

# Denmark's Chemicals Industry: Progress and Challenges

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Denmark's chemicals industry is characterized by a variety of innovative companies, especially in the life sciences. To remain competitive, these companies must continue to invest in innovation, and the country's universities must fill a growing need for highly educated engineering professionals.

Like other European countries in the late nineteenth and early twentieth centuries, Denmark's economy grew from agricultural roots (1). However, unlike some of its neighbors (including Germany and the United Kingdom), Denmark's transition from an agricultural to an industrial economy was slow. For example, it took until the 1960s for the value of Denmark's industrial output to exceed the value of its agricultural output (2). Obstacles to Denmark's industrialization in the early twentieth century included its lack of domestic raw materials and mineral resources, and its relatively small domestic market (2).

For Denmark to grow under such constraints in the late 1800s and early 1900s, its industry in general, and its chemicals industry in particular, concentrated on identifying and manufacturing products for export that could be derived from the country's agricultural sector. Formative life-science-based industries built their foundation on existing agricultural cooperatives that produced milk and meat (2). Today, companies like Danish Crown (a global meat exporter) and MD Foods (a Danish dairy company that merged in 2000 with the Swedish dairy cooperative Arla to form Arla Foods)

Monetary conversions from Danish krone (DKK) to U.S. dollars are based on the exchange rate in effect on Jan. 22, 2013, 1 DKK = US\$0.178.

remain successful examples of this early phase of Denmark's industrialization (see sidebar, p. 56).

Another agriculture-based company that set the stage for Denmark's modern chemicals industry was Danish Sugar. Founded in 1872, the company became one of Europe's largest sugar producers, and later merged with Dansk Handels- og Industri Co. to form Danisco in 1989. Prior to its acquisition by DuPont in 2011, Danisco had emerged as a successful biotech company, diversifying away from sugars to produce food ingredients and industrial enzymes.

Thus, in the 21st century, Denmark's agricultural route to progress has culminated in a variety of internationally successful companies producing niche products in the pharmaceutical, biotechnology, chemicals, and energy sectors.

## Modern life-science industries

Denmark is home to many companies that specialize in chemistry- and biotechnology-based products and processes — among them, Novo Nordisk, H. Lundbeck, Novozymes, Coloplast, LEO Pharma, and Chr. Hansen (Table 1).

Novo Nordisk is the largest pharmaceutical and biotechnology company in Denmark, and an example of how a modern chemical company emerged from an agricultural base.

**Table 1. Many of Denmark's most prominent companies are in the pharmaceutical and biotechnology industries.**

Company	Description/Products	Market share in 2011†	Sales in 2011†
<b>Novo Nordisk</b>	A pharmaceutical company specializing in therapeutic proteins, primarily for diabetes care but also for the treatment of hemophilia and growth hormone deficiency.	51% share (by volume) of world insulin market; 46% of synthetic insulin market	66.3 billion DKK (US\$11.8 billion)
<b>H. Lundbeck</b>	A pharmaceutical company specializing in developing treatments for brain disorders such as Alzheimer disease, Parkinson's disease, bipolar disorder, depression, epilepsy, Huntington's disease, and schizophrenia.	Cipralext held a 16.7% share of the aggregate European market for antidepressants	16 billion DKK (US\$2.85 billion)
<b>Novozymes</b>	A biotechnology company that develops industrial enzymes with diverse applications in homecare products, bioenergy, food and beverages, agriculture, biopharmaceuticals, wastewater treatment, textiles, pulp and paper, and leather.	The world's largest producer of industrial enzymes, with a 47% share of the global market	10.5 billion DKK (US\$1.87 billion)
<b>Coloplast</b>	A healthcare company highly specialized in ostomy, continence, urology, and wound and skin care products and services.	The global market leader, with a market share of 35–40% for continence care (permanent catheters), and a 10% share of the combined global market for urology products	10.2 billion DKK (US\$1.8 billion)
<b>LEO Pharma</b>	A specialty pharmaceutical company specializing in dermatology and critical care treatments for psoriasis, eczema, skin infections, actinic keratosis, and non-melanoma skin cancer.		7.7 billion DKK (US\$1.37 billion)
<b>Chr. Hansen</b>	A bioscience company that develops natural ingredients for the food, nutrition, pharmaceutical, and agricultural industries, with products such as cultures, enzymes, probiotics, and natural colors.		4.72 billion DKK (US\$0.84 billion)

