

*Caprolactam*  
99/00-4

*March 2001*

# TABLE OF CONTENTS

		Page
<b>I</b>	<b>EXECUTIVE SUMMARY</b>	- 1 -
	A. SYNOPSIS	- 1 -
	B. TECHNOLOGY DEVELOPMENTS	- 1 -
	1. Enhancements to Conventional Technology	- 2 -
	2. Caprolactam from Alternative Sources	- 2 -
	C. TECHNO-ECONOMICS	- 5 -
	1. Enhancements to Conventional Technology	- 5 -
	2. Routes Based on Butadiene	- 5 -
	D. COMMERCIAL STATUS	- 8 -
	1. Consumption	- 8 -
	2. Supply/Demand Balance	- 9 -
	3. Trade	- 9 -
	4. Ammonium Sulfate	- 10 -
	E. STRATEGIC ISSUES	- 12 -
	1. Cyclicity	- 12 -
	2. Nylon Feedstocks from One Source	- 13 -
	F. NYLON RECYCLING	- 14 -
	G. CONCLUSIONS	- 15 -
<b>II</b>	<b>INTRODUCTION</b>	- 16 -
	A. AIM OF THE STUDY	- 1 -
	B. OVERVIEW	- 17 -
	1. Enhancements to Conventional Technology	- 17 -
	2. Caprolactam from Alternative Sources	- 17 -
	C. CHEM SYSTEMS PRODUCTION COST METHODOLOGY	- 20 -
	1. Capital Cost Estimation	- 20 -
	(a) Battery Limits Investment	- 20 -
	(b) Off-Sites Investment	- 21 -
	(c) Contractor Charges <sup>(2)</sup> Typically 15-25 Percent of Installed BL and OS Costs	- 22 -
	(d) Project Contingency Allowance <sup>(2)</sup>	- 22 -
	(e) Working Capital	- 22 -
	(f) Other Project Costs <sup>(3)</sup>	- 23 -
	(1) Start-Up/Commissioning Costs	- 23 -
	(2) Miscellaneous Owner's Costs	- 23 -
	2. Cost of Production Elements	- 24 -
	(a) Battery Limits	- 24 -
	(b) Production Costs	- 25 -
	(1) Labor	- 25 -

**TABLE OF CONTENTS**  
**(Continued)**

	<b>Page</b>
<b>III</b>	
<b>CAPROLACTAM FROM AROMATIC-DERIVED FEEDSTOCKS</b>	<b>- 26 -</b>
<b>A. COMMERCIAL TECHNOLOGIES</b>	<b>- 26 -</b>
1. Overview	- 26 -
2. Process Chemistry	- 26 -
(a) Cyclohexanone Synthesis	- 26 -
(b) Oxime Formation with Cyclohexanone Using Hydroxylamine	- 28 -
(c) Beckmann Rearrangement of Cyclohexanone Oxime to Caprolactam	- 28 -
(d) Manufacture of Hydroxylamine	- 29 -
(e) SNIA Cyclohexanecarboxylic Acid Process	- 30 -
(f) Toray Process	- 30 -
3. Process Technology	- 31 -
(a) DSM Process	- 31 -
(1) Cyclohexane Oxidation	- 31 -
(2) Hydroxylamine Preparation and Cyclohexanone Oximation	- 36 -
(3) Beckmann Rearrangement and Neutralization	- 38 -
(4) Ammonium Sulfate Extraction and Recovery	- 38 -
(5) Final Caprolactam Purification	- 38 -
(b) Allied Signal's Phenol Route	- 39 -
(1) Cyclohexanone Production from Phenol	- 40 -
(2) Hydroxylamine Production	- 41 -
(3) Oximation/Rearrangement	- 42 -
(4) Neutralization/Solvent Recovery and Purification	- 42 -
(5) Ammonium Sulfate Crystallization	- 42 -
(c) Polimex/PolSERVICE (Capropol® Process)	- 42 -
(1) Cyclohexanone Unit	- 43 -
(2) Hydroxylamine Unit	- 46 -
(3) Caprolactam Unit	- 48 -
(d) SNIA Process	- 49 -
(e) Toray Process	- 50 -
<b>B. PROCESS DEVELOPMENTS</b>	<b>- 53 -</b>
1. Overview	- 53 -
2. Process Chemistry	- 53 -
(a) EniChem Developments	- 53 -
(b) Sumitomo Developments	- 56 -
3. Process Description	- 57 -
(a) EniChem Ammoximation	- 57 -
(b) Sumitomo	- 58 -
<b>C. OBSERVATIONS</b>	<b>- 60 -</b>

