



Caprolactam

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CHEMSYSTEMS



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INTRODUCTION

Caprolactam (white crystals, moderately soluble in water, mp 69 °C) may be represented by the structure shown below:



Caprolactam

Essentially, all of its production is consumed in the manufacture of nylon 6 which is used for fiber (clothing, carpets and industrial fibers) and for resin production, where it is used as an engineering thermoplastic, mainly in the automotive, electrical and electronics sectors, and for extrusion for products such as monofilaments and film.

In the early 2000s, the global caprolactam market suffered from declining demand and operating rates as a result of the economic downturn. Since then, global capacity additions have been limited as producers remained cautious of the caprolactam market outlook. On the other hand, plant operating rates have increased to the point where capacity is coming close to limiting industry growth. Developed regions such as Western Europe and North America are projected to show minimal growth, but China has been and is expected to remain a major net importer due to rapid growth in the corresponding end-use sectors. As a result, significant capacity additions will be required in the upcoming years, most likely in Asia and conceivably, the Middle East, to sustain demand growth.

Since the only real end-use for caprolactam is in the production of nylon 6, the caprolactam market is highly cyclical due to the dependency of the nylon 6 market and economic activity in the various automotive and textile sectors.

This report discusses:

- Key business developments and technology licensing status
- General strategic issues to be considered by those in the caprolactam business (i.e., ammonium sulfate byproduct, barriers to entry, competitiveness, key success factors, market fundamentals, pricing fundamentals).
- Commercial technologies
- Alternative/developing technologies
- Cost of production economics for commercial and alternative/developing processes
- Commercial market applications and supply, demand and trade analyses

CURRENT TECHNOLOGY

Several process technologies are discussed.

Aromatics Feedstock based Technologies

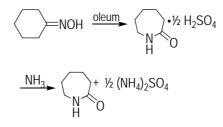
Currently, practically all commercial caprolactam production globally is based on aromatics feedstocks:

- Over 95 percent of this global production is either from cyclohexane (from benzene) or phenol via cyclohexanone and the cyclohexanone oxime.
- The remaining less than five percent of installed caprolactam capacity is via the cyclohexane photonitrozation process of Toray, which goes directly from cyclohexane to the oxime, or the SNIA Viscosa process, which utilizes toluene as feedstock and proceeds via oxidation-hydrogenation-nitrozation.

This aromatics-based technology, which is currently the only real method employed for commercial production, is mature and consequently, there have been few developments noted in the last five years.

In brief, cyclohexanone oxime is the key intermediate and it is produced mainly via oximation of cyclohexanone with hydroxylamine (although commercial production via two other routes is employed, (i.e., photonitrozation of cyclohexane) or ammoximation of cyclohexanone with hydrogen peroxide and ammonia).

Cyclohexanone oxime (gray crystals, insoluble in water, mp 208 °C) is converted to caprolactam mainly via a process known as the Beckmann rearrangement. A solution of cyclohexanone in oleum/sulfuric acid is heated and maintained at a temperature of around 100 °C, and within a few minutes the oxime is rearranged to the lactam sulfate, as shown by the first equation below. The lactam sulfate is then neutralized with ammonia releasing the caprolactam product with coproduction of ammonium sulfate as illustrated in the second equation below.



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Cyclohexanone sulfate is also converted to caprolactam in some commercial processes by another route known as the Sumitomo rearrangement. This involves direct conversion of the oxime to the lactam using a modified zeolite catalyst at elevated temperature in the vapor phase. The process is illustrated by the chemical equation below.

Caprolactam production from aromatic feedstocks process chemistry is discussed in detail. In addition, the following technologies are described in some depth:

- DSM process
- Honeywell phenol process
- Cyclopol process
- Toray photonitrozation process
- EniChem ammoximation
- Sumitomo rearrangement
- SNIA Viscosa toluene process

ALTERNATIVE PROCESSES

Since caprolactam production is relatively complex and capital intensive, considerable effort has been made to find alternative routes to caprolactam, both using alternative petrochemical feedstocks as well as, more recently, using renewable raw materials.

Two main petrochemical-based technologies have been developed, based on the primary feedstocks butadiene and adiponitrile

Both these technology processes are discussed in detail in this report.

A novel recent development has been research into a renewables based route to caprolactam, which, if commercialized, would enable the production of "bio nylon 6". Two approaches are being pursued, both using lysine derived from dextrose fermentation as the starting material. Both these processes are still in their infancy. Nevertheless, they offer exciting developments in caprolactam technology, not least because of the ever increasing price of crude oil.

This technology process is discussed in detail in this report.

ECONOMICS

Nexant has developed several costs of production estimates for caprolactam production and these can be summarized as follows:

1. Commercial aromatic-based routes: production cost evaluations for seven process technologies (summarized below) that employ this route have been developed.

Name	Feedstock	Oximation	Beckmann	Other
Raschig	Cyclohexane	Raschig	Traditional	-
NO Reduction	Cyclohexane	NO Reduction	Traditional	-
HPO	Cyclohexane	HPO	Traditional	-
Honeywell	Phenol	Raschig	Traditional	-
Sumitomo	Cyclohexane	Ammoximation	Sumitomo	-
Toray	Cyclohexane	-	-	Photonitrosation
SNIA	Toluene	-	-	SNIA
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- 2. Speculative economics for two non-commercial but petrochemical-based processes, one based on butadiene feedstock and the other on adiponitrile feedstock.
- 3. Speculative economics for embryonic biobased production processes based on lysine via dextrose.
- 4. Regional economics comparison: Since production economics between regions can show significant differences depending on domestic prices for raw material, utilities, labor etc. the economics of production in three major regions Western Europe, the United States, and China and also examines the potential of caprolactam production in the Middle East. The widely licensed DSM HPO technology with a leader-scale plant capacity of 200 kta and purchasing cyclohexane on the market has been chosen as the basis for comparison. All cost factors are taken at region specific values.

All cost tables given in this report include a breakdown of the cost of production in terms of raw materials, utilities direct and allocated fixed costs, by unit consumption and per metric ton and annually, as well as contribution of depreciation to arrive at a cost estimate (a simple nominal return on capital is also included)

COMMERCIAL APPLICATIONS & REGIONAL MARKET REVIEW

In essence, all production of caprolactam is consumed in the synthesis of nylon 6 fibers and resins. Around 70 percent of caprolactam is used to manufacture nylon 6 fibers for clothing, carpets and industrial fibers. The remaining 30 percent is consumed for nylon 6 resin production, where it is used as an engineering thermoplastic, mainly in the automotive, electrical and electronics sectors, and for extrusion for products such as monofilaments and film.

Consumption of nylon 6 fiber into clothing has been declining in developed markets due to a general shift towards polyester. Demand in this sector is largely driven by growth in Asia, and in niche applications such as microfiber.

The carpet fiber market is highly regional, with growth plateauing in North America and Europe due to competition from polypropylene, polyethylene terephthalate (PET) and polytrimethylene terephthalate (PTT). However, there is demand growth in regions such as Central Europe, and in the higher performance carpeting market.

- Global supply, demand and trade data are given and discussed.
- In addition, supply, demand and trade data is given for the regions of North America, South America, Western European, Central and Eastern Europe, and Asia Pacific
- A list of plants in each region above is given showing plant capacity, owning company, location and annual tonnage produced is given



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