†Data provided here are taken from statistics reported in the companies' annual reports for 2011

Beginning on a modest scale in the 1920s, two Copenhagen-based companies — Nordisk Insulinlaboratorium and Novo Terapeutisk Laboratorium — started to manufacture insulin from bovine pancreas, which was readily available from the meat industry's slaughterhouses. Over the years, competition between the two companies spurred an impressive series of innovations and growth, as each developed and refined new insulin products. Nordisk produced insulin with protamine in 1935, crystalline protamine insulin in 1944, and highly purified porcine insulin in 1977, while Novo marketed zinc-protamine-insulin (ZIP) in 1936, Lente products in 1953, and highly purified insulin (MC insulin) in 1977, and converted porcine insulin into human insulin in 1982. During the 1960s, Novo branched out to produce new pharmaceutical chemicals for hormone replacement therapy, as well as industrial enzymes such as Alcalase, which is used in detergents. In the 1980s, the companies pioneered new insulin-delivery systems, such as Nordisk's Infuser insulin pump in 1983 and InsuJect insulin pen in 1986, and Novo's NovoPen in 1985 and Novolet — the world's first disposable syringe — in 1989 (3).

After decades of individual development, in 1989 the two companies merged to form Novo Nordisk, which became a global leader in diabetes care and industrial

enzymes. In 2000, Novo Nordisk split into a healthcare business (the company name remained Novo Nordisk) and an enzyme business (Novozymes). Since then, both companies have continued to grow by investing in research and development in their niche markets, including growth hormone therapy, and expanding into new areas such as hemophilia care. Today, Novo Nordisk has the highest market capitalization among all the companies traded on the Copenhagen Stock Exchange, and both Novo Nordisk and Novozymes receive high rankings in the Dow Jones Sustainability Index, in recognition of their economic, environmental, and socially responsible sustainability practices.

The development of such strong companies within the pharmaceuticals and biotechnology sectors has attracted other companies that supply complementary technologies and solutions. For example, NNE Pharmaplan A/S (founded in 1989 and owned by Novo Nordisk) has for decades served as a consultant to Denmark's pharmaceuticals industry, and has expanded globally with international offices that provide a wide range of services, including design, construction, optimization, and startup of pilot-scale and production processes. It is now one of the world's largest engineering and consulting companies specializing in pharmaceutical and biotechnological industries.

*Article continues on next page*

### FOODS AND BEVERAGES: DENMARK'S EARLY "LIFE-SCIENCES" INDUSTRIES

Denmark's meat industry has long been an important economic activity. Danish pig farms produce about 28 million pigs annually, of which 90% are exported. The largest meat producer and processing company, Danish Crown, together with its subsidiaries, has annual sales of 55.1 billion DKK (US\$9.8 billion), and is Europe's largest and the world's second-largest producer of pig meat (4).

The Danish dairy industry has an annual processing capacity of 4.7 billion kg of milk, with exports in 2011 valued at 15.8 billion DKK (approx. US\$2.8 billion) (5). Arla Foods, an international cooperative owned by Danish, Swedish, and German dairy farmers, is Europe's largest dairy group, with revenues of 54.9 billion DKK (US\$9.8 billion) in 2011 (6). An important research and development challenge for Arla Foods is to improve the sustainability (e.g., water and energy efficiency, CO<sub>2</sub> footprint) of its business activities, as well as to diversify its products by developing high-value-added milk-based products.

In the beverages sector, the Carlsberg brewery, founded in 1847, continues to grow on a global scale. Carlsberg's sales in 2011 of 63.5 billion DKK (US\$11.3 billion) make it the fourth-largest brewer of beer in the world (7). The Carlsberg Laboratory embodies the company's rich history of innovation. Established in 1875, the laboratory has been credited with many innovations, including a method for nitrogen measurement (Kjeldahl nitrogen), and a method for culturing pure yeast. The lab has also pioneered research and technology development in the life sciences (8).

### Energy challenges and progress

Until the 1970s, Denmark had no significant domestic reserves of oil and natural gas, which posed an obvious barrier to the development of petroleum-based industries.