**TABLE OF CONTENTS**  
**(Continued)**

		<b>Page</b>
<b>IV</b>	<b>CAPROLACTAM FROM NON-AROMATIC DERIVED FEEDSTOCK</b>	- 61 -
	A. INTRODUCTION	- 61 -
	B. BUTADIENE (BASF/DSM/DUPONT)	- 62 -
	1. Overview	- 62 -
	2. Basic Equations	- 62 -
	3. Chemistry	- 63 -
	4. Process Description	- 65 -
	C. CAPROLACTAM FROM ADIPONITRILE	- 69 -
	1. Adiponitrile from Butadiene	- 69 -
	(a) Process Chemistry	- 69 -
	2. Process Description	- 70 -
	3. Adiponitrile from Acrylonitrile	- 72 -
	4. Caprolactam/HMDA from Adiponitrile	- 75 -
	(a) Process Chemistry	- 75 -
	(b) Process Description	- 76 -
	(c) The Case for Selective Hydrogenation	- 78 -
<b>V</b>	<b>PROCESS ECONOMICS</b>	- 80 -
	A. BASIS	- 80 -
	B. CAPROLACTAM BASED ON AROMATIC-DERIVED FEEDSTOCKS	- 83 -
	1. Conventional Approaches	- 83 -
	(a) Capropol®	- 83 -
	(b) Non-Integrated Leader	- 83 -
	(c) Phenol (Allied Signal)	- 86 -
	(d) Toray (Photochemical)	- 86 -
	(e) SNIA (Toluene)	- 86 -
	2. Process Enhancements	- 90 -
	(a) DSM/HPO	- 90 -
	(b) EniChem (Peroxide)	- 90 -
	(c) Sumitomo Enhancement	- 90 -
	3. Cost of Production Summary	- 90 -
	C. NON-AROMATIC ROUTES TO CAPROLACTAM	- 97 -
	1. Butadiene/Carbon Monoxide	- 97 -
	2. Cost of Production Summary	- 109 -
	D. WESTERN EUROPE	- 111 -
	E. SELECTED SENSITIVITIES	- 114 -

**TABLE OF CONTENTS**  
**(Continued)**

	<b>Page</b>
<b>VI</b>	<b>COMMERCIAL STATUS</b> - 116 –
A.	OVERVIEW - 116 –
B.	GLOBAL MARKET - 117 –
1.	Consumption - 117 –
2.	Supply/Demand Balance - 118 –
3.	Trade - 118 –
4.	Ammonium Sulfate - 119 –
C.	UNITED STATES - 122 –
1.	Caprolactam Supply - 122 –
2.	Supply/Demand Balance - 122 –
D.	WESTERN EUROPE - 124 –
1.	Caprolactam Supply - 124 –
2.	Supply/Demand Balance - 125 –
E.	JAPAN - 126 –
1.	Caprolactam Supply - 126 –
2.	Supply/Demand Balance - 126 –
F.	OTHER REGIONS - 128 –
1.	Latin America - 128 –
2.	East Asia - 129 –
3.	Eastern Europe - 131 –
G.	INTERMATERIAL COMPETITION - 132 –
<b>VII</b>	<b>STRATEGIC ISSUES</b> - 134 –
A.	MARGIN REVIEW - 134 –
1.	Caprolactam from Cyclohexane - 134 –
2.	Caprolactam from Phenol - 136 –
3.	Caprolactam from Butadiene - 138 –
B.	NYLON FEEDSTOCK INTEGRATION ISSUES - 139 –
<b>VIII</b>	<b>CAPROLACTAM FROM NYLON CARPET RECYCLING</b> - 143 –
A.	OVERVIEW - 143 –
B.	EVERGREEN - 144 –
C.	RECYCLING METHODOLOGY - 145 –
1.	Collection and Pre-Processing - 145 –
2.	De-Polymerization - 145 –
3.	Work-Up - 146 –

