in Nagoya (Japan). They produce different sweets and beverages. By using of fermentation technology from microorganisms, Meito Sangyo Co., Ltd. Fine chemicals Division produces unique products, such as polysaccharide and enzymes. The different biocatalysts they offer are described in Table 16.14, all of them with application at the food industry [30].

Table 16.14. Hydrolytic enzymes commercialized by Meito Sangyo Co., Ltd. [30]

Enzyme	Purpose	Specific activity
Lipase MY from <i>Candida cylindracea</i>	Flavour development	30,000 U/g
Lipase OF from <i>Candida cylindracea</i>	Flavour development Hydrolysis of oils and fats	360,000 U/g
Lipase PL from <i>Alcaligenes</i> sp.	Modification of oil and fats	ca. 100,000 U/g
Lipase QLM from <i>Alcaligenes</i> sp.	Modification of oil and fats	ca. 60,000 U/g
Lipase SL from <i>Burkholderia cepacia</i>	Hydrolysis of oils and fats	ca. 45,000 U/g
Lipase TL from <i>Pseudomonas stutzeri</i>	Hydrolysis of oils and fats	ca. 50,000 U/g
Phospholipase D from <i>Actinomadura</i> sp.	Modification of phospholipids	1,500 U/g

16.4.6. Oriental Yeast Co., Ltd.

Oriental Yeast is a manufacturer with headquarters in Tokyo (Japan), with a long-established history of technological innovations originally derived from baker's yeast production. In its food business, the company develops a variety of food ingredients in

addition to yeast while focusing on yeast-related biotechnology applications. Among the different companies that belong to Oriental Yeast, OYC Americas is based in Vista (CA, USA), and its laboratory of yeast and fermentation has over 13,000 strains of yeast as stock cultures, and works to develop applications for high-performing, high-functioning yeasts and fermented products.

Among the different products they commercialize [31], various enzymes (e.g. dehydrogenases, phosphatases, dioxygenases, oxidases, peroxidases, glucosidases), coenzymes, and recombinant enzymes from human source can be mentioned. These enzymes can be acquired at different quantities (from few enzyme units or mg to kU or bulk).

16.4.7. Takabio

Takabio is a global company which supplies a series of enzymes for food industry applications produced by Shin Nihon Chemical in Anjo (Japan). With more than 20 years of expertise in the field of enzymes and biotechnologies behind them, the Takabio teams support food sector manufacturers all over the world by providing enzymes for a wide variety of industrial applications [32]. Some of the different biocatalysts that are commercialized appear in Table 16.15.

Table 16.15. Selected enzymes commercialized by Takabio company [32].

Enzyme	Application
α -Galactosidase from <i>Aspergillus niger</i>	Nutrition (human and animal), dietary supplements
Amylases from <i>Aspergillus niger</i> and <i>Aspergillus oryzae</i>	Liquefaction and saccharification of starch, dietary supplements
Catalase from <i>Aspergillus niger</i>	Multiple food applications
Dipeptidyl-aminopeptidase from <i>Aspergillus niger</i>	Dipeptide production
Glucose oxidase from <i>Penicillium chrysogenum</i>	Multiple food applications
Lipase from <i>Aspergillus niger</i> , <i>Candida rugosa</i> and <i>Rhizomucor miehei</i>	Hydrolysis of oils and fats
Proteases and peptidases from <i>Aspergillus oryzae</i> , <i>Aspergillus niger</i> , <i>Bacillus subtilis</i> and <i>Aspergillus melleus</i>	Dairy industry, dietary supplements

16.4.8. Toyobo Co., Ltd.

This company has been a leading and prominent manufacture of overall textiles in Japan. After diversification, they are expanding their product lines in other fields such films, plastics, electronics-based, biochemical-related, and medical-related business [33]. One of those product line-up is Toyobo Enzymes, which come out of the technologies in fermentation and purification accumulated over the last several decades. The Biochemical Department is located in Osaka (Japan), manufacturing enzymes since two decades (Table 16.16).

Table 16.16. Selected biocatalysts commercialized by Toyobo Co., Ltd. [33]

Enzyme	Microorganism	Specific activity
N-Acetylneuraminic acid aldolase	Microorganism not specified	>15 U/mg
Cholesterol esterase	<i>Pseudomonas</i> sp.	>100 U/mg
Diaphorase	<i>Clostridium</i> sp.	>30 U/mg
β -Galactosidase	<i>Escherichia coli</i>	>500 U/mg
Glucose oxidase	<i>Aspergillus</i> sp.	>180 U/mg
Glucose-6-phosphate dehydrogenase	<i>Leuconostoc</i> sp.	>400 U/mg
Glutamate dehydrogenase	<i>Proteus</i> sp.	>300 U/mg
Glycerol dehydrogenase	<i>Cellulomonas</i> sp.	>50 U/mg
D-3-Hydroxybutyrate dehydrogenase	<i>Pseudomonas</i> sp.	>100 U/mg
Leucine dehydrogenase	<i>Bacillus</i> sp.	>20 U/mg
Peroxidase	Horseradish	>250 U/mg
Purine-nucleoside phosphorylase	Microorganism not specified	>15 U/mg
Pyruvate oxidase	<i>Pseudomonas</i> sp.	>1.5 U/mg

16.5. Outlook

In the last few years, the development of biocatalytic methodologies has experienced a great development. As it has been shown in the present book, biocatalysts offer a set of advantages which makes them really useful in the preparation of highly valuable compounds. Most of the enzymatic preparations are employed in sectors as food and beverages, for cleaning purposes, for biofuel production and in agriculture, and also an important number of processes have been performed applying (tailored) biocatalysts in the (bio)pharmaceutical industrial sector and also applied to organic synthesis in both industry and academia. By this reason, nowadays several chemical and biotechnological companies provide different types of enzymes in their portfolio of products, from SMEs devoted mainly to enzyme's preparation, modification and immobilization, to huge transnational companies in which biocatalysts are part of their business interest.

With this final contribution, authors want to stress the relevance that biocatalysis field is gaining at commercial level, and also to facilitate to researchers interested in developing experiments in this area, some of the most important supplier enzyme companies at different locations. Many of them have recently appeared, emphasizing the larger impact that Biotechnology, and more specifically biocatalysis, is taking place at industrial level and, in a broader sense, in society. With the outstanding developments made in the recent decades in molecular biology, bioinformatics, microbiology, material science and process engineering, more robust, active and selective enzymatic forms (as pure or partially purified enzymes, as whole cell biocatalysts or in immobilized forms), are expected to appear in the next years not only to fulfil the desired requirements to synthesize a target molecule at industrial level, but also in order to find novel reactivities that nowadays seem to be inaccessible [34].

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