This changed with the technology development that allowed the exploitation of oil and gas in the North Sea that began in 1972 and 1984, respectively. These efforts were led by the Dansk Undergrunds Consortium (DUC) — an alliance between A.P. Møller (today known as AP Møller-Mærsk), Shell, and Chevron — which in 1962 had been awarded concessions by the Danish government for the development of oil and gas. Since 1984, oil and gas exploration has been open to other companies, among them DONG Energy, Denmark's national energy company, whose operations include power generation and distribution, as well as oil and gas exploration and production.

Thanks to these North Sea activities, Denmark's industries were not only able to fulfill their own fossil energy needs, but Denmark has since become a net exporter of energy through companies that include Mærsk Oil and DONG Energy — albeit on a modest scale compared to

neighbors such as Norway. In 2011, Denmark's oil and natural gas exports were 48.3 billion DKK (US\$8.6 billion) and 9.9 billion DKK (US\$1.76 billion), respectively (9).

Denmark's early lack of domestic fossil resources established a long tradition of industries using other forms of energy, notably wind power. The wind power industry was supported by such home-grown companies as Vestas, established in 1898, which began developing windmills in the 1970s and today is a global technology leader in the field of wind turbine manufacturing and related energy services.

Today, in the arena of biomass-based renewable energy production, Inbicon (a subsidiary of DONG Energy) has developed a technology for cellulosic ethanol production that employs an enzymatic hydrolysis and fermentation route. Inbicon has tested the technology on a demonstration scale at the Asnæs Power Station in Kalundborg, Denmark — where the biomass refinery is integrated into the coal-fired power plant by using the steam from the power plant to pretreat the biomass. This technology is being used in first- and second-generation ethanol production, power plants, and other combined heat and power (CHP) plants.

Danish power plants have long been market leaders in clean-coal technologies, boasting fuel-energy-to-electricity power efficiencies of close to 50%. With CHP production, overall efficiencies have exceeded 80% (10). This success has been the result of collaborations between industry and academia, including fundamental chemical engineering research in process technology and high-temperature materials. Such collaboration has also led to breakthroughs in the application of biomass and waste to power and heat production. For example, during the 1990s, technologies for grate firing of biomass and waste were developed in cooperation with companies such as Babcock & Wilcox Vølund, and Burmeister and Wain Energy A/S. These technologies have been installed in many plants worldwide.

### Science and technology clusters

Following the emergence and success of the industrial-park concept, which pools together a critical mass of specialized competences in a certain geographical area (see *CEP*, Oct. 2011, pp. 44–47), Denmark has established chemical clusters of its own. These include the Medicon Valley, Agro Food Park, and Welfare Tech regions, as well as an important collaboration devoted to renewable energy.

The Medicon Valley, which spans the region between eastern Denmark (including the greater Copenhagen area) and southern Sweden (Figure 1), has established itself as one of Europe's strongest life-sciences clusters in pharmaceuticals, biotechnology, and medical technology. Medicon Valley brings together more than 300 companies (among them Novo Nordisk, Lundbeck, and AstraZeneca) with academic research

## DENMARK'S CHEMICALS AND MATERIALS COMPANIES

Not all of Denmark's chemicals-industry success stories are in the pharmaceuticals and biotech sectors. The following chemical industry sectors are among Denmark's largest, and among the country's largest employers of chemical engineers.

**Catalysts and catalytic processes** — Founded in 1940, Haldor Topsøe is a major applied-research company in the field of catalysts and catalytic process technology. Applications of its R&D range from oil refining, to air pollution/emission control in motor vehicles and power plants, to the production of bulk chemicals such as sulfuric acid, methanol, and ammonia.

**Building materials** — Originating as an equipment supplier in the 1880s, FLSmidth remains a significant player in the heavy process industries. It is among the world's largest companies in the cement industry, providing engineering, equipment, and plant design and operation support services. The company recently expanded its business to include the capability to provide full flow-sheet solutions for the mineral industry, e.g., for the production of copper, gold, coal and iron.

**Coatings** — Hempel began in 1915 as a supplier of

paints for maritime applications, and has grown into a global developer of heavy-duty protective coatings for the marine industry (coatings for ships, oil platforms, and sea-based wind farms), and for land-based industry and infrastructure. Hempel has focused on its specialized niche, combining technology development with global business development.