**TABLE OF CONTENTS**  
**(Continued)**

	<b>Page</b>
<b>IX</b>	
<b>REFERENCES</b>	- 147 -
A. US PATENTS RELEVANT TO NYLON RECYCLING	- 147 -
B. US PATENTS RELEVANT TO IMPROVED BECKMAN REARRANGEMENT	- 147 -
C. US PATENTS RELEVANT TO ALTERNATIVE CAPROLACTAM ROUTES	- 147 -
 <b>APPENDIX</b>	
I SUPPORTING COST OF PRODUCTION ESTIMATES FOR CAPROLACTAM AND FEEDSTOCKS	
 II SUPPORTING COST OF PRODUCTION ESTIMATES FOR CAPROLACTAM AND FEEDSTOCKS FOR WESTERN EUROPE	

## TABLES

		PAGE NO
Table I.C.1	COST OF PRODUCTION SUMMARY FOR CAPROLACTAM	- 6 -
Table I.C.2	COST OF PRODUCTION SUMMARY FOR CAPROLACTAM VIA NON-AROMATIC FEEDSTOCKS	- 7 -
Table I.D.1	GLOBAL CAPROLACTAM DEMAND BY REGION, 1990-2015	- 8 -
Table III.A.1	TYPICAL OPERATING CONDITIONS OF KA OIL FROM CYCLOHEXANE VIA THE BORIC ACID ROUTE	- 32 -
Table III.B.1	CAPROLACTAM TECHNOLOGY SUMMARY	- 53 -
Table III.B.2	FIRST STAGE AMMOXIMATION REACTION SUMMARY	- 55 -
Table III.B.3	AMMOXIMATION REACTION SUMMARY	- 56 -
Table V.A.1	PRICING BASIS, Q1/2000	- 81 -
Table V.A.2	UTILITIES BASIS, Q1/2000	- 82 -
Table V.B.1	COST OF PRODUCTION ESTIMATE FOR CAPROLACTAM PROCESS: CAPROPOL BACK-INTEGRATED INTO BENZENE	- 84 -
Table V.B.2	COST OF PRODUCTION ESTIMATE FOR CAPROLACTAM PROCESS: CYCLOHEXANE WITHOUT INTEGRATION	- 85 -
Table V.B.3	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: PHENOL (PURCHASED)	- 87 -
Table V.B.4	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: TORAY/PHOTOCHEMICAL	- 88 -
Table V.B.5	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: SNIA/TOLUENE	- 89 -
Table V.B.6	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: CYCLOHEXANE/DSM HPO	- 91 -
Table V.B.7	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: PHENOL/DSM HPO	- 92 -
Table V.B.8	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: CYCLOHEXANE/ PEROXIDE	- 93 -
Table V.B.9	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: CYCLOHEXANE/ PEROXIDE/FLUID BED	- 94 -
Table V.B.10	COST OF PRODUCTION SUMMARY FOR CAPROLACTAM (USGC, Q1/2000, 200 000 tons per year capacity)	- 95 -
Table V.C.1	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: BUTADIENE (BASF/DSM/DUPONT)	- 98 -
Table V.C.2	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: BUTADIENE (DUPONT/BASF) WITH HEXAMETHYLENE DIAMINE CO-PRODUCT	- 99 -
Table V.C.3	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM/HEXAMETHYLENE DIAMINE PROCESS: BUTADIENE (DUPONT/BASF)	- 100 -
Table V.C.4	COST OF PRODUCTION ESTIMATE FOR: HEXAMETHYLENE DIAMINE PROCESS: BUTADIENE (DUPONT)	- 101 -

