

PERP Report

Styrene/Ethylbenzene

03/04-8

November 2004



44 South Broadway, White Plains, New York 10601, USA
Tel: +1 914 609 0300 Fax: +1 914 609 0399

Copyright© by Nexant, Inc. 2004

This Report was prepared by Nexant, Inc. ("Nexant") and is part of ChemSystems Process Evaluation/Research Planning (PERP) Program. Except where specifically stated otherwise in this Report, the information contained herein is prepared on the basis of information that is publicly available, and contains no confidential third party technical information to the best knowledge of Nexant. The aforesaid information has not been independently verified or otherwise examined to determine its accuracy, completeness, or feasibility.

Neither Nexant, Subscriber, nor any person acting on behalf of either assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information contained in this Report. Nexant does not represent or warrant that any assumed conditions will come to pass.

The Report is submitted on the understanding that the Subscriber will maintain the contents confidential except for the Subscriber's internal use. The Report shall not be reproduced, distributed, or used outside Subscriber's organization without first obtaining prior written consent by Nexant. Each Subscriber agrees to use reasonable effort to protect the confidential nature of the Report.

Contents

Section	Page
1 Summary	1
1.1 INTRODUCTION	1
1.2 TECHNOLOGY	1
1.3 ECONOMICS.....	3
1.3.1 Ethylbenzene.....	3
1.3.2 Styrene	4
1.4 COMMERCIAL	6
2 Introduction	8
3 Technology	9
3.1 ETHYLBENZENE	9
3.1.1 Chemistry.....	9
3.1.2 Liquid Phase Alkylation with Zeolite Catalysts	10
3.1.3 CDTECH Alkylation	19
3.1.4 Aluminum Chloride Liquid Phase Alkylation	28
3.2 STYRENE.....	31
3.2.1 Dehydrogenation Process.....	31
3.2.2 Propylene Oxide/Styrene Monomer (POSM) Coproduct Process.....	45
3.3 ALTERNATE TECHNOLOGIES.....	53
3.3.1 Styrene via Benzene and Ethane.....	53
4 Recent Developments	55
4.1 PROCESS VARIATIONS.....	55
4.1.1 Direct Heating Technology	55
4.1.2 Oxidative Dehydrogenation using Carbon Dioxide.....	56
4.1.3 Extractive Distillation for Styrene Recovery from Pygas.....	56
4.1.4 Co-product Free Propylene Oxide Technology	57
4.2 PATENT SURVEY	59
5 Economic Analysis	62
5.1 BASIS	62
5.1.1 Pricing Basis	62

5.1.2	Investment Basis	62
5.1.3	Cost of Production Basis.....	63
5.2	ETHYLBENZENE	64
5.2.1	Liquid-Phase Zeolite-Catalyzed Alkylation/Transalkylation	64
5.2.2	Reactive Distillation with Dilute Ethylene	64
5.2.3	Liquid-Phase AlCl ₃ -Catalyzed Alkylation/Transalkylation.....	67
5.2.4	Comparison of Ethylbenzene Processes	67
5.3	STYRENE.....	70
5.3.1	Catalytic Dehydrogenation	70
5.3.2	Propylene Oxide/Styrene Monomer	72
5.3.3	Comparison of Styrene Processes.....	76
5.4	GENERAL SENSITIVITIES	78
6	Commercial Analysis	80
6.1	UNITED STATES.....	80
6.1.1	Consumption.....	80
6.1.2	Supply	81
6.1.3	Supply, Demand and Trade.....	82
6.2	WESTERN EUROPE	84
6.2.1	Consumption	84
6.2.2	Supply	85
6.2.3	Supply/Demand and Trade	87
6.3	JAPAN	88
6.3.1	Consumption	88
6.3.2	Supply	90
6.3.3	Supply/Demand Balance.....	90
6.4	EAST ASIA	91
6.4.1	South Korea	91
6.4.2	Taiwan.....	93
6.4.3	China	95
7	References	98

