

Styrene/Ethylbenzene

Table of Contents

A Report by Nexant

Process Evaluation/Research Planning (PERP) Program

PERP Report 2013-7 – Published December 2013

www.nexantthinking.com

Section	Page
1 Executive Summary	1
1.1 INTRODUCTION	1
1.2 TECHNOLOGY OVERVIEW	2
1.3 COST OF PRODUCTION OVERVIEW	3
1.4 COMMERCIAL OVERVIEW	4
1.4.1 Consumption	4
1.4.2 Supply	6
1.4.3 Supply/Demand/Trade	8
2 Introduction.....	9
2.1 TECHNOLOGY OVERVIEW	10
2.2 BUSINESS DEVELOPMENTS	11
2.3 TECHNOLOGY HOLDERS AND LICENSING STATUS.....	12
2.3.1 Badger Licensing LLC.....	13
2.3.2 Lummus Technology/UOP LLC.....	14
2.3.3 Versalis	14
2.3.4 Styron.....	14
2.3.5 LyondellBasell and Shell	15
2.4 PHYSICAL AND THERMODYNAMIC PROPERTIES	15
2.5 SPECIFICATIONS.....	16
2.6 HEALTH HAZARDS.....	17
2.6.1 Styrene	17
2.6.2 Ethylbenzene	17

2.7	STORAGE AND TRANSPORTATION.....	18
2.7.1	Styrene	18
2.7.2	Ethylbenzene	19
3	Commercial Technologies	20
3.1	CHEMISTRY	20
3.2	ETHYLBENZENE	21
3.2.1	Chemistry	21
3.2.2	Liquid Phase Alkylation with Zeolite Catalysts	23
3.2.3	Alkylation via Catalytic Distillation	31
3.2.4	Aluminum Chloride Liquid Phase Alkylation	39
3.3	STYRENE.....	42
3.3.1	Conventional Ethylbenzene Dehydrogenation Process	42
3.3.2	Propylene Oxide/Styrene Monomer (POSM) Co-product Process ...	57
4	Developing Technologies	64
4.1	GREEN CHEMISTRY AND BIOTECHNOLOGY	64
4.1.1	Recent Developments	64
4.1.2	Ethylene from Ethanol	64
4.1.3	Benzene from Biomass	65
4.2	DIRECT HEATING UNIT TECHNOLOGY	68
4.3	STYRENE VIA BENZENE AND ETHANE.....	70
4.3.1	Introduction.....	70
4.3.2	Recent Developments	71
4.3.3	Process Description.....	71
4.4	STYRENE VIA METHANOL AND TOLUENE.....	80
4.4.1	Introduction.....	80
4.4.2	Exelus Methanol/Toluene to Styrene Process.....	80
4.4.3	Process Description.....	82
4.4.4	Development Status	84
4.5	PATENT SURVEY	84
5	Process Economics	86
5.1	COSTING BASIS	86

5.1.1	Investment Basis	86
5.1.2	Pricing Basis	86
5.1.3	Cost of Production Basis.....	88
5.2	COST OF PRODUCTION ESTIMATES	89
5.2.1	Ethylbenzene.....	89
5.2.2	Styrene	99
5.2.3	Developing Styrene Technologies	111
5.2.4	Comparison of Styrene Processes.....	114
5.3	SENSITIVITY ANALYSES	119
6	Commercial Applications	120
7	Regional Market Analysis	122
7.1	GLOBAL	122
7.1.1	Consumption	122
7.1.2	Supply	124
7.1.3	Supply/Demand/Trade	125
7.2	NORTH AMERICA	127
7.2.1	Consumption	127
7.2.2	Supply	128
7.2.3	Supply/Demand/Trade	129
7.3	WESTERN EUROPE	130
7.3.1	Consumption	130
7.3.2	Supply	131
7.3.3	Supply/Demand/Trade	132
7.4	ASIA PACIFIC	134
7.4.1	Consumption	134
7.4.2	Supply	135
7.4.3	Supply/Demand/Trade	136
8	Glossary	138
9	References	140