**TABLES**  
**(Continued)**

		<b>PAGE NO</b>
Table V.C.5	COST OF PRODUCTION ESTIMATE FOR: ADIPONITRILE PROCESS: BUTADIENE (DUPONT)	- 102 -
Table V.C.6	COST OF PRODUCTION ESTIMATE FOR: ADIPONITRILE PROCESS: ELECTROCHEMICAL (SOLUTIA)	- 103 -
Table V.C.7	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: FROM ADIPONTIRILE (BUTADIENE) WTH HEXAMETHYLENE DIAMINE CO-PRODUCT	- 104 -
Table V.C.8	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM/ HEXAMETHYLENE DIAMINE PROCESS: (DUPONT/BASF) ADIPONITRILE FROM BUTADIENE	- 105 -
Table V.C.9	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: FROM ADIPONTIRILE (ACRYLONITRILE) WTH HEXAMETHYLENE DIAMINE CO-PRODUCT	- 106 -
Table V.C.10	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM/ HEXAMETHYLENE DIAMINE PROCESS: (DUPONT/BASF) ADIPONITRILE FROM ACRYLONITRILE	- 107 -
Table V.C.11	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: FROM ADIPONTIRILE (BUTADIENE) NO HEXAMETHYLENE DIAMINE CO-PRODUCT	- 108 -
Table V.C.12	COST OF PRODUCTION SUMMARY FOR CAPROLACTAM VIA NON-AROMATIC FEEDSTOCKS (USGC, Q1/2000)	- 109 -
Table V.D.1	COST OF PRODUCTION SUMMARY FOR CAPROLACTAM (Western Europe, Q1/2000, 200 000 tons per year capacity)	- 111 -
Table V.D.2	COST OF PRODUCTION SUMMARY FOR CAPROLACTAM VIA NON-AROMATIC FEEDSTOCKS (USGC, Q1/2000)	- 111 -
Table VI.A.1	TYPICAL CAPROLACTAM SPECIFICATIONS & PROPERTIES	- 116 -
Table VI.B.1	GLOBAL CAPROLACTAM DEMAND BY REGION, 1990-2015	- 117 -
Table VI.C.1	UNITED STATES CAPROLACTAM CAPACITY, END 2000	- 122 -
Table VI.C.2	UNITED STATES CAPROLACTAM SUPPLY/DEMAND BALANCE, 1990-2015	- 123 -
Table VI.D.1	WEST EUROPEAN CAPROLACTAM CAPACITY, END 2000	- 124 -
Table VI.D.2	WEST EUROPEAN CAPROLACTAM SUPPLY/DEMAND BALANCE, 1990-2015	- 125 -
Table VI.E.1	JAPANESE CAPROLACTAM CAPACITY, END 2000	- 126 -
Table VI.E.2	JAPANESE CAPROLACTAM SUPPLY/DEMAND BALANCE, 1990-2015	- 127 -
Table VI.F.1	LATIN AMERICAN CAPROLACTAM CAPACITY, END 2000	- 128 -
Table VI.F.2	LATIN AMERICAN CAPROLACTAM SUPPLY/DEMAND, BALANCE, 1990-2015	- 128 -