Appendix	Page
A Nexant’s ChemSystems Capital Cost Estimates	A-1
B PERP Program Title Index	B-1
Figure	Page
1.1 Comparison of Ethylbenzene Costs	4
1.2 Comparison of Styrene Costs.....	5
3.1 Lummus/UOP EB One Ethylbenzene Process	11
3.2 ExxonMobil/Badger EBMax Process Flowsheet.....	17
3.3 Block Schematic Diagram Of Typical FCC Gas Plant.....	20
3.4 Schematic Flow Diagram For Dilute Ethylene Pretreating	22
3.5 Process Flow Diagram CDTECH Ethylbenzene Process	25
3.6 AlCl ₃ Catalyzed Ethylbenzene Process.....	29
3.7 Lummus/UOP Classic Styrene Monomer Dehydrogenation.....	33
3.8 Lummus/UOP Classic Styrene Monomer Process Distillation	34
3.9 ATOFINA/Badger Styrene Process.....	41
3.10 Lummus/UOP Smart Styrene Process	46
3.11 Styrene Production Chemistry Via POSM Process	47
3.12 Styrene/P.O. Via Lyondell Process: Peroxid. + Epoxid.	50
3.13 Styrene/P.O. Via Lyondell Process: Styrene/PO Recovery.....	51
4.1 Chemistry of Sumitomo Chemicals’ Co-Product Free Propylene Oxide Process.....	58
5.1 Comparison of Ethylbenzene Costs	69
5.2 Capacity Effect on Ethylbenzene Cost	70
5.3 Propylene Oxide Price Effect on Styrene Cost.....	72
5.4 Comparison of Styrene Costs.....	77
5.5 Capacity Effect on Styrene Cost.....	77
5.6 Feed Price Effect on Ethylbenzene Cost.....	78
5.7 Ethylbenzene Price Effect on Styrene Cost Catalytic Dehydrogenation Process.....	79
6.1 U.S. Styrene Consumption by Derivative, 2003.....	80
6.2 U.S. Styrene Supply and Demand, 2000-2010	83
6.3 West European Styrene Consumption by Derivative, 2003	84

6.4	West European Styrene Supply/Demand Balance, 2000-2010.....	88
6.5	Japanese Styrene Consumption by Derivative, 2003.....	89
6.6	South Korean Styrene Consumption by Derivative, 2003.....	91
6.7	Taiwanese Styrene Consumption by Derivative, 2003.....	93
6.8	Chinese Styrene Consumption by Derivative, 2003.....	95

Table		Page
1.1	Comparison of Ethylbenzene Process Costs.....	3
1.2	Comparison of Styrene Process Costs.....	5
1.3	U.S. Styrene Supply and Demand.....	6
1.4	West European Styrene Supply/Demand Balance.....	6
1.5	Japanese Styrene Supply/Demand Balance.....	7
1.6	Global Styrene Supply/Demand Summary.....	7
3.1	Ethylbenzene Feedstock and Product Specifications for Lummus/UOP EBOne Process.....	15
3.2	Typical Gas Composition from FCC Olefins Recovery Unit.....	21
3.3	Typical Composition of Pretreated FCC Offgas.....	23
3.4	Dilute Ethylene Specification for the CDTECH Process.....	28
3.5	Lummus/UOP Classic Styrene Process Feedstock, Product, and By-product Specifications.....	39
3.6	Ethylbenzene Hydroperoxidation Selectivity.....	48
4.1	Comparison of Hydroperoxidation Parameters.....	59
4.2	Styrene/Ethylbenzene Patents/Applications.....	60-61
5.1	Costs/Prices for Inputs.....	62
5.2	Cost of Production Estimate for: Ethylbenzene Process: Liq-Ph Alkylation – Zeolite Cat.....	65
5.3	Cost of Production Estimate for: Ethylbenzene Process: Reactive Distillation w/Dilute Ethylene.....	66
5.4	Cost of Production Estimate for: Ethylbenzene Process: Liq-Ph Alkylation - AlCl ₃ Cat.....	68
5.5	Comparison of Ethylbenzene Process Costs.....	69
5.6	Cost of Production Estimate for: Styrene Process: Catalytic Dehydrogenation.....	71

5.7	Cost of Production Estimate for: Styrene Process: Propylene Oxide as Co-Prod. (Valued @ ROCE via Chlorohydrin Process)	73
5.8	Cost of Production Estimate for: Propylene Oxide Process: Chlorohydrin - Integ. W/Chlor-Alkali.....	74
5.9	Cost of Production Estimate for: Styrene Process: Propylene Oxide as Co-Prod. (Valued @ ExportPrice)	75
5.10	Comparison of Styrene Process Costs	76
6.1	U.S. Styrene Consumption by Derivative, 2002-2010	81
6.2	U.S. Styrene Capacity, 2002-2007.....	82
6.3	U.S. Styrene Supply and Demand, 2002-2010	83
6.4	West European Styrene Consumption, 2002-2010.....	85
6.5	West European Styrene Capacity, 2002-2007	86
6.6	West European Styrene Supply/Demand Balance, 2002-2010.....	87
6.7	Japanese Styrene Consumption, 2002-2010	89
6.8	Japanese Styrene Capacity, 2002-2007.....	90
6.9	Japanese Styrene Supply/Demand Balance, 2002-2010.....	90
6.10	South Korean Styrene Consumption, 2002-2010	92
6.11	South Korean Styrene Capacity, 2002-2007.....	92
6.12	Taiwanese Styrene Consumption, 2002-2010	94
6.13	Taiwanese Styrene Capacity, 2002-2007.....	94
6.14	Chinese Styrene Consumption, 2002-2010.....	96
6.15	Chinese Styrene Capacity, 2002-2007	97