

Styrene/Ethylbenzene
99/00-6

August 2000

TABLE OF CONTENTS

	Page
I EXECUTIVE SUMMARY	1
A. INTRODUCTION	1
B. TECHNOLOGY	1
C. ECONOMICS	4
1. Ethylbenzene	4
2. Styrene	4
D. COMMERCIAL	8
II INTRODUCTION	10
III COMMERCIAL TECHNOLOGY	12
A. ETHYLBENZENE	12
1. Chemistry	12
2. Liquid Phase Alkylation with Zeolite Catalysts	14
(a) Lummus/UOP EB One Process	14
(b) Mobil/Badger EB Max Process	19
3. CDTECH Alkylation	23
4. Aluminum Chloride Liquid Phase Alkylation	31
B. STYRENE	35
1. Dehydrogenation Process	35
(a) Chemistry	35
(b) Lummus/UOP CLASSIC SM Dehydrogenation	37
(c) Fina/Badger Dehydrogenation	45
(d) Lummus/UOP SMARTTM Dehydrogenation	50
2. Propylene Oxide Coproduct Process	52
(a) Chemistry	52
(b) Process Description	56
IV RECENT DEVELOPMENTS	60
A. PROCESS VARIATIONS	60
1. Flameless Distributed Combustion	60
2. Ethylbenzene Integrated with an Olefins Plant	61
3. Energy-Saving Distillation Options for Styrene/EB Separation	62
B. PATENT SURVEY	62

TABLE OF CONTENTS (Continued)

	Page
V ALTERNATIVE TECHNOLOGIES	67
A. BUTADIENE DIMERIZATION/DEHYDROGENATION	67
1. Chemistry	67
(a) Cyclodimerization of Butadiene	67
(b) Oxidative Dehydrogenation of 4-Vinylcyclohexene	69
2. Process Description	69
B. METHANOL ALKYLATION OF TOLUENE	72
1. Chemistry	72
2. Process Description	73
 VI ECONOMICS	 76
A. BASIS	76
1. Pricing Basis	76
2. Investment Basis	77
3. Cost of Production Basis	77
B. ETHYLBENZENE	78
1. Liquid-Phase Zeolite-Catalyzed Alkylation/Transalkylation	78
2. Reactive Distillation with Dilute Ethylene	80
3. Liquid-Phase AlCl ₃ -Catalyzed Alkylation/Transalkylation	80
4. Comparison of Ethylbenzene Processes	84
C. STYRENE	86
1. Catalytic Dehydrogenation	86
2. Propylene Oxide/Styrene Monomer	86
3. Butadiene Dimerization/Dehydrogenation	90
4. Comparison of Styrene Processes	96
D. GENERAL SENSITIVITIES	100
 VII COMMERCIAL ANALYSIS	 102
A. UNITED STATES	102
1. Consumption	102
2. Supply	102
3. Supply, Demand and Trade	103

**TABLE OF CONTENTS
(Continued)**

	Page
B. WESTERN EUROPE	106
1. Consumption	106
2. Production	106
3. Supply/Demand and Trade	110
C. JAPAN	111
1. Consumption	111
2. Supply	111
3. Supply/Demand Balance	112
D. EAST ASIA	113
1. South Korea	113
(a) Consumption	113
(b) Supply	114
(c) Supply/Demand Balance	115
2. Taiwan	115
(a) Consumption	115
(b) Supply	116
(c) Supply/Demand Balance	117
3. China	117
(a) Consumption	117
(b) Supply	118
(c) Supply/Demand Balance	120
4. Thailand	121
(a) Consumption	121
(b) Supply	121
(c) Supply/Demand Balance	122
E. GLOBAL SUMMARY	122
REFERENCES	124
APPENDIX	126
PERP TITLE INDEX	131

TABLES

	Page	
Table I.C.1	Comparison of Ethylbenzene Process Costs	4
Table I.C.2	Comparison of Styrene Process Costs	6
Table I.D.1	U.S. Styrene Supply and Demand	8
Table I.D.2	West European Styrene Supply/Demand Balance	8
Table I.D.3	Japanese Styrene Supply/Demand Balance	9
Table I.D.4	Global Styrene Supply/Demand Summary	9
Table III.A.1	Ethylbenzene Feedstock and Product Specifications	20
Table III.A.2	Typical Gas Composition from FCC Olefins Recovery Unit	23
Table III.A.3	Typical Composition of Pretreated FCC Offgas	25
Table III.A.4	Dilute Ethylene Specification for the CDTECH Process	31
Table III.B.1	Lummus/UOP Classic Styrene Process Feedstock, Product, and Byproduct Specifications	45
Table III.B.2	Ethylbenzene Hydroperoxidation Selectivity	53
Table IV.B.1	Styrene/Ethylbenzene Patents/Applications	63-66
Table VI.A.1	Costs/Prices for Inputs	76
Table VI.B.1	Cost of Production Estimate for: Ethylbenzene Process: Liq-Ph Alkylation – Zeolite Cat.	79
Table VI.B.2	Cost of Production Estimate for: Ethylbenzene Process: Reactive Distillation	82
Table VI.B.3	Cost of Production Estimate for: Ethylbenzene Process: Liq-Ph Alkylation – AlCl ₃ Cat.	83
Table VI.B.4	Comparison of Ethylbenzene Process Costs	84
Table VI.C.1	Cost of Production Estimate for: Styrene Process: Catalytic Dehydrogenation	88
Table VI.C.2	Cost of Production Estimate for: Styrene Process: Propylene Oxide as Co-Prod. (Valued @ ROCE via Chlorohydrin Process)	89
Table VI.C.3	Cost of Production Estimate for: Propylene Oxide Process: Chlorohydrin – Integ. w/Chlor-Alkali	91