Appendix	Page
A Definitions of Capital Cost Terms Used in Process Economics	A-1
B Definitions of Operating Cost Terms Used in Process Economics	B-1
C PERP Program Title Index (2004 - 2013)	C-1
Figure	Page
1.1 Styrene Value Chain	1
1.2 Global Styrene Consumption by End-Use	5
1.3 Global Styrene Consumption by Region	6
1.4 Regional Styrene Capacity	7
1.5 Global Styrene Supply, Demand, and Trade	8
2.1 Styrene Value Chain	10
3.1 Lummus/UOP EBOne™ Ethylbenzene Process	24
3.2 ExxonMobil/Badger EBMax Process Flowsheet.....	30
3.3 Block Schematic Diagram of Typical FCC Gas Plant.....	33
3.4 Schematic Flow Diagram for Dilute Ethylene Pretreating	34
3.5 Process Flow Diagram CDTECH® Ethylbenzene Process	37
3.6 AlCl ₃ Catalyzed Ethylbenzene Process	40
3.7 Lummus/UOP Classic Styrene	44
3.8 Lummus/UOP Classic Styrene Monomer Process Distillation	45
3.9 TOTAL/Badger Styrene Process	52
3.10 Lummus/UOP Smart™ Styrene Process.....	56
3.11 Styrene Production Chemistry via POSM Process	58
3.12 Styrene/PO Via LyondellBasell Process: Peroxid. + Epoxid.	61
3.13 Styrene/PO Via LyondellBasell Process: Styrene/PO Recovery	62
4.1 Biomass to Aromatics Flow Diagram	67
4.2 Virent's Bioforming® Process Flow Diagram	69
4.3 Dow/Snamprogetti Ethane to Styrene Process	71
4.4 Dow Ethane to Styrene Process Dehydrogenation Section	73
4.5 Reactor Section	74
4.6 Dow Ethane to Styrene Process Alkylation Section	77

4.7	Dow Ethane to Styrene Process C ₂ /H ₂ Recovery Section	78
4.8	Dow Ethane to Styrene Process Styrene Recovery Section.....	79
4.9	ExSyM Styrene via Methanol and Toluene	83
5.1	Comparison of Ethylbenzene Costs	94
5.2	Capacity Effect on Ethylbenzene Cost	95
5.3	Comparison of Ethylbenzene Costs via Liquid Phase Zeolite Catalyzed Alkylation	96
5.4	Propylene Oxide Price Impact on Styrene Cost of Production.....	102
5.5	Capacity Effect on Styrene Cost.....	103
5.6	Comparison of Styrene Costs via Catalytic Dehydrogenation	104
5.7	Comparison of Styrene Costs via POSM.....	108
5.8	Comparison of Styrene Costs.....	114
5.9	Styrene Plant Size Growth: Average and World Scale.....	115
5.10	Styrene Technology Evolution	117
5.11	Percentage Production of Styrene Technologies	118
5.12	Variation of Styrene Cost of Production with Ethylene and Benzene Prices	119
6.1	Styrenics Molecules	121
6.2	Main Chemical Uses of Styrene	121
7.1	Global Styrene Consumption by End-Use	123
7.2	Global Styrene Consumption by Region	124
7.3	Regional Styrene Capacity.....	125
7.4	Global Styrene Supply, Demand, and Trade	126
7.5	North America Styrene Consumption by End-Use.....	127
7.6	North America Styrene Supply, Demand, and Trade	130
7.7	Western Europe Styrene Consumption by End-Use.....	131
7.8	Western Europe Styrene Supply, Demand, and Trade	133
7.9	Asia Pacific Styrene Consumption by End-Use	134
7.10	Asia Pacific Styrene Supply, Demand, and Trade	137