**TABLES**  
**(Continued)**

		<b>PAGE NO</b>
Table VI.F.3	EAST ASIAN CAPROLACTAM CAPACITY, END 2000	- 130 -
Table VI.F.4	EAST ASIAN CAPROLACTAM SUPPLY/DEMAND BALANCE 1990-2015 - 130 -	
Table VI.F.5	EAST EUROPEAN CAPROLACTAM CAPACITY, END 2000	- 131 -
Table VII.B.1	COST OF PRODUCTION ESTIMATE FOR: ADIPIC ACID PROCESS: CYCLOHEXANE OXIDATION BY AIR (COBALT CATALYST) AND NITRIC ACID	- 140 -
Table VII.B.2	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: THEORETICAL ADIPIC ACID/HMDA CO-PRODUCT WITH BUTADIENE/CYCLOHEXANE FEED	- 141 -
Table VII.B.3	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: ADIPIC ACID/HMDA CO-PRODUCT WITH BUTADIENE FEED ONLY	- 142 -
Table AI.A.1	COST OF PRODUCTION ESTIMATE FOR: CUMENE PROCESS: HETEROGENEOUS BENZENE ALKYLATION	- 148 -
Table AI.A.2	COST OF PRODUCTION ESTIMATE FOR: PHENOL PROCESS: OXIDATION WITHOUT AMS RECOVERY	- 149 -
Table AI.A.3	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: PHENOL (BACK-INTEGRATED)	- 150 -
Table AI.A.4	COST OF PRODUCTION ESTIMATE FOR: HYDROGEN PEROXIDE PROCESS: ANTHRAQUINONE AUTO-OXIDATION	- 151 -
Table AI.B.1	COST OF PRODUCTION ESTIMATE FOR: SYNTHESIS GAS (1.7:1) PROCESS: PARTIAL OXIDATION	- 152 -
Table AI.B.2	COST OF PRODUCTION ESTIMATE FOR: CARBON MONOXIDE PROCESS: CRYOGENIC SEPARATION FROM 1.7:1 SYNGAS (PARTIAL OXIDATION)	- 153 -
Table AI.B.3	COST OF PRODUCTION ESTIMATE FOR: HYDROGEN CYANIDE PROCESS: ANDRUSSOW/BY-PRODUCT VALUATION FOR ACRYLONITRILE	- 154 -
Table AI.B.4	COST OF PRODUCTION ESTIMATE FOR: ACRYLONITRILE PROCESS: AMMOXIDATION WITH HCN BY-PRODUCT	- 155 -
Table AI.B.5	COST OF PRODUCTION ESTIMATE FOR: HYDROGEN CYANIDE PROCESS: ANDRUSSOW/FEEDSTOCK FOR ADIPONITRILE	- 156 -
Table AI.B.6	COST OF PRODUCTION ESTIMATE FOR: ADIPONITRILE PROCESS: BUTADIENE (DUPONT)	- 157 -
Table AI.B.7	COST OF PRODUCTION ESTIMATE FOR: HYDROGEN CYANIDE PROCESS: ANDRUSSOW/FEEDSTOCK FOR ADIPONITRILE	- 158 -

**TABLES**  
**(Continued)**

		<b>PAGE NO</b>
Table All.A.1	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: CAPROPOL BACK-INTEGRATED INTO BENZENE	- 159 -
Table All.A.2	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: CYCLOHEXANE WITHOUT INTEGRATION	- 160 -
Table All.A.3	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: PHENOL (PURCHASED)	- 161 -
Table All.A.4	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: TORAY/PHOTOCHEMICAL	- 162 -
Table All.A.5	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: SNIA/TOLUENE	- 163 -
Table All.A.6	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: CYCLOHEXANE/DSM HPO	- 164 -
Table All.A.7	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: PHENOL/DSM HPO	- 165 -
Table All.A.8	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: CYCLOHEXANE/PEROXIDE	- 166 -
Table All.A.9	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: CYCLOHEXANE/PEROXIDE/FLUID BED	- 167 -
Table All.B.1	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: BUTADIENE (BASF/DSM/DUPONT)	- 168 -
Table All.B.2	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: BUTADIENE (DUPONT/BASF) WITH HEXAMETHYLENE DIAMINE CO-PRODUCT	- 169 -
Table All.B.3	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM/ HEXAMETHYLENE DIAMINE PROCESS: BUTADIENE (DUPONT/BASF) BED	- 170 -
Table All.B.4	COST OF PRODUCTION ESTIMATE FOR: HEXAMETHYLENE DIAMINE PROCESS: BUTADIENE (DUPONT)- 171 -	
Table All.B.5	COST OF PRODUCTION ESTIMATE FOR: ADIPONITRILE PROCESS: BUTADIENE (DUPONT)	- 172 -
Table All.B.6	COST OF PRODUCTION ESTIMATE FOR: ADIPONITRILE PROCESS: ELECTROCHEMICAL (SOLUTIA)	- 173 -
Table All.B.7	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: FROM ADIPONITRILE (BUTADIENE) WITH HEXAMEHTYLENE DIAMINE CO-PRODUCT	- 174 -
Table All.B.8	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM/ HEXAMETHYLENE DIAMINE PROCESS: (DUPONT/BASF) ADIPONITRILE FROM BUTADIENE	- 175 -