**TABLES
(Continued)**

		Page
Table VI.C.4	Cost of Production Estimate for: Styrene Process: Propylene Oxide as Co-Prod. (Valued @ Export Price)	92
Table VI.C.5	Cost of Production Estimate for: Styrene Process: BD Dimer./Oxydehydro. (Dow)	94
Table VI.C.6	Comparison of Styrene Process Costs	97
Table VII.A.1	U.S. Styrene Consumption	102
Table VII.A.2	U.S. Styrene Capacity	103
Table VII.A.3	U.S. Styrene Supply and Demand	104
Table VII.B.1	West European Styrene Consumption	106
Table VII.B.2	West European Styrene Production	108
Table VII.B.3	West European Styrene Capacity	109
Table VII.B.4	West European Styrene Supply/Demand Balance	110
Table VII.C.1	Japanese Styrene Consumption	111
Table VII.C.2	Japanese Styrene Capacity	112
Table VII.C.3	Japanese Styrene Supply/Demand Balance	113
Table VII.D.1	South Korean Styrene Consumption	114
Table VII.D.2	South Korean Styrene Capacity	114
Table VII.D.3	South Korean Styrene Supply/Demand Balance	115
Table VII.D.4	Taiwanese Styrene Consumption	116
Table VII.D.5	Taiwanese Styrene Capacity	116
Table VII.D.6	Taiwanese Styrene Supply/Demand Balance	117
Table VII.D.7	Chinese Styrene Capacity	119
Table VII.D.8	Chinese Styrene Supply/Demand Balance	120
Table VII.D.9	Thai Styrene Capacity	121
Table VII.D.10	Thai Styrene Supply/Demand Balance	122
Table VII.E.1	Global Styrene Supply/Demand Summary	123

FIGURES

		Page
Figure I.C.1	Comparison of Ethylbenzene Costs	5
Figure I.C.2	Comparison of Styrene Costs	7
Figure III.A.1	Lummus/UOP EB One Ethylbenzene Process	15
Figure III.A.2	Mobil/Badger EBMax Process Flowsheet	22
Figure III.A.3	Block Schematic Diagram of Typical FCC Gas Plant	24
Figure III.A.4	Schematic Flow Diagram for Dilute Ethylene Pretreating	26
Figure III.A.5	Process Flow Diagram CDTech Ethylbenzene Process	28
Figure III.A.6	AlCl ₃ Catalyzed Ethylbenzene Process	33
Figure III.B.1	Lummus/UOP Classic Styrene Monomer Proc. Dehydrogenation	38
Figure III.B.2	Lummus/UOP Classic Styrene Monomer Process Distillation	39
Figure III.B.3	Fina/Badger Styrene Process	47
Figure III.B.4	Lummus/UOP Smart Styrene Process	51
Figure III.B.5	Styrene Production Chemistry via the Lyondell Process	54
Figure III.B.6	Styrene/P.O. via Lyondell Process: Peroxid. + Epoxid.	57
Figure III.B.7	Styrene/P.O. via Lyondell Process: Styrene/P.O. Recovery	58
Figure V.A.1	Styrene from Butadiene Dow Process	70
Figure V.B.1	Block Flow Diagram Styrene Synthesis from Methanol and Toluene	74
Figure VI.B.1	Investment Effect on Ethylbenzene Cost	81
Figure VI.B.2	Comparison of Ethylbenzene Costs	85
Figure VI.B.3	Capacity Effect on Ethylbenzene Cost	87
Figure VI.C.1	Propylene Oxide Price Effect on Styrene Cost	93
Figure VI.C.2	Butadiene Price Effect on Styrene Cost	95
Figure VI.C.3	Comparison of Styrene Costs	98
Figure VI.C.4	Capacity Effect on Styrene Cost	99
Figure VI.D.1	Feed Price Effect on Ethylbenzene Cost Liquid-Phase Alkylation Zeolite Catalyst	100
Figure VI.D.2	Ethylbenzene Price Effect on Styrene Cost Catalytic Dehydrogenation Process	101
Figure VII.A.1	U.S. Styrene Supply and Demand	105
Figure VII.B.1	West European Styrene Consumption, 1998	107