Table	Page
1.1 Comparison of Styrene Production Costs	4
1.2 Global Styrene Supply, Demand, and Trade	8
2.1 Ethylbenzene Licensors and Technology Holders.....	12
2.2 Styrene Licensors and Technology Holders	13
2.3 Key Physical and Thermodynamic Properties	15
2.4 Key Physical and Thermodynamic Properties	16
2.5 Commercial Specification (Standard Specifications for Styrene (ASTM D2827-13))	16
2.6 Commercial Specification (Standard Specifications for Ethylbenzene (ASTM D3193-09))	17
3.1 Ethylbenzene Feedstock and Product Specifications for Lummus/UOP EBOne™ Process	27
3.2 Typical FCC Offgas Composition from FCC Olefins Recovery Unit.....	32
3.3 Typical Composition of Pretreated FCC Offgas.....	35
3.4 Dilute Ethylene Specification for the CDTECH® Process	39
3.5 Lummus/UOP Classic Styrene Process Feedstock, Product, and Byproduct Specifications	49
3.6 Ethylbenzene Hydroperoxidation Selectivity	59
4.1 Styrene/Ethylbenzene Patents/Applications	85
5.1 Prices of Raw Materials, Products, Utilities, and Labor.....	87
5.2 Cost of Production Estimate for Ethylbenzene Process: Liquid Phase Zeolite Catalyzed Alkylation, USGC	90
5.3 Cost of Production Estimate for Ethylbenzene Process: Reactive Distillation with Dilute Ethylene, USGC	92
5.4 Cost of Production Estimate for Ethylbenzene Process: Liquid Phase Alkylation with AlCl ₃ Catalyst, USGC	93
5.5 Comparison of Ethylbenzene Process Costs.....	94
5.6 Ethylbenzene Process Economics via Liquid Phase Zeolite Catalyzed Alkylation ..	96
5.7 Cost of Production Estimate for Ethylbenzene Process: Liquid Phase Zeolite Catalyzed Alkylation, Middle East	97
5.8 Cost of Production Estimate for Ethylbenzene Process: Liquid Phase Zeolite Catalyzed Alkylation, China	98

5.9 Cost of Production Estimate for Styrene Process: Catalytic Dehydrogenation	100
5.10 Cost of Production Estimate for Styrene Process: Propylene Oxide as Co-product.....	101
5.11 Styrene Process Economics via Catalytic Dehydrogenation	104
5.12 Cost of Production Estimate for Styrene Process: Catalytic Dehydrogenation, Middle East.....	105
5.13 Cost of Production Estimate for Styrene Process: Catalytic Dehydrogenation, China	106
5.14 Styrene Process Economics via POSM.....	107
5.15 Cost of Production Estimate for Styrene Process: POSM, Middle East.....	109
5.16 Cost of Production Estimate for Styrene Process: POSM, China.....	110
5.17 Cost of Production Estimate for Styrene Process: Dow Ethane to Styrene Process.....	112
5.18 Cost of Production Estimate for Styrene Process: Exelus ExSyM Process via Toluene and Methanol.....	113
5.19 Comparison of Styrene Process Costs	114
5.20 Global POSM Plants	117
7.1 Global Styrene Supply, Demand, and Trade	126
7.2 North America Styrene Capacities.....	128
7.3 North America Styrene Supply, Demand, and Trade	129
7.4 Western Europe Styrene Capacities.....	132
7.5 Western Europe Styrene Supply, Demand, and Trade	133
7.6 China Styrene Capacities	135
7.7 Asia Pacific Styrene Supply, Demand, and Trade	136

NexantThinking™ PERP PROGRAM



www.nexantthinking.com

The NexantThinking's Process Evaluation/Research Planning (PERP) program is recognized globally as the industry standard source for information relevant to the chemical process and refining industries. PERP reports are available as a subscription program or on a single report basis.

Contact Details:

New York: Marcos Nogueira Cesar, Vice President, Global Products, E&CA: NexantThinking™
Phone: + 1-914-609-0324, e-mail: mcesar@nexant.com

New York: Heidi Junker Coleman, Global Programs Support Manager
Phone: + 1-914-609-0381, e-mail: hcoleman@nexant.com

Nexant, Inc. (www.nexant.com) is a leading management consultancy to the global energy, chemical, and related industries. For over 38 years, ChemSystems has helped clients increase business value through assistance in all aspects of business strategy, including business intelligence, project feasibility and implementation, operational improvement, portfolio planning, and growth through M&A activities. Nexant has its main offices in San Francisco (California), White Plains (New York), and London (UK), and satellite offices worldwide.

Copyright © by Nexant Inc. 2014. All Rights Reserved.