**TABLES**  
**(Continued)**

		<b>PAGE NO</b>
Table All.B.9	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: FROM ADIPONITRILE (ACRYLONITRILE) WITH HEXAMETHYLENE DIAMINE CO-PRODUCT	- 176 -
Table All.B.10	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM/ HEXAMETHYLENE DIAMINE PROCESS: (DUPONT/BASF) ADIPONITRILE FROM ACRYLONITRILE	- 177 -
Table All.B.11	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: FROM ADIPONITRILE (BUTADIENE) NO HEXAMETHYLENE DIAMINE CO-PRODUCT	- 178 -
Table All.C.1	COST OF PRODUCTION ESTIMATE FOR: CUMENE PROCESS: HETEROGENEOUS BENZENE ALKYLATION	- 179 -
Table All.C.2	COST OF PRODUCTION ESTIMATE FOR: PHENOL PROCESS: OXIDATION WITHOUT AMS RECOVERY	- 180 -
Table All.C.3	COST OF PRODUCTION ESTIMATE FOR: CAPROLACTAM PROCESS: PHENOL (BACK-INTEGRATED)	- 181 -
Table All.C.4	COST OF PRODUCTION ESTIMATE FOR: HYDROGEN PEROXIDE PROCESS: ANTHROQUINONE AUTO-OXIDATION	- 182 -
Table All.C.5	COST OF PRODUCTION ESTIMATE FOR: SYNTHESIS GAS (1.7:1) PROCESS: PARTIAL OXIDATION	- 183 -
Table All.C.6	COST OF PRODUCTION ESTIMATE FOR: CARBON MONOXIDE PROCESS: CRYOGENIC SEPARATION FROM 1.7:1 SYNGAS (PARTIAL OXIDATION)	- 184 -
Table All.C.7	COST OF PRODUCTION ESTIMATE FOR: HYDROGEN CYANIDE PROCESS: ANDRUSSOW/BY-PRODUCT VALUATION FOR ACRYLONITRILE	- 185 -
Table All.C.8	COST OF PRODUCTION ESTIMATE FOR: ACRYLONITRILE PROCESS: AMMOXIDATION WITH H <sub>2</sub> CN BY-PRODUCT	- 186 -
Table All.C.9	COST OF PRODUCTION ESTIMATE FOR: HYDROGEN CYANIDE PROCESS: ANDRUSSOW/FEEDSTOCK FOR ADIPONITRILE	- 187 -
Table All.C.10	COST OF PRODUCTION ESTIMATE FOR: ADIPONITRILE PROCESS: BUTADIENE (DUPONT)	- 188 -
Table All.C.11	COST OF PRODUCTION ESTIMATE FOR: HYDROGEN CYANIDE PROCESS: ANDRUSSOW/FEEDSTOCK FOR ADIPONITRILE	- 189 -