**Crop protection** — Cheminova offers customized chemical crop-protection products that help farmers to increase the yield and quality of foods, animal feed, and biofuel crops. The company has innovated environmentally friendlier products with lower organic-solvent content.

**Equipment** — Established in 1883, Alfa Laval is a leader in heat transfer, separations, and fluid handling, and its products are used in industries that include food, water, energy, environmental protection, and pharmaceuticals. Two other Danish companies in the equipment sector are GEA Niro, a supplier of process equipment for spray drying, fluid-bed drying, and freeze drying; and Anhydro, which designs and develops innovative liquid-concentration and powder-processing equipment.

institutes (such as the Univ. of Copenhagen, the Technical Univ. of Denmark, and Lund Univ. in Sweden) and clinical research centers. This uniting of resources and expertise in the life sciences allows for intensive collaboration and synergies that foster innovative ideas and new-product development.

The Agro Food Park cluster, which was established in 2009 in Skejby, Århus, brings together agricultural and food companies such as Arla Foods, Danish Crown, Århus-Karlshamn, and Danisco, with research institutions, including Århus Univ. Another cluster, Welfare Tech, established in 2010 in the southern Denmark city of Odense, concentrates on "welfare" technologies — namely household assisted-living products, including such innovations as cleaning robots.

In 2007, Denmark's former National Laboratory for Renewable Energy — Risø — was integrated into the Technical Univ. of Denmark (DTU), at its campus in Roskilde, 35 km west of Copenhagen. This center devoted to renewable energy combines university education, research, and innovation in chemical and biochemical engineering.

### More and better scientists and engineers

Danish chemical companies have demonstrated that they have the resources to innovate, compete, and expand on a global scale in highly specialized niche markets. This has required an interdisciplinary array of business, scientific, and technical abilities — from product development and production technologies, to distribution, marketing, and supply chain logistics. To sustain a leadership position in today's market, these industries must rely on a highly qualified workforce with a broad range of skills and knowledge in science

and engineering, including chemical engineering. This places an emphasis on higher education, and in particular on PhD education — to supply more (and higher quality) graduates with the skills and knowledge needed to support these knowledge-intensive industries.

Denmark's higher-education system has responded well to the demand for trained workers. Denmark's official bureau of statistics (Danmarks Statistik) has charted a steady increase in the number of students receiving BS, MS, and PhD degrees in engineering and the sciences for the period 2001–2009 (11). In fact, Denmark saw an average 10% annual increase in the number of PhD graduates between 1998 and 2006, placing Denmark third in the world on this measure, behind only China and Mexico (12).



Image courtesy of Øresundsbron

▲ **Figure 1.** Medicon Valley is one of Europe's largest industrial clusters, home to many life sciences companies. The complex straddles the Øresund strait, which lies between Malmö in Sweden and the greater Copenhagen area in Denmark — joined by the iconic Øresund Bridge.

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**Table 2. A statistical analysis of Denmark's future supply and demand for engineers with technical and natural sciences competencies projects a shortfall (13).**

Supply	2010	2015	2020
BS in engineering	43,865	40,608	38,452
MS in engineering	27,527	30,152	33,248
MS in natural sciences	33,345	37,174	41,044
<b>Demand</b>			
BS in engineering	44,641	45,474	47,073
MS in engineering	27,682	32,338	38,201
MS in natural sciences	33,691	43,343	57,132
<b>Shortfall</b>			
BS in engineering	776	4,866	8,621
MS in engineering	155	2,186	4,953
Engineers in total	931	7,052	13,574
Scientists	346	6,169	16,088

The quality of Denmark's PhD education is high, comparing favorably with other developed countries (14). And, while the recent increases in the number of PhD graduates has created an oversupply problem in some countries (including Japan and the U.S.), Denmark's biotechnology, chemicals, and processing industries have been able to absorb the increased supply of PhD graduates. However, analyses indicate that Denmark will soon face a workforce shortage, and must expand the capacity and international reach of its PhD education system.