## FIGURES

		PAGE NO
Figure I.B.1	ROUTES TO NYLON FROM AROMATIC-DERIVED FEEDSTOCKS WITH PROCESS ENHANCEMENTS	- 3 -
Figure I.B.2	ROUTES TO NYLON FROM NON-AROMATIC-DERIVED FEEDSTOCKS	- 3 -
Figure I.C.1	COMMERCIAL CAPROLACTAM PRODUCTION COST SUMMARY (Aromatic-derived feedstocks, 200,000 tons per year, USGC, Q1/2000)	- 6 -
Figure I.C.2	CAPROLACTAM PRODUCTION COST SUMMARY (non-aromatic- derived feedstocks, 20,000 tons per year, USGC, Q1/2000)	- 7 -
Figure I.D.1	GLOBAL CAPROLACTAM CONSUMPTION BY REGION, 1990-2015	- 8 -
Figure I.D.2	GLOBAL CAPROLACTAM SUPPLY/DEMAND BALANCE 1990-2015	- 9 -
Figure I.D.3	GLOBAL CAPROLACTAM TRADE BY REGION, 1990-2015	- 10 -
Figure I.D.4	GLOBAL AMMONIUM SULFATE DEMAND BY REGION, 1999	- 11 -
Figure I.D.5	GLOBAL AMMONIUM SULFATE TRADE BY REGION, 1990-2015	- 11 -
Figure I.E.1	CAPROLACTAM THEORETICAL HISTORICAL MARGINS BY TECHNOLOGY (United States, US dollars per ton, by quarter)	- 12 -
Figure I.E.2	CAPROLACTAM THEORETICAL HISTORICAL RETURNS BY TECHNOLOGY (United States, US dollars per ton, by quarter)	- 13 -
Figure II.A.1	ROUTES TO NYLON FROM AROMATIC-DERIVED FEEDSTOCKS WITH PROCESS ENHANCEMENTS	- 18 -
Figure II.A.2	ROUTES TO NYLON FROM NON-AROMATIC-DERIVED FEEDSTOCKS	- 18 -
Figure III.A.1	ROUTES FOR CAPROLACTAM PRODUCTION	- 27 -
Figure III.A.2	KA OIL FROM CYLCLOHEXANE: BORIC ACID ROUTE	- 32 -
Figure III.A.3	CYCLOHEXANONE FROM CYCLOHEXANOL/ CYCLOHEXANONE	- 36 -
Figure III.A.4	CAPROLACTAM PROCESS WITH CONVENTIONAL BECKMANN REARRANGEMENT	- 37 -
Figure III.A.5	CAPROLACTAM FINAL PURIFICATION	- 39 -
Figure III.A.6	SCHEMATIC FLOW DIAGRAM ALLIED SIGNAL PHENOL ROUTE TO CAPROLACTAM	- 40 -
Figure III.A.7	CAPROLACTAM PRODUCTION GENERAL BLOCK DIAGRAM	- 44 -
Figure III.A.8	CYCLOHEXANONE BLOCK DIAGRAM CAPROPOL PROCESS	- 45 -
Figure III.A.9	HYDROXYLAMINE SULFATE BLOCK DIAGRAM CAPROPOL PROCESS	- 47 -
Figure III.A.10	CAPROLACTAM BLOCK DIAGRAM CAPROPOL PROCESS	- 48 -
Figure III.A.11	SNIA PROCESS BLOCK DIAGRAM	- 51 -

**FIGURES**  
**(Continued)**

		<b>PAGE NO</b>
Figure III.B.1	ENICHEM AMMOXIMATION PROCESS FLOW DIAGRAM	- 57 -
Figure III.B.2	SUMITOMO FLUID BED BECKMANN REARRANGEMENT	- 59 -
Figure IV.B.1	CAPROLACTAM BLOCK FLOW DIAGRAM DUPONT/DSM/ BASF PROCESS	- 65 -
Figure IV.B.2	DUPONT/DSM/BASF CAPROLACTAM FROM BUTADIENE ESTERIFICATION	- 66 -
Figure IV.B.3	DUPONT/DSM/BASF CAPROLACTAM FROM BUTADIENE HYDROFORMATION	- 68 -
Figure IV.B.4	DUPONT/DSM/BASF CAPROLACTAM FROM BUTADIENE AMINATION & CLYCLISATION	- 68 -
Figure IV.C.1	AND FROM BUTADIENE DUPONT PROCESS ADIPONITRILE REACTION	- 71 -
Figure IV.C.2	AND FROM BUTADIENE DUPONT PROCESS ADIPONITRILE RECOVERY	- 71 -
Figure IV.C.3	ADN VIA SOLUTIA ACRYLONITRILE PROCESS	- 73 -
Figure IV.C.4	ACN + HMDA DUPONT/BASF PROCESS HYDROGENATION	- 77 -
Figure IV.C.5	CAPROLACTAM FROM AMINOCAPRONITRILE - DUPONT/ BASF CYCLIZATION	- 78 -
Figure V.B.1	COMMERCIAL CAPROLACTAM PRODUCTION COST SUMMARY (Aromatic-derived feedstocks, 200,000 tons per year, USGC, Q1/2000)	- 95 -
Figure V.B.2	COMMERCIAL CAPROLACTAM PRODUCTION COST SUMMARY (NO AMMONIUM SULFATE CREDIT) (Aromatic- derived feedstocks, 200,000 tons per year, USGC, Q1/2000)	- 96 -
Figure V.C.1	CAPROLACTAM PRODUCTION COST SUMMARY (non-aromatic-derived feedstocks, 200,000 tons per year, USGC, Q1/2000)	- 110 -
Figure V.D.1	COMMERCIAL CAPROLACTAM PRODUCTION COST SUMMARY (Aromatic-derived feedstocks, 200,00 tons per year, Western Europe, Q1/2000)	- 112 -
Figure V.D.2	COMMERCIAL CAPROLACTAM PRODUCTION COST SUMMARY (NO AMMONIUM SULFATE CREDIT) (Aromatic- derived feedstocks, 200,000 tons per year, Western Europe, Q1/2000)	- 112 -
Figure V.D.3	CAPROLACTAM PRODUCTION COST SUMMARY (non- aromatic-derived feedstocks, 200,000 tons per year, Western Europe, Q1/2000)	- 113 -
Figure V.E.1	CASH COST SENSITIVITY - SCALE (United States, US dollars per ton)	- 114 -