The Danish Society for Engineers (IDA) has carried out a supply and demand analysis of Denmark's engineering graduates (13). The study has revealed that by 2020, at the

economy's current growth rate, Denmark will have a shortage of nearly 30,000 engineers and scientists: 13,574 trained in technical sciences (chemical and biochemical engineers, as well as other technical specializations relevant to the chemical and processing industries), and 16,088 graduates trained in natural sciences such as bioinformatics, biology, physics, chemistry, mathematics, and statistics (Table 2). Even under a low-growth scenario, the IDA projects that there will be a combined shortage of 18,000 engineers and scientists in 2020.

Danish universities are collaborating with stakeholders in industry, government, and engineering societies to educate a new generation of engineers to keep up with current and future demands for a high-quality workforce. Among these efforts, the Technical Univ. of Denmark's (DTU) department of chemical and biochemical engineering is training researchers at the PhD and postdoctoral levels. DTU also offers an International Elite Master Education program in cooperation with companies such as Hempel and Haldor Topsøe, through which students are connecting with companies that take a global approach to research, innovation, and design.

## In closing

Denmark's chemicals industry includes an array of innovative world-class companies. Among its successes, Denmark has co-established an important industrial cluster, Medicon Valley, to attract pharmaceuticals, biotechnology, and medical technology companies, leveraging the multi-disciplinary competences and skills of the participants to spur further innovation and growth.

The Danish higher-education system, in collaboration with industry and government, is well positioned to meet the challenge of educating the next generation of engineers and scientists, contributing to the nation's research and knowledge base, and keeping Denmark competitive. CEP

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## LITERATURE CITED

1. **Henriksen, I.**, "An Economic History of Denmark," EH.Net Encyclopedia, edited by Robert Whaples, <http://eh.net/encyclopedia/article/henriksen.denmark> (2006).
2. **Jespersen, K. J. V.**, "A History of Denmark," Palgrave Macmillan, New York, NY (2004).
3. **Novo Nordisk**, "Novo Nordisk History," [www.novonordisk.com/images/about\\_us/history/history\\_uk.pdf](http://www.novonordisk.com/images/about_us/history/history_uk.pdf) (2010).
4. **Danish Crown**, "Annual Report 2011," <http://annualreport2011.danishcrown.dk/>
5. **Danish Agriculture and Food Council**, Dairy Statistics 2011, [www.agricultureandfood.dk/Prices\\_Statistics/Annual\\_Statistics.aspx#UPRpTegRYUU](http://www.agricultureandfood.dk/Prices_Statistics/Annual_Statistics.aspx#UPRpTegRYUU) (2011).
6. **Arla Foods**, "Annual Report 2011," <http://annualreport2011.arla.com>.
7. **Carlsberg Group**, "Annual Report for 2011," [www.carlsberg-group.com/investor/news/Pages/SEA04\\_AR2012\\_28022012.aspx](http://www.carlsberg-group.com/investor/news/Pages/SEA04_AR2012_28022012.aspx).
8. **Juma, C.**, "Innovation and Wealth of Nations," Harvard Kennedy School, Belfer Center for Science and International Affairs, [www.technologyandpolicy.org/2012/03/14/innovation-and-the-wealth-of-regions](http://www.technologyandpolicy.org/2012/03/14/innovation-and-the-wealth-of-regions) (2012).
9. **Danish Energy Agency**, "Oil and Gas Production and Subsoil Use in Denmark, 2011," [www.ens.dk/EN-US/oilandgas/reportoilgas/Sider/Forside.aspx](http://www.ens.dk/EN-US/oilandgas/reportoilgas/Sider/Forside.aspx) (2011).
10. **Lund, H., and B. V. Mathiesen**, "Energy System Analysis of 100% Renewable Energy Systems — The Case of Denmark in Years 2030 and 2050," *Energy*, **34** (5), pp. 524–531 (2009).
11. **Danmarks Statistik**, [www.dst.dk/en/Statistik.aspx](http://www.dst.dk/en/Statistik.aspx)
12. **Cyranoski, D., et al.**, "Education: The PhD Factory," *Nature*, **472**, pp. 276–279 (2011).
13. **The Danish Society for Engineers (IDA)**, "Prognose for mangel på ingeniører og scient.er 2020," <http://ida.dk/sites/english/Sider/IDA.aspx> (2011).
14. **Danish Ministry of Science, Technology, and Innovation**, "PhD Education in Denmark: Report from an International Evaluation Panel," <http://en.fivu.dk/publications/2006/a-public-good-phd-education-in-denmark> (Apr. 2006).

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