**FIGURES**  
**(Continued)**

		<b>PAGE NO</b>
Figure V.E.2	CASH COST SENSITIVITY - FEEDSTOCK (United States, US dollars per ton)	- 115 -
Figure VI.B.1	GLOBAL CAPROLACTAM CONSUMPTION BY REGION, 1990-2015	- 117 -
Figure VI.B.2	GLOBAL CAPROLACTAM SUPPLY/DEMAND BALANCE, 1990-2015	- 118 -
Figure VI.B.3	GLOBAL CAPROLACTAM TRADE BY REGION, 1990-2015	- 119 -
Figure VI.B.4	GLOBAL AMMONIUM SULFATE DEMAND BY REGION	- 120 -
Figure VI.B.5	GLOBAL AMMONIUM SULFATE TRADE BY REGION, 1990-2015	- 121 -
Figure VI.C.1	UNITED STATES CAPROLACTAM SUPPLY/DEMAND BALANCE, 1990-2015	- 123 -
Figure VI.D.1	WEST EUROPEAN CAPROLACTAM SUPPLY/DEMAND BALANCE, 1990-2015	- 125 -
Figure VI.E.1	JAPANESE CAPROLACTAM SUPPLY/DEMAND BALANCE, 1990-2015	- 127 -
Figure VI.F.1	LATIN AMERICAN CAPROLACTAM SUPPLY/DEMAND BALANCE, 1990-2015	- 129 -
Figure VI.F.2	EAST ASIAN CAPROLACTAM SUPPLY/DEMAND BALANCE, 1990-2015	- 131 -
Figure VI.G.1	GLOBAL DEVELOPMENTS IN SYNTHETIC FIBRE PRODUCTION	- 132 -
Figure VI.G.2	1998 MAN-MADE FIBRE PRODUCTION BY REGION	- 133 -
Figure VII.A.1	CAPROLACTAM AND ITS FEEDSTOCKS, HISTORICAL PRICES	- 134 -
Figure VII.A.2	CAPROLACTAM FROM BENZENE, HISTORICAL MARGINS (United States, US dollars per ton, by quarter)	- 135 -
Figure VII.A.3	CYCLOHEXANE, HISTORICAL MARGINS (United States, US dollars per ton, by quarter)	- 135 -
Figure VII.A.4	CAPROLACTAM FROM CYCLOHEXANE, HISTORICAL MARGINS	- 136 -
Figure VII.A.5	PHENOL HISTORICAL MARGINS	- 137 -
Figure VII.A.6	CAPROLACTAM FROM MERCHANT PHENOL, HISTORICAL MARGINS (United States, US dollars per ton, by quarter)	- 137 -
Figure VII.A.7	CAPROLACTAM FROM BUTADIENE/CO, THEORETICAL HISTORICAL MARGINS (United States, US dollars per ton, by quarter)	